Project report 0803

# Climatomology problems in Lascaux

Reflections on my visit to the cave 13 novembre 2009

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Plan

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## 1. The goal of this visit

Few people have had the occasion to visit the Lascaux cave since the beginning of the current crisis. I was however invited, in the company of Pierre Vidal, to visit it on 13 November 2008, in order to meet Monsieur Fred Benoist, engineer and director of the office of studies at OTCE, the person in charge of installing the new air conditioning system. The objective was to observe the new, in 2000, installation of the air conditioning system as the replacement for the « Guyon » machine that had been in operation until that time. We did not know one or the other of the actual installations, it was useful for us to visit the cave together to be able to make a critical assessment on the air conditioning system. This visit followed that of 5 April 2008 with M. Marc Gauthier, president of the Lascaux scientific committee, for the constitution of a working group on the climate of the cave. In that project, it is not only a question of the design of the machine but also the actual impact of it on the climate within the cave and the impact on the conservation of the paintings. We did indeed visit the installations in the machine room, accompanied by Mme Muriel Mauriac, administrateur à DRAC Aquitaine et Messieurs Pierre Vidal (ingénieur honoraire au LRMH), Fred Benoist, Jean Michel Geneste, conservateur de la grotte de Lascaux, tow of his collaborators, the engineers Bernard Giraudel and Stephan Koenig. Following the meeting I and Jean Michel Geneste visited the cave, the presence of the others was not allowed by the protocols in place.

I thank very much Madame Mauriac, Monsieur Geneste and Monsieur Benoist for the reception they made. I was sensitive to the fact that Madame Mauriac amiably gave me her place for me to visit the cave.

## 2. Climate in the cave during the years 1960-1970

### 2,1 The problem of stabization of the parameters

The first crisis of conservation of the paintings of Lascaux in 1960 was the reason that an air conditioning machine was emplaced to renew the air necessary because of the many visitors each day. Jacques Marsala, one of the inventors and guardians of the cave, had already seen for years the phenomenon of ocndesation and flowing of water on the painted walls colored sometimes by pigments of paintings. The appearance and development of green algae, the famous « malade verte » provoqued the closing of the cave to visitors in 1963, stopping of the air conditioning and formation of the first scientific commission to safeguard Lascaux cave.

After the « maladie verte », of which the biologists on the commission succeeded in bringing to an end since 1964 (report Laporte), hid a problem, perhaps more serious, that of the modification of the cacitic support of paintings called « maladie blanche ».

The alert about eh « malade blanche » was made but Dr. Bauer, a member of the commission who studied the evolution of the green algae. The cave, closed to the public and with the machine stopped, Dr. Bauer observed on (stereo) photographs the formation of outgrowths and veils (coverings) of calcite precipitation. In nearby zones, he noticed an attack phenomenon (micro craters) on the calcite support for the paintings.

The problem of calcite was immediately identified as that of the physicochemical cycle of $CO_2$, the precipitation of calcium carbonate from solution in the form of calcite crystals and their dissolution, the two phenomenon are dependent on the infiltration of calcareous water and the evaporation of surface water containing more or less dissolved calcium carbonate. It was only natural that the commission entrusted the study of the cave to an physico-chemist engineer.

The goal of the work that was entrusted to me was to find, if possible, the initial conditions of the cave, and then to discover the recent causes of the physico-chemcial disequilibrium. **It was necessary to discover the the natural mechanisms of climate regulate in the cave and reestablish equilibrium conditions between the air in the cave and the painted wall.**

Between 1964 and 1965, in close connection with the first scientific commission to saveguard Lascaux, and with a team of technicians which I formed in place, we had established the method, designed and developed the measuring instruments, that had not existed nor could be adapted, and completed the first scientific study of climate in the cave. This study allowed me to conceive of a climate control system that functioned from 1965 to 2000 that controlled the parameters to stablized the environment and kept the paintings in a good conservation state. The essential conclusions of this study were contained in 5 reports saved by the adminstration and in a public review article in 1980 (Guyon 1980). It is the same principle that had been behind installation of the new machine in 2000 and is probably the cause of the current crisis. The results of the climate study, the principals of the mahcine and it method of operation are given in appendix 1.

