Important
Ce document ne doit pas dépasser 30 pages, dans la mise en page et la typographie fournies par l'ANR. Ce point constitue un critère de recevabilité de la proposition de projet. Les propositions de projet ne satisfaisant pas aux critères de recevabilité ne seront pas évaluées.

Acronyme / Acronym	**HVIV**		
Titre du projet	High Voltage holding In Vacuum		
Proposal title			
Comité d'évaluation/Evaluation Committee			
Type de recherche / Type of research	☐ Recherche Fondamentale / Basic Research **X** Recherche Industrielle / Industrial Research ☐ Développement Expérimental / Experimental Development		
Coopération internationale (si applicable) / International cooperation (if applicable)	☐ OUI **X** NON		
Aide totale demandée / Grant requested	516 906,05 €	**Durée du projet / Projet duration**	36 mois

- *Ce document ne doit pas dépasser 30 pages, au format fourni par l'ANR (mise en page et typographie). Ce point constitue un critère de recevabilité de la proposition de projet.*

1. RESUME DE LA PROPOSITION DE PROJET / EXECUTIVE SUMMARY

Vacuum insulation is applied in high voltage apparatus such as power circuit breakers and low loss capacitors. The highest possible electrical breakdown strength should be expected in ideal vacuum, since no charge carriers are present in the inter-electrode gap [1]. Vacuum thus appears as an effective alternative to gas insulators such as sulfur hexafluoride (SF_6), perfluorocarbons (CF_4, C_2F_6, or the promising C_4F_8) which present the drawback of being global warming potential gases. But electrons emitted by the cathode directly cross the gap without any collision phenomena, and pre breakdown is frequently encountered, so limiting the use of vacuum for power circuit breakers. The role played by metallic microprotusions in the field emission mechanism is now well understood but an alternative emission mechanism proposed by Latham et al [2] implies non-conductive or semi-conductive materials such as oxide layers or impurities, including adsorbed gases.

Another field of application is in the controlled fusion domain. Fusion reactions in hot plasmas inside future Tokamak reactors (ITER, DEMO) are initiated by injecting high power beams of neutral D° atoms at high energy (1 MeV for ITER) into the plasma. Negative ions are accelerated by an intense electric field between electrodes at high voltage under vacuum and neutralised in a downstream gas target. The connection between the power supplies under SF6 and the electrodes under vacuum is made through an insulating passage called the bushing.

Experiments at IRFM on the MV testbed (1MV, 100mA) have shown that the voltage holding is limited by the appearance of breakdowns if two electrodes are too close. The voltage holding with distance follows a square root law for distances larger than 1 cm. This dependence indicates according to the theory by Cranberg an exchange of micro clumps that cause breakdowns when they evaporate on the opposing electrode.

Another performance limitation is the appearance of a sizeable electron current (100mA at 400kV) resulting from field emission that appears to follow the Fowler-Nordheim law. This unwanted dark current can be reduced, even eliminated, by the presence of gas in the vacuum vessel.

This very beneficial feature is consistent with an increase of the work function of the metal. This would be caused by the adsorption of gas induced by an intense electric field. This physisorption process allows atoms to stick around emitting micro protrusions. Due to this, the emitting surface is reduced and the work function is increased.

This research project aims to study the field-induced adsorption process by joining theoretical and modelling work with small-scale and large-scale experiments in several laboratories. The objective is to find physical conditions that favour the increase in surface work function, thus leading to an increased voltage holding in vacuum (by suppression of the dark current and absence of breakdowns) under high electric fields (50-100 kV/cm) between large electrode surfaces.

This ANR project proposes specific research on the high-voltage holding under vacuum conditions. Four different laboratories work on 5 different themes:

- Fundamental studies and modelling of field induced gas adsorption (LCAR Toulouse).

- Simulation of field emission from a realistic surface and micro ionisation around emitting micro tips (LPGP, Paris).
- Experimental study of the field emission and field-induced adsorption of gas with adjustable parameters (electrodes surface conditioning, electrodes material, electric field intensity, electrodes gap distance, gas nature and pressure); model validation (Supelec, Paris).
- Study of the high voltage holding in vacuum using different materials and surface treatments to eliminate micro particles and micro tips. Large scale application of the previous more fundamental studies (IRFM, CEA Cadarache).
- Construction and test of a prototype compact bushing, using all the knowledge gained in this project (IRFM, CEA-Cadarache).