## 2.2 Questions to ask about climate control:

1- Is a climate control system necessary to preserve the mineral support of the paintings : a) problem of calcite, b) problem of the integrity of the pigments ?
2- Is a climate assitance machine truely necessary to stabilize the microbiological system and will it prevent the invasion of fungi ?
3- Does a climate control system pose a risk for the paintings ?
4- If the response to one or two main questions is yes, them, what should the characteristics of the system be and its mode of functioning ?

*It seems that the scientific committee has responded yes, tacitly if not formally, to the four questions since the installation the first exchange of heat in the salle des taureaux; a second is envisaged ths year in the right-hand passage.*

## 3 The actual situtation

### 3.1 Topology of the places.

One reaches the bull hall by a metal stair that approximately reproduces the slope of the fall found at the time of the discovery. The area underneath the stair was carved out to create the machine room within which was installed the first machine for conditioning the air. The ceiling of the machine room is made up of a concrete slab insulated from the entry by a soft metallic roof, slightly inclinded to recover rainwater that has penetrated the porous stone of the cave. A stone wall separates the machine room from « area 2 » (often labeled sas 2 on diagrams of the cave) which is a natural extension of the Salle des Taureax and which is itself separated by a second stone wall. The stair reaches ground level in the middle of « area 2 ».

### 3.2 Description of the existing machine.

The new system works under the principal of exchanging heated air (humid air) placed behind the high openings in the wall of the machine room. These are installed on imposing metal support tubes. These exchangers are of a type different from their predecesors, they are designed with a tight grid of cells placed in a metal formwork through which one forces the passage of the air by means of ventilators. These exchangers are installed on pylons in metallic tubes immediately next to the openings. At the time of the visit, the ventilators had already been dismounted, one of the formwork had been removed and a third exchanger had been installed, suspended in the air between the two first. It was not possible to get a detailed explanation of the machine because Monsieur Benoist did not know any more. It is therefore easy to understand the reason for the third exchanger, indeed, operating for an unspecified period of time, the conservator said, one removes the ventilators not envisaged in the schedule of conditions. Thus stripped the exchangers lose any effectiveness and cannot function like the predecessors by cooling the air of the draught of convection since they block its passage.

One can think that this partial disassembling of the machine was probably carried out to avoid the diffusion of the spores of *Fusarium solani* which quickly made their appearance in the machine room, in particular on the insulating coatings of the cold water tubes. Jean Michel Geneste has also said that he had all the coatings removed and cleaned to eliminate the spores.

This machine has other characteristics that distinguishes it from the « Guyon » machine:

- The new machine only uses a primary circuit of cold water. The cold water is made by two generators situated outside the cave, one of which was not working.
- The original primary cold water supply was stopped up. Les gaines de calfeutrage des conduites d'eau froide primaire initialement livrées avec la machine ont été enlevées.
- According to certain observers, after the first tests, one realized that the machine is too

powerful. One cold have reduced this strength by idleing the ventilators, instead of removing the ventilators, thus rendering the system very ineffective.

### 3,3 Operation of the machine and draft ammendments

It is clear that many attempts were made to make this machine effective. The last to date is the condition where we found it on 13 November and has been for the past year according to Jean Michel Geneste. It is regretable that Philippe Malaurent, who participated in the installation and the testing of this machine was not invited to visit (with me). Asked about the results of the experimentation, Monsieur Benoist said that the machine only had an effect on the first part of the Salle des Taureau. This result is deduced from the temperature measurements and the numerical simulations carried out by the Trefle laboaratory. Monsieur Benoist has assured me that to replace the faulty machine, the principle of the exchanger installations of new, one in the room of the Bulls, the other in the alcove ( ?) on the right hand side had been decided and that new measuring instruments had been ordered to measure disturbances in airflow in the vicinity of these exchangers.

### 3.4 Conclusion

The new machine installed in 2000 is all in place and functioning already today on a reduced level, that does not allow it to run efficiently. Although its design is rather different from that of the machine "Guyon", it could perhaps have functioned despite everything if one of the ventilators essential for proper operation had not been dismounted.

*The* Fusarium solani *fungal invasion that marked the true beginning of this crisis may have been cuased by something other than the erratic operation of the new machine. It is necessary to look at the sharp variations of moisture and temperature conditions under which the installation work was performed (for the cause).*

In effect, if the foram insulation coating the cold water tubes in the machine room brought the *Fusarium* spores in, as confirmed by the conservator, this lack of sterilization is probably not the cause of the invasion of the fungus into the remainder of the cave. Indeed, the biological analyses (by LRMH) showed that the *Fusarium solani* which had rapidly invaded the cave had another origin then that of the machine room infection. According to the specialistes from LRMH, i twas always present in the ground. To explain its rapid development requires another explanation, for example:
**a**-The thermal shock from the arrival of very cold air in the cave when all of the doors werer opened in winter for several days.
**b**-Inundation of the machine room floor and in « sas 2 » with torrential water from the mtal roof that was not collected anymore because the metal tubes had been dismounted for installation of the new larger equipment. The water no doubt traveled through the ground to the adjacent rooms, sas 3 and the Bull Hall. It woud be interesting to ask the restorators who did the treatment for *Fusarium* about this.

***To return to the old system?***

The goal of all the experimentation with the new machine since 2000 is not very clear, is it to return to the same functional regimen of the Guyon machine ? But one knows how the old system worked since the retirement of Pierre Vidal in 1993? Is the intention to provide experimental data for development of the numerical simulation model established by the ministry of culture in collaboration with EDF?

After long talks with Pierre Vidal, we have arrived at the conclusioin that it is wise and rather easy to return to the conditions before installation of the new machine. A simple idea that comes naturally to mind: If, as Philippe Malurent said, the exisiting machine is capable of running in a reduced mode, it would be rather simple to put the ventilators back in place. One could then return to the (former) climatic conditions in the Bull Hall and also in the « divertical axis », close to that that preceded dismantaling of the « Guyon » machine. It would then only be necessary to to control the sterilization state of the installation to avoid all new microbial infestations and to adequately measure the dynamics of the machine.

**Installing new exchangers in the Bull Room is probably neither useful nor necessary**

During this short visit, there was no opportunity to discuss the 3 fundamental questions about what one wanted from this the new machine. However, the installation of new exchangers in the Bull Room and the right-hand side passage does not appear to be justified. It is also dangerous because it is not desireable to change the equilibrium conditions in different parts of the cave without risking an unforseen alteration in the biological equilibrium.

**3.5- Visit to the painted cavity**

After spending some time in the machine room, Monsieur Geneste and I, paridly made a tou of the decorated cave. The Bull Hall was very weakly lit, it was not possible to observe the paintings long enough to make a judgement on the evolution of their state since my last visits in the 1980-1990s. However, I could note that the mositure guages that we had installed in 1964, and had been constantly present since, did not indecate condensation on the Bull Hall' walls. Is thie because of the current operation of the air conditioning ? In addtion, I did not observe any traces of *Fusarium solani* which had invaded the cave. Jean Michel Geneste pointed out to me a section near the cceiling at the entry of the dirverticule axis that had been colonized and then cleaned by the restorers. The fungus had not reappeared which is very positive. Shold it be concluded from this that the spores and germs disappeared and that a new fungal infestation in the future is excluded ?

The visit to the right part of the cave enabled me to note the abundance of the black and grey spots which, thus far, have not dissapeared, despite repeated treatments. Traces of degradation of the benches of old Gours are visible in several places.

I could also note as well that the wizard was partially blocked by a plaster block and as a consequence exchanges between the lower Karstique network and the outside, which in the sixties was via the passage on the right-hand side and the Bull Room was made today by the « ensablées » room.
*It should be noted that I had proposed the installation of this partition in 1965 to reduce the*

*increase of CO2 in the cave following drops in atmospheric pressure. Since then the ystem was supplemented by mechanical pumping of CO2 from the bottom of the well.*

I also noted that the grating which had been placed in the ground of the Bull Hall to prevent dust caused by foot traffic of visitors had been removed ; perhaps this contributed to diffusion of the microorganisms.