2. CONTEXTE, POSITIONNEMENT ET OBJECTIFS DE LA PROPOSITION / CONTEXT, POSITION AND OBJECTIVES OF THE PROPOSAL

The energy of future neutral beam injector (NBI) heating systems of fusion power plants like ITER and DEMO ranges from 1 to 2 MeV. The additional heating power due to NBI is one of the key elements to succeed in creating a self-sustaining fusion plasma in tokamak reactors. NBI systems are based on powerful hydrogen or deuterium negative ion electrostatic accelerators (an ion beam of several tens of MW) where electrodes are polarized by high-voltage DC power supplies. On ITER, the accelerator accelerates the beam (that is extracted from a large plasma ion source) in five stages of 200 keV each before the 1 MeV beam is neutralised by interaction with a gas target and transmitted to the reactor plasma that is confined by strong magnetic fields. The beam line and the fusion reactor chamber are under vacuum, while all the electrical components (power supplies) are far away from the nuclear island of the reactor, connected to the injector via a long pressurised (SF_6) high-voltage transmission line. The bushing is a key component of NBI that connects the transmission line under SF_6 and the injector that is under vacuum.
Collisions between negative ions and background gas inside the accelerator cause loss of negative ions due to stripping reactions. To minimise such losses, the entire accelerator on ITER is suspended inside the vacuum vessel. Therefore, voltage holding in near vacuum conditions must be ensured between surfaces that are 200 kV apart (accelerator stages and bushing surfaces) and also surfaces that are 1 MV apart in voltage (the vessel wall and the ion source that provides the accelerator with negative ions). The system is described in [3].
The voltage holding between two electrodes that are separated by a short distance (< 1 cm) increases linearly with the distance (V~d). For large distances, therefore high voltages, this is no longer true and voltage holding appears to be proportional with the square root of the distance ($V\sim\sqrt{d}$). This is traditionally explained by clump theory, first formulated by Cranberg [4]. This theory assumes that small clumps are accelerated between the electrodes and evaporate on impact, thus causing breakdown. By adding as condition that Paschen breakdown must occur in the expanding gas bubble, Slivkov formulated a modified version of the same [5] that can be used to explain a much larger variety of high-voltage holding phenomena [6] and eventually suggest modifications to the design of the negative-ion accelerator for ITER.

High-voltage systems in vacuum not only break down, they can also give rise to electric currents traversing the vacuum. Such so-called "dark currents" tend to rise exponentially with voltage and thereby limit *de facto* the maximum voltage that can be attained in a high-voltage installation [7]. The presence of a potential difference of 1 MV inside the ITER neutral beam vessel thus presents a risk of dark current limiting the voltage holding.
The dark current can be suppressed or reduced by a long process of high-voltage conditioning and/or, instantaneously, by adding a small amount of hydrogen or helium gas into the vacuum tank. The gas effect is completely and instantly reversible [7]. This suggests that field emission takes place and that the work function in the Fowler-Nordheim expression is modified by the gas. Gas being adsorbed on emitting micro protrusions under the influence of the electric field is the likely cause of this [8,9,10]. Clumps also seem to play a role as at higher voltages ever lower electric fields are sufficient to cause dark current.
The objectives of the proposed work then become clear. In a program of accompanying research for ITER one wants to gain insight and understanding of the high-voltage holding phenomena with the goal of becoming more confident in the high-voltage holding design of large installations like those proposed on ITER and fusion reactors that are further in the future. It is also proposed to develop a compact high-voltage bushing as a back-up solution for ITER using the knowledge gained earlier in the programme. This bushing should have better high-voltage holding and reduced dark current and may also be incorporated in a neutral beam system for DEMO.

2.1. CONTEXTE ET ENJEUX ECONOMIQUES ET SOCIETAUX / CONTEXT, SOCIAL AND ECONOMIC ISSUES

The interest of the proposed project is in developing an additional source of energy, fusion power. Neutral injection and its high-voltage problems are a part in its technological development, but their improvement requires fundamental research; the understanding of elementary phenomena leads to better design and optimized configurations.
Practically, there are only two test beds in the world that have a capability of reaching 1 MV. These are at IRFM in France (1 MV, 0.1A) and at JAEA in Naka, Japan (1 MV, 1A). A 400 kV test bed under construction at the University of Padova (Italy) also deserves to be mentioned. The Japanese test bed cannot be used for the high voltage studies as it is currently damaged by the earthquake and committed to accelerator studies. Thus, only the test bed at IRFM can reach 1 MV and is at the same time available for high voltage studies.
The IRFM test bed is currently being used for high-voltage breakdown studies for ITER. The current studies and the future studies proposed in this ANR are unique in the world.

2.2. POSITIONNEMENT DU PROJET / POSITION OF THE PROJECT

The ITER project is a world wide cooperation between seven partners, the EU, the USA, Japan, China, South Korea, India and Russia. Its goal is to demonstrate the feasibility of power generation by controlled nuclear fusion. To achieve high-yield fusion, the DT plasma must be heated to high temperatures (tens of keV) by a variety of external heating methods, one of which is neutral beam injection.
The proposed project is accompanying research into the little explored domain of high-voltage holding in large scale vacuum systems. The ion source (held at -1 MV) and

accelerator for ITER neutral beams will be suspended in "vacuum" (D_2 gas will be present at a pressure of around 0.02 Pa) at close proximity to the walls (0.9 m).
The 1 MV test bed at IRFM [7] is a large scale installation, 5 m long and 3 m high. It is extremely well suited for ITER relevant experimentation on high-voltage phenomena in vacuum in large systems. The results of the experimentation will also be relevant to neutral beam systems on future fusion machines like DEMO, for which a beam energy of the order of 1-2 MeV is required.