Finally the « sas » Bauer separating the Bull Hall from the pasage on the right was also removed.

### 3.6 Instrumentation

On the instrumentaton plan, I noted the small number of measuring stations to monitor physicochemical parameters in the cave. The lack of sufficient information will certainly make it difficult to make a precise comparison with the predictions of the simulation program. In particular, the current instruments do not permit measurement of the temperature changes of the machine in the Bull Room nor the humidity nor the speed of the air flow in the middle of the openings of the machine room or the Bull Hall. This prohibits any serious evaluation (modeling ?) of the role of the air conditioning machine within the simulation program. Monsieur Benoist told me that this problem was on the way to being resolved and that new equipment was to be ordered.

## 4 Conclusions questions and recommandations

### 4.1 The first question one can pose is what is the real state of the paintings and engravings ?

One cannot depend on one visit, without adequate lighting and precise visual references make a final judgement ont the current state of the walls and the changes of the cave paintings. The freacoes are always there, impressionistic and moving, but what is their real state ? How often and over how long a time must we examine them in order to see visible deterioration ?

In our opinion, the cave must be observed every day in order to permit a rapid intervention response during unexpected changes in climatic conditions : water leaks, machine shutdowns, breakdowns of the regulation systems, etc. It is the role of the guardian to ensure this first visual observations. A thorough observation must also be made at regular intervals by means of modern techniques to determine the change of the various parameters that characterize the state of the paintings' surface : humidity, color, fine structure of the calcite.

It is essential to be able to compare these measurements in the coures of time over years. It is thus equally necessary to make a spatial map, that the role of which is to report on the state (of the cave) ; these results should be available to the people in charge of monitoring the protocols. It would also be necessary to have comparative classification of all photodocumentation of the whole cave available to the whole scientific community. I think in particular of the photographs taken by different conservators, such as those of Norbert Aujoulat made for a recent publication of his work on Lascaux and those of others. This poses the question of copywright which is necessary to regulate the success of safeguarding the cave.

**4.2- What awaits us on a system for climate regulation**

The question of what is a good climate regulation system has been asked and unanswered for years ; we still do not have a satisfactory answer since the unfortuante installation of the system in 2000. The question has received new urgency after the declaration of Christine Albanel, ministre de la Culture et de la Communication in July 2008.

How to tackle this problem ? It is clear that the originators of the machine in 2000 wished to reproduce with modern material the conditions before 2000: Stabile climate in the cave and stable microbial environment. What is it today ?

The answer to that question is not evident, in effect, it is clear that the climate parameters (humidity, air current rate, composition of principal elements, e.g., $O_2$, $N_2$, $CO_2$, can be controlled or modified overall or locally by appropriate physical systems, the question is to know what the effect of a particular choice of parameters on the evolution in the short or long term on the biofilm and ecosystem of the cave. We know for example that the water, oxygen and organic material is necesssary for development of microorganisms, any changes of the parameters has consequences, certainly in the long term on the balance of the biotope.

In the situation that we find ourselve in today it seems unreasonable and dangerous to want to install temperature regulator stations in the Bull Hall and to the right of the cave.

Putting these in place will introduce a new perturbation in the cave that we can not predict today what the consequences will be. It should not be excluded, but such a decision involves many scientific disciplines **Il ne faut pas l'exclure, mais une telle décision relève de la pluridisciplinarité scientifique et ne peut-être prise au sein d'un groupe "machine" restreint à sa composition actuelle.** A thorough dicussion with all the specialists of all disciplines is necessary.

We recall that in the first part of this report the earlier system « guyon » allowed maintenance of the climate in the Bull Hall very close to the natural equilibrium conditions, while avoiding condensation on the walls. I recommend that as that is know in the report "Climat Lascaux" we put in place an identical system of equivalent.
The problem raised by the slight variation in temperature gradient in the Bull Hall and in the diverticule axis is not doubt surmountable.