2.3. ÉTAT DE L'ART / STATE OF THE ART

As described in section 2, the high-voltage problematic on future neutral beam system consists of the following:

1. voltage holding between accelerator surfaces and also the surfaces of the bushing (200 kV on ITER),
2. voltage holding between the suspended ion source and vacuum vessel (1 MV on ITER). Two phenomena are most relevant here:
    a. electrostatic breakdowns between vacuum vessel and ion source and/or accelerator,
    b. presence of a continuous dark current between these surfaces.

1. Voltage holding between surfaces

The voltage holding between two electrodes that are separated by a short distance ($d < 1$ cm) increases linearly with the distance ($V \sim d$), i.e. the electric field remains constant and the breakdown condition is purely related to the electric field. For larger distances, therefore high voltages, this is no longer true and voltage holding appears to be proportional with the square root of the distance ($V \sim \sqrt{d}$). This is traditionally explained by clump theory, first formulated by Cranberg [4]. This theory assumes that small clumps are accelerated between the electrodes and evaporate on impact, thus causing breakdown. By adding as condition that Paschen breakdown must occur in the expanding gas bubble, Slivkov formulated a modified version of the same [5] that can be used to explain a much larger variety of high-voltage holding phenomena [6]. The maximum voltage vs. electrode distance measured at IRFM is given in Fig. 1.

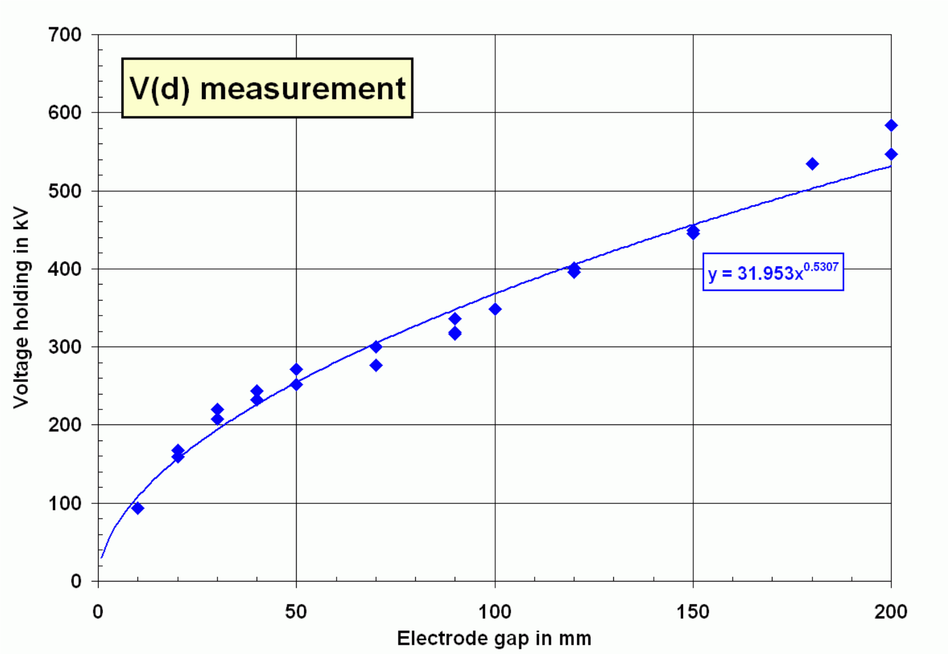


Fig. 1: *Measured voltage holding vs. gap at IRFM. The blue line represents a power law fit through the measured points.*

Future experimentation will concentrate on establishing the effect of using different surface treatments. Different materials, polishing (to remove micro tips), rinsing in ultrapure water (to remove clumps) and glow discharge surface conditioning in argon are proposed. Whereas it is not expected that a linear relationship can be established at larger distances, it is expected that the curve in Fig. 1 can be moved vertically. As ultraclean conditions are required, it is proposed to perform these experiments in a small test bed. The results can be applied to reduce the surfaces of the high-voltage bushing, which are an important issue to future beam systems on machines like DEMO, that have to be as compact as possible.

2. Dark current

In the situation of very clean electrode surfaces, dark current is initiated through field emission and its magnitude follows the Fowler-Nordheim (FN) law. With real-life surfaces, micro protrusions that are always present, give rise to a much higher dark current than is calculated from the FN law. Commonly, the effect of micro protrusions is incorporated in the expression through the field enhancement factor β, which is approximately equal to the ratio of its height and radius. Then the electrons impacting the anode give rise to secondary processes that amplify the dark current.
In non-clean systems, particle clumps and microdischarges can initiate field emission by damaging the cathode. Cathode damage can result from the fresh formation of microprotrusions or from the removal of surface layer leading to a decrease in work function. The subsequent dark current will again follow the FN characteristic. IRFM have demonstrated the presence of dark current at extremely low electric fields (0.4 kV/cm) from a so-called "dark current probe" that was electrically insulated from the rest of the system

[7,11]. The probe material had no influence at all on the current but shielding the probe with 0.5 mm thick aluminium reduced the current to zero, excluding X-rays as a cause.
The various surface treatments of cathode materials can change the work function. Also untreated material can be superficially oxidised (so called 'native oxide') and obtain a different work function as the parent metal.
Finally, it was demonstrated at IRFM that gas injection in a large gap system reduces the dark current intensity, possibly by increasing the cathode work function [7]. Evidence exists that the gas forms a surface layer under the action of a strong electric field (such as would exist at the tip of micro protrusions) which changes the work function significantly [8,9,10]. Figure 2 gives the dark current in the MV testbed at IRFM for different gas pressures and applied voltages. It can be appreciated that the presence of a small quantity of gas is of huge benefit to the maximum voltage that can be reached.
A coordinated study that involves several laboratories is proposed to understand, control and optimise the process of field induced adsorption of gases. LCAR and LPGP will take care of the modelling while SUPELEC will study the electron field emission from surface controlled cathodes under high vacuum. The field-induced gas adsorption process will also be studied.

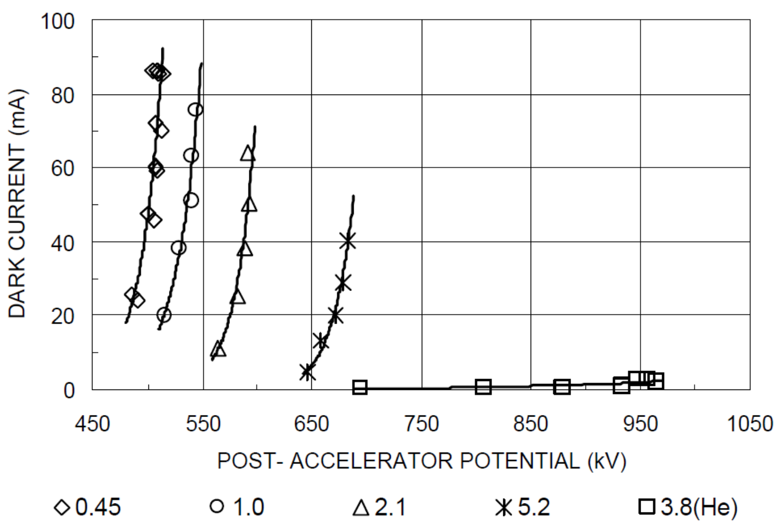


Fig. 2: *Measured dark current vs. voltage and pressure from [7]. The legend gives the D_2 or He gauge pressure (as measured with a Penning gauge) in 10^{-5} mbar.*

2.4. OBJECTIFS ET CARACTERE AMBITIEUX/NOVATEUR DU PROJET / OBJECTIVES, ORIGINALITY AND NOVELTY OF THE PROJECT

It is not certain that the ion source and accelerator for ITER can withstand the required 1 MV nor is it certain that the accelerator can withstand electrostatic breakdowns with high stored energy. The proposed program aims at gaining insight in the high-voltage problematic and its results will provide the knowledge necessary to propose improvements in the ITER neutral beam system. A to-be-developed alternative compact bushing will provide a back-up solution for ITER and can serve in future neutral beam systems.

The work at IRFM will concentrate on the voltage holding of large systems and the development of a compact bushing. The compact bushing will reduce the stored energy in the system due to its smaller axial length. Surface treatments to increase the voltage holding will be tested in a smaller dedicated test bed in which clean conditions can be ensured. Polishing will be tested with the aim of removing micro tips. Rinsing in ultrapure water serves to remove clumps. Finally, glow discharges in argon are proposed which should have an effect both on clumps and on micro tips. The result of this work should lead to a system with higher voltage holding capability.
At LCAR the electric field induced gas adsorption and its effect on the work function and field-emitted current will be modelled. Such phenomena have already been studied in the case of carbon-nanotubes [16,17,18]. Their shape allows them to intensify electric fields. Hydrogen or water molecules can physisorb on closed nanotubes: their binding energy is of the order of 10 meV in the absence of electric field, but this can increase strongly due to polarization effects in the presence of field. It was shown that the presence of the adsorbate significantly influences the electronic work function. A key parameter is the difference in the electronegativity of the substrate and the adsorbate. Another influencing parameter is the change of the electronic local density of states near the adsorbate at the Fermi level. One originality of the present project is to extrapolate this kind of concepts and tools from this rather fundamental research field to the present engineering context in two steps. The first involves calculating the gas coverage from the sticking probabilities and the desorption rate in the presence of the electric field. Then the effect of the gas coverage on the electronic work function shall be calculated.
LPGP has developed a code modelling the tip equilibrium between the electron current emitted and the tip temperature (O-VIP1), depending on the macroscopic electric field and the tip geometry. In the present project, the LPGP contribution is to build a novel numerical tool capable to simulate large area 'artificial' surfaces by randomly distributing several geometries of tips (cylinders, cones, ellipses, and hyperbolas). This model should predict the total amount of electrons emitted by the surface under high electric fields. The results can be directly compared with IRFM for large area and large gap and SUPELEC for small areas and gaps. The modelling results provided by LCAR on the change of the work function of the surface material can be easily tested in terms electron emission change, since the material work function is an input data of O-VIP code.
The modelling by LCAR will be carefully verified by experimentation at SUPELEC. They will experimentally study the electron field emission from controlled cathode surfaces in high vacuum. Also the field-induced adsorption process on a controlled electrode surface and its effect on the work function and field emission will be studied.