**4.3 What can we expect from the numerical simulation program ?**

The attention of the members of the committee and those responsible for the cave L'attention des membres du comité et des responsable de la grotte was distracted too much by what one can call a technological mirage, that of a precise mathematical model that can model the complete physico-chemical condition of exchanges of gas and biological material between the air and the wall paintings. It is very important to say as well the importance of this program for the conservation program of Lascaux cave and for all the programs of study and conservation of

painted caves. However to think that in the pressing situation in which we are today such a program can replace serious study and measurements on the ground is a serious error.

In effect, this program in principal capable of calculating the thermodynamics of exchange and the evolution of air flow in a complex volume like that of the cave can be useful if suitably documented. It is necessarily dependent upon running a great number of experiments to determine with suficient precision the very numerous unknown parameters upon which the calculations depend. Currently, certain data are missing, like those for natural ventilation associated with variations in atmospheric pressure. Or those which concerning water that percolates through microscopic cracks in the walls. These micro infiltrations seem, according to François Bourges, play a role in dermining the thermodynamic regulations of the Chavet cave, for example. Even a sophisticated simulation program can not, in the near future, replace a scientific team and a rigorous ground obervation protocol. I have already made such remarks to to Marc Gauthier who responded to me, and **I am also of the opinion that the program can be especially helpful to make decisions** (is this latter part Marc Gauthier's response Translator's question ?).

### 4.4 Global climate change

The experts on the committee, many times over two years, made reference to global climate change as a reason for the problems in the cave. The increase in temperature since 1980 is about 1°C, it is accompanied by a regular and slow elevation of the temperature in the cave with delays increasing with depth. The bottom of the axial diverticule located lower than the entry of the Bull Hall would be now on average colder which would impact on the covection we had observed in the 1960-70s and consequently would inhibit the renewal of air in this part of the cave. It should be noted that at the time of our study in the 60s, we could observe different convection patterns with different cells in the various parts of the cave. Consequently, I think the assumption of the nonrenewal of the air in the DA appears not very probable to me and at least deserves to be checked by precise measurements and not only by dubious calculations. In addition, if one does not observe water condensation on paintings of the axial diverticulum, is it necessary to ensure a fast and permanent renewal of the air ?

### 4.5 Other physical methods to treat microbes

A number of scientists who know the underground environment and conservation question why we should support at all costs chemical treatment with large amounts of liquid near paintings when the treatments are not very specific and may destroy a great part of the biotype without knowing how and which species may replace them ? Mechanical pulling of spores and fungi, carried out with much precaution, is always dangerous. The physicists and chemists in food science can treat the molds locally or globally by electromagnetic radiations or by killing them by changing the compostion of air. These techniques are used in many industries and probably represent much less danger for pigments; should then not be considered as complementary or replacement methods to those used today ?

## 5 Comments and perspectives : Le LIST,

One can not ignore, among the causes of the current difficulties, the management of the scientific managment of the cave. It is clear that to safeguard the paintings of Lascaux is above all a scientific question ( ?). Saveguarding Lascaux is the responsibility of the French state which has all of the resources of the Ministère des affaires Culturelles. The traditional operating mode tested successfully at the time of the first crisis of the years 1960 finds its limits today. It is necessary to set up a proper scientific managment of the cave. It is with this intention and in order to help the ministry and its administration to set up this new type of management that we have, with some colleagues, conceived the LIST, "Lascaux Scientific International Think Tank". This group, independent of any administration and any organization, gathers researchers among the best international experts in all the disciplines concerned with the safeguard of paintings of Lascaux. Hard sciences include physics, chemistry, biology, and geology are particularly represented there. The members of the LIST which will attend the symposium organized by the ministry for the Culture the 26 and February 27 will have the prime objective to get informed about the achievements of the scientific committee and in the second place to contribute by their questions and suggestions to establish a more complete view of the complex problem of the conservation of Lascaux and underground partimony.