3. PROGRAMME SCIENTIFIQUE ET TECHNIQUE, ORGANISATION DU PROJET / SCIENTIFIC AND TECHNICAL PROGRAMME, PROJECT ORGANISATION

3.1. PROGRAMME SCIENTIFIQUE ET STRUCTURATION DU PROJET / SCIENTIFIC PROGRAMME, PROJECT STRUCTURE

LCAR and LPGP will provide the modelling, SUPELEC will perform experimentation on carefully prepared surfaces under ultra clean conditions and IRFM will do experiments in the large 1 MV testbed, construct a new compact bushing and test it in a small purpose-built new testbed, where the environment can be more carefully controlled.

1. IRFM (CEA-Cadarache)

A. Magnetic fields are used in negative-ion accelerators to deflect electrons out of the beam before they are fully accelerated and thus prevent loading components with power. It is proposed to use Helmholz coils to simulate the long range magnetic field as exists in the proposed accelerator for ITER. Short-range magnetic fields will be simulated by incorporating similar permanent magnets as proposed for ITER in the electrodes. The influence of the magnetic fields on voltage holding will be assessed at ITER relevant gas pressures (from vacuum to up to 0.1 Pa H_2 pressure).

B. The voltage holding between two electrodes will be attempted to be increased by surface treatment. Polishing will be tested with the aim of removing micro tips. Rinsing in ultrapure water serves to remove clumps. Finally, glow discharges in argon are proposed which should have an effect both on clumps and on micro tips.

C. Short-circuiting alternate stages in the bushing doubles the electric field between the other stages if the same voltage is maintained. As the high electric field in the bushing could be at the origin of the dark current in the tank, doubling its intensity should result in an important increase of the dark current following the FN law. If, however, the "total voltage effect" is the limiting factor (particle clumps and particle exchanges), then the same voltage over 5 rings can be held as with the 9 rings. This experiment would confirm (or otherwise) that with the present bushing design the electric field compression under vacuum with is a real issue for the ITER bushing.

D. The dark current probe [7] consists of an "electrode" (that can be a wire mesh or a solid copper or stainless steel plate) and a “backplate”. The electrode is mounted flush with, and electrically isolated from, the inner vessel wall. The electrode can be biased to 1 kV relative to the backplate. The electrical currents flowing from the electrode and the backplate are measured. The following experimentation, using the wire mesh as electrode, is proposed:

   a. To measure the current on the backplate while the high voltage on the test bed anode is switched off.

   b. To measure the current while the high voltage on the anode is switched on (using a couple of different values).

If microparticles cause the dark current, we shall see nothing in the case of (a), but we should get signal on (b). If microprotrusions are implicated in the current generation at very low fields, experiment (a) should show signal. If this is not the case and exchange of dust ("clump theory") is the cause of the dark current, experiment (a) results in zero current.

E. We also propose a dedicated experiment targeting the reduction of microparticles on the electrode surfaces in the 1 MV test bed: baking the electrodes at 200°C with a substantial gas filling pressure (~0.1-0.5 bar N_2), followed by pumping. In parallel, we would measure the micro-particle trap rate by filters inserted in the pumping system. We should observe its decay with the number of cycles, and in the end, the voltage holding and dark current curves taken before and after this experimentation should indicate the usefulness of this procedure.
F. It is possible that the dark current originates at least for some cases from micro-tips (whether their work function is reduced by water and pollutants or not). A conditioning protocol aiming to destroy them could be performed. It is proposed to run the system at high dark current value (>50 mA) in a tank filled with argon (pressure below the Paschen threshold) for a long time. Argon gas is chosen because it is heavy and ionises easily. Shot duration should not exceed a couple of seconds to avoid thermal load on electrodes. By running in argon, local ionization of argon molecules due to electrons emitted by the micro-tips would induce argon bombardment of the tips by the local enhancement of the electric field and possibly destroy them in this way. Again, the voltage holding and dark current curves taken before and after this experimentation indicate the usefulness of this procedure.
G. If the dark current is initiated by the electric field acting on the cathode surfaces (and subsequently amplified by secondary processes and exchanges of particle clumps), it makes sense to reduce the electric field inside the vacuum. In the ITER vacuum tank, the electric field is highest inside the bushing, therefore it is proposed to modify the layout of the same. One would change the concept of the bushing by an inversion of its topology: the central column at 1MV would cross the bushing from part to part under SF6 gas, to supply the bottom part (under vacuum) at 1MV; a two stage bushing holding 400 kV is in Fig. 3. The inside of the bushing can be filled with low-pressure gas (0.1 Pa H_2 or He) to suppress the dark current. The 2-stage concept in Fig. 3 can easily be extended to 3 or 5 stages. As the electric field in the vacuum is lower and the field compression occurs under gas, the dark current should be strongly reduced. A comparison with the conventional design would be performed in the same HV condition and conditioning protocol. It is proposed to test a 3-stage bushing at 600 kV. Existing porcelain insulators, available at IRFM, will be used for the construction of this compact bushing.

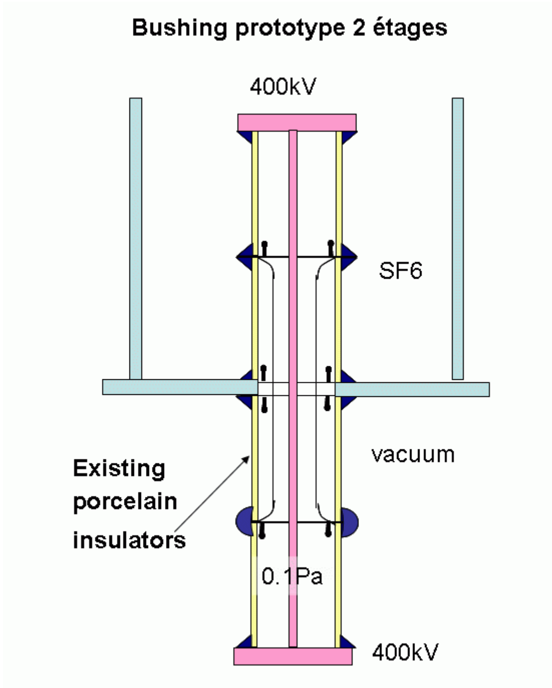


Fig. 3: *A prototype compact bushing (2 stages) as proposed by IRFM.*

2. LCAR

The dark current can be instantaneously suppressed by adding a small amount of hydrogen or helium gas into the vacuum tank. This effect is completely and instantly reversible [7]. This suggests that field emission takes place and that the work function in the Fowler-Nordheim expression is modified by the gas. Gas being absorbed on emitting micro protrusions under the influence of the electric field is the likely cause of this [8,9,10]. LCAR will provide the modelling of the field adsorption of hydrogen and helium gas on micro tips. This will require 2 steps:

A. First compute the coverage of the surface for the conditions considered here. Indeed, gases like hydrogen or helium interact weakly with the surface in the absence of external electric field. Coverage is the result of the balance between adsorption induced by dissipative processes (energy flow from gas to surface) and desorption processes (energy flow from surface to gas). At room temperature, in the absence of field, desorption rate is high for physisorbed species, and coverage is low even if sticking probability is high. However, electric field polarizes the atoms and molecules of the gas to such extent that attractive interaction with the surface increases. Desorption becomes less efficient in this case. Computing the sticking probabilities and desorption rate is thus one aim to be achieved. From these data, an estimate of the coverage level can be performed.
B. Once coverage is obtained, its effect on emission properties has to be computed. This requires computation of electronic work function. This quantity is indeed central in Nordheim-Fowler model of field emission.

3. LPGP

The group 'Theory and Modelling of Plasmas' of LPGP develops numerical codes to simulate plasmas and related phenomena involving charged particles. Specifically on the modelling of the electron emission from asymmetric tips under high voltage, LPGP and CEA DAM collaborate since 2010 aiming at better understanding of the mechanisms governing the vacuum breakdown. LPGP developed the code O-VIP1 (Orsay – Vacuum Insulation Percolation – 1 dimension) that deals with the heat equilibrium at steady state in one dimension (1D), the tip being assumed first a cylinder defined by its radius (R) and aspect ratio AR (height (H = AR * R). The temperature profile along the tip comes out of the calculation after the total convergence of O-VIP code taking into account the radiative transfer at the tip and Nottingham effect.

The LPGP contribution to the HVIV project is to build a novel numerical tool capable to simulate large area 'artificial' surfaces by randomly distributing several geometries of tips (cylinders, cones, ellipses, and hyperbolas). This model should predict the total amount of electrons emitted by the surface under high electric fields.

A. Using O-VIP code, it is possible to create a database of the simple (axi-symmetric) microprotrusions, which could be responsible of the dark current, as presented in Section 2.3 – 3. Note that O-VIP uses the macroscopic electric field as input data and it calculates itself the microscopic field and the enhancement factor (β). The external field will be provided by the experiment (IRFM, SUPELEC).
B. Using the database previously developed, the next step is to build 'artificial' realistic surfaces presenting microprotrusions by the random distribution of elementary axi-symmetric tips with random aspect ratio. Hence, is possible to estimate the total current emitted by such a surface and the formation of hot spots on these artificial surfaces. .
C. Test of the novel surface code (LPGP) for several materials tested in the project partner laboratories (IRFM, SUPELEC). Test of the work function data estimated by quantum calculations of the atoms or molecules adsorption on the surface (LCAR).
D. Finally, LPGP will simulate the propagation of the surface emitted electron through the gas filling the gap between the electrodes by a Particle-in-Cell (PIC) approach. This model of the micro-ionisation phenomena corresponds to Townsend regimen of the discharge and should predict the conditions for the current amplification and filling gas dependency. The obtained currents will be compared with the experimental ones.

4. SUPELEC:

The modelling by LCAR and LPGP will be carefully verified by experimentation at SUPELEC. As a first step, the electron field emission from surface controlled cathode in high vacuum will be studied. The second step will consist with investigations on the field-induced gas adsorption effect on field emission (i.e. dark current intensity) and material work function, assuming an unchanged β parameter.