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Le 21 février 2009

**Note post symposium**

The symposium "Lascaux and the conservation in underground medium" in which several members of the LIST took part was remarkably organized. It allowed very profitable meetings and contacts with researchers of the international community and those of the scientific committee. In particular the very open contacts established with the persons in charge for the Ministry, the administration and the scientific committee really gave us hope that an effective collaboration for setting-up of a new model of scientific management of the cave of Lascaux (can be set up).

## Appendix 1

### The question of cave climate during 1960-1970

### 1 Principal results obtained

Between 1964 and 1965, in close connection with the first scientific commission to saveguard Lascaux, and with a team of technicians who I formed in place, we established the method, designed and developed the measuring instruments, which did not exist or were not adapted, and made the the first complete scientific study of the cave climate. The essential conclusions of this work are consigned in 5 reports/ratios preserved by the administration and in an article published in the review of synthesis in 1980. The significant results which are still valid today are summarized here:

**Climatic stability:**
The microclimate of the cave was much more stable than we imagined:

**Humidity:**
The humidity of the air was between 97 and 100%

**Ventilation :**
The ventilation of the cave was convective in barometric periods of stability. The engine of this convection was the slight differences in temperature of some tenth of degrees appearing between the ceiling and the ground during the annual cycle. The ceiling of the Bull Hall was colder in summer and heater in winter because of the relative delay in the propagation of the thermal waves through the rock, depending upon its thickness. This natural ventilation effect of the partially open to the outside cave and the lower karstic network also results in the absence of Radon, this rare, radioactive gas, heavy, present in weak proportions in the air and which tends to accumulate in the low cavities not well-ventilated like the cellars of dwellings or the caves closed.

**Temperature :**
Let us recall that the set-point temperature of the air for the first system of conditioning, conceived for visitors, was 14°C, whereas the average temperature of the cave measured between 1964 and 1965 was in fact 12°4 (is this 12°C or 12.4 ?). This value is very precisely equal to the external average temperature during 10 preceding years what shows the thermal role of shock absorber of the rock roof of the cave. The temperature of the air and that of the rock being in balance, the speed of the exchanges between the air and the rock were extremely low. The entry of the Bull Hall was more exposed to the variations in temperature from the lowest thickness of the roof of rock, and moisture because of the presence of zones of water infiltration (zone of the Unicorn) and of the effects of the entry (doors, walls, chambers) could express light imbalances leading either to drainings of the wall or to water condensations.

**$CO_2$ concentration gradient:**

The carbon dioxide observed in the cave did not come only from the breathing of the visitors but also from the underground karstic network. The air of this network, in balance with a seepage of water very rich in dissolved calcium carbonate, contains a strong dissolved CO2 concentration. During barometric pressure drops, the air of the underground grid slackens in the cavity and this one escapes by the natural openings. We observed that CO2 the concentration, normally weak

<0.3% went up abruptly to dangerous levels for man (some %) at the time of abrupt falls of atmospheric pressure.

## 2 The first ventilation studies on the cave

The protocol called “opening of the oculus” was proposed by professor Schoeller of the university of Bordeaux. Its conclusions deserve to be reported because the question rests today following the opening of the doors during the period of work and the inversion of concomitant temperature between the bottom of the axial diverticulum and the entry of the Bull Hall. The experiment which was carried out in winter aimed to insert the external cold air into the cave to cool the hotter air saturated with moisture in the Bull Hall in order to lower its percentage of moisture and to drain the walls of the room. This operation had in fact a principal goal to observe thereafter the possible appearance of infiltrations or water streamings, sources of contribution of dissolved limestone and possible precipitations.

I directed the total measurements at the time of this protocol. The oculus, located on the roof of the cave close to the entry was open during the winter of 1964. Indeed a cold airstream was immediately established, which descended the staircases to the Bull Hall and was propagated in the room until the bottom of the axial diverticulum. The warmer air rose up to the vault and crossed the higher opening placed in the wall of the Bull Hall, thus a large convection cell was created. The temperatures of the warmer vault and the colder ground of the cave balanced in a few days and the intensity of the draught quickly decreased. The consequence of this contribution of cold air was indeed the reduction in the moisture of the air and the relative draining of the walls.