A sphere (6mm diameter) to plane electrode geometry will be used (Fig. 4), the plane electrode (20 cm^2) being the cathode. The material of both anode and cathode will be selected (copper, stainless steel, gold) and coupled according to their specific work function. The surface electrode will be carefully prepared, by soft polishing, rinsing with ultrapure water and conditioning with an argon glow discharge. The surfaces will be characterized using profilometer, scanning electron microscopy, and atomic force microscopy techniques. Prior to experiments, water and volatile impurities will be desorbed from the surfaces by heating the electrodes to 150°C, directly in the vacuum tank. The gap between the tip of the spherical anode and the cathode surface will range from 100µm to 10mm and according to the DC negative voltage applied to the cathode, a 250 MV.m^{-1} maximum electric field intensity will be reached for the shorter electrodes gap.

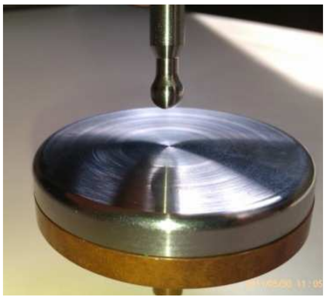


Fig. 4: *Electrodes arrangement in the vacuum chamber.*

The electron field emission current is measured at the anode electrode, insulated from the grounded vacuum chamber. The threshold value of the dark current is presently 1nA, and maximum intensities of tens of microamperes were measured. The current signal is recorded (5kHz sampling rate) and an example of dark current runaway is presented in Figure 5. When recording field emission current, it was found that for low emission activity, the current was not continuous, but consisted of trains of current pulses; for higher emission intensity, the pulses merged into a continuous signal and a non-reversible behaviour was observed (i.e. high intensity of the dark current obtained for lower applied voltage values); damages of the cathode surface could also be observed. On the contrary, situations where transient trains of current pulses were observed and disappeared after a few minutes were encountered; fusion or sputtering of emission sites such as protuberances. The shape of the current signal will then be correlated to the reversibility of phenomena.

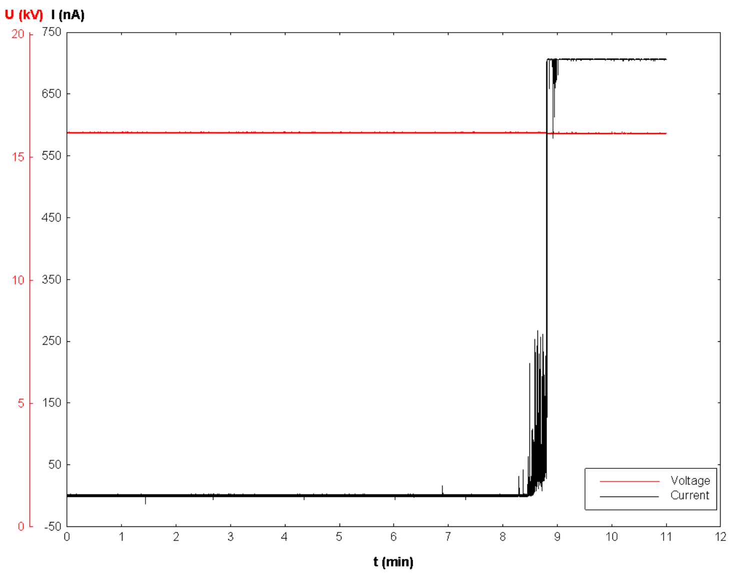


Fig. 5: *Dark current runaway, stainless steel electrodes, 16kV, 230µm electrodes gap.*

At this time, a 5×10^{-6} Pa (5×10^{-8} mbar) vacuum can be achieved in the experimental vessel. Experiments will be conducted from 5×10^{-5} Pa to 5×10^{-3} Pa, by introducing a selected gas (He, H_2). Dark current nature and intensity will be investigated (variable electrode gaps and applied voltages) for different pressure and nature of the injected gas, with several electrode materials and surface states.

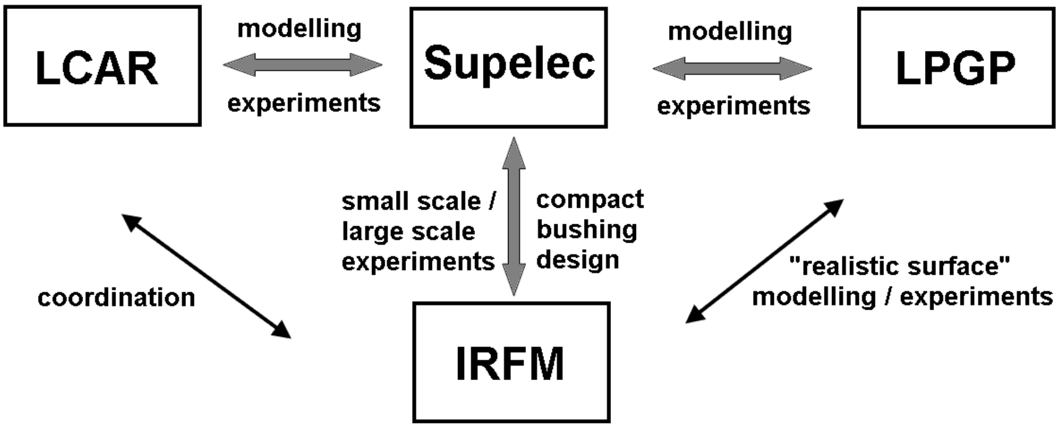
3.2. MANAGEMENT DU PROJET / PROJECT MANAGEMENT

It is proposed that Dr. H.P.L. de Esch will be coordinator of this project. The detailed results obtained by LCAR, SUPELEC, LPGP and IRFM will be used for the design and construction of the prototype compact bushing to be developed at IRFM.