Thereafter, and until the installation of the machine “Guyon” after 1965, not only one, but several cells of convection were observed in the Bull Hall, whereas, as far as I remember the temperature in the axial diverticulum and that of the Bull Hall were practically equal.

The first conclusion to be drawn from this study is the capacity of the rock mass of the cave to mitigate (absorb ?) the variations in temperature of the air and to adapt quickly to new equilibrium conditions, this should not have changed today. The assumption of an effect of the global climate warming o about 1° C observed in the area of Lascaux since 1980 on dynamics and of the stability of the micro climate of the cave is without solid base. If this change were at the origin of the current crisis, its effect should have appeared well before the alteration work of the new machine, say in the Nineties. Moreover the cave, for 18000 years, has adapted to climatic variations much greater.

The second conclusion is that draught coming from the input area of the cave can quickly and effectively modify the thermal equilibrium conditions on the level of the painted wall. This observation with besides be at the origin of my project of system of climatic assistance. There is no reason in principle that with the restarting of such a system, it is not possible any more to act directly on the atmosphere of the Bull Hall, if not on that of the axial diverticulum.

It is while inspiring to me by the observations of this protocol that I imagined to finely control the temperature of the air of the Bull Hall to control its moisture while having behind the wall of the machine room of the exchangers of heat on the circuit air convectif and laid out so that they do not disturb the natural draughts. This air, practically saturated with water, cooled, gives up part of its moisture. Heavier than the ambient air, it runs out by gravity towards the ground and turns over in chamber 2 (sas 2) and the room of the Bulls via the openings placed in the base of the walls between the machine room the Bull Hall. On the basis of measureming the speed of the draughts, temperature, and humidity of the air, I conceived a system made up of two exchangers of heat (water-air) placed on the circuit of the air convectif and laid out in the machine room behind high openings placed in the wall which separates it from chamber 2. The system of water cooling used a double circuit: a primary circuit with external generators, those which were used for the first machine installed for the visitors, and a secondary circuit located in the machine room using a changer (water-water) intermediate. It is Pierre Vidal and the other engineers who succeeded me who finally installed and developed the system, in particular, the precise positioning of the exchangers, not too close (1 to 2 m) to the openings in order not to disturb the draughts of convection.

## 3 Operating mode of the system

The system had calculated how much to compensate for moisture and heat released by 50 people standing in the Bull Hall. In reality, the commission restricted the number to 5 people per day.

The heating flow was easily adjustable either by that of the secondary water circuit, or by the set of slides coming to block the openings of the wall of the machine room. In practice, this machine was started during certain times of the year when the differences in temperature between the air and the wall of the BullHall induced condensations that were likely to physically degrade paintings, either by flow or chemically by acid attack of calcite.

## 4 The condition of paintings during the years 1965-2000

The question of measuring the physical, chemical, and biological state of the painting is obviously essential. It does not seem that the photographic macro observations, as those of Dr. Bauer, were systematically continued since 1965, except for the work of Pierre Vidal in the Eighties. Abundant photographic documentation is an invaluable element of comparison, but what is its scientific value?

The daily observation of the walls in company of Jacques Marsal enabled me to note the regression of the green zones following work of the biologists of the commission. Many people, who visited the cave in company of Jacques Marsal or of Pierre Vidal between years 1970 and 1990 affirm that they observed paintings in a stable state. Jacques Marsal besides regarded this constancy of the state of paintings as a miracle after having attended the first crisis of the années1960.

## 5 Conclusions

The machine installation following the crisis of the Sixties, robust, of a simple operation, regulated to maintain the conditions of moisture and temperature of the air of the Bull Hall as close as possible to their values of balance did not bring an important disturbance to the climate of the cave but only one small assistance to the climate of the Bull Hall allowed compensation for the small variations of the climate, natural or caused by human presence. This machine functioned for nearly 35 consecutive years while making it possible for the cave to gradually adapt to the slow variations of the external climate as it had always done before the human intervetion.

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