The project is divided into six tasks.

1. The experimental work using the 1MV testbed at IRFM (sect. 3.1, 1A-1F).
2. The design, construction and testing of the new bushing at IRFM (sect. 3.1, 1G)
3. The modelling of the field adsorption of hydrogen and helium gas on micro tips by LCAR (sect. 3.1, 2).
4. The development by LPGP of the two simulation codes that model the total current emitted by 'artificial' surfaces and the ionisation of gas by a field-emitting micro tip (sect. 3.1, 3).
5. The experimental studies of the electron field emission, field-induced adsorption of H_2 and He and their effect on the work function by SUPELEC (sect. 3.1, 4).
6. Benchmarking of the novel codes by LPGP and LCAR to the experiments by SUPELEC and IRFM.

Each task is divided in subtasks corresponding to specific works made by one group, under the responsibility of the group. The coordinator will in particular ensure the time sequence between subtasks, in agreement with the global planning presented in section 3.4. The work of the coordinator is also to share either experimental expertise or simulation results, to insure good progress of the whole project.
Meetings between the four groups will be organized every six months, alternately in the four laboratories, in order to analyze the progress made and to define the detailed planning for the next period. This will also give the possibility to discuss the results and to pool the resources of both groups in case of difficulty. Extraordinary meetings could be organised in case of technological issues.
When necessary for the progress of the project, participation of an individual researcher from one laboratory will be organized through a longer stay in the other laboratory. The interactions between the different groups are presented graphically in the diagram below.



3.3. DESCRIPTION DES TRAVAUX PAR TACHE / DESCRIPTION BY TASK

3.3.1 TACHE 1 / TASK 1

Task 1 consists of the high-voltage experiments at IRFM, CEA Cadarache. The experiments and their technical preparation are to be performed by H.P.L. de Esch, F. Villecroze and L. Christin. The following work is foreseen, all to be performed by IRFM

First year:

A. The influence of the magnetic fields on voltage holding will be assessed at ITER relevant gas pressures (from vacuum to up to 0.1 Pa H2 pressure); see sect. 3.1, 1A.
B. The influence of surface treatments such as polishing, rinsing in ultrapure water and glow discharges in argon will be measured. These treatments should have an effect both on clumps and on micro tips.

Second year:

C. Short-circuiting alternate stages in the existing 9-ring bushing as described in sect. 3.1. The aim is to assess if the dark current is determined by micro tips or by particle clumps.
D. The experiments with the dark current probe have the same objective. It will be necessary to adept the vacuum tank in order to integrate the probe.

Third year:

E. Reduction of microparticles on the electrode surfaces in the 1 MV test bed. The electrodes will be baked at 200 °C with a substantial gas filling pressure (~0.1-0.5 bar N2), followed by pumping through filters that trap the micro particles. After several cycles during which the micro particle trap rate is measured, the voltage holding and dark current are measured. In this way the usefulness of this procedure can be established.

F. Destruction of micro tips will be attempting by running the system in Ar gas below the Paschen threshold at high dark current. An increase in voltage holding will signal success of this procedure.

The experiments and their results will be described in regular progress reports.

Risks and risk mitigation: (1) the power supply can be broken beyond economical repair, in which case the program is off. (2) in "B", if one or two rings in the bushing appear broken, they can be short-circuited as it is not necessary to perform any of the experiments at the full 1 MV. No great risks are foreseen in the execution of the other points.

3.3.2 TACHE 2 / TASK 2

Task 2 is the design, construction and testing of a 3-stage prototype compact bushing by IRFM. It will incorporate the knowledge gained by the work from all the partners in this ANR. The experiments and their technical preparation are to be performed by H.P.L. de Esch, F. Villecroze and L. Christin. The following work is foreseen, all to be performed by IRFM.

First year:

The design of a 1-stage bushing. Materials and surface finishing remain open because they will be determined by the work that is going on simultaneously.

Second year:

A 1-stage bushing will be constructed using the best materials and surface treatment found due to the work in the first year. To make a future bushing as compact as possible, the distance between the surfaces must be minimised, a feat that can be achieved by holding low-pressure gas (<0.1 Pa) inside the bushing. The voltage holding and dark current characteristics of this bushing will be tested.

Third year:

A 3 stage prototype bushing will be built and tested to at least 600 kV. For this, additional engineering work must be carried out. A new flange must be built that covers the space left over by the removal of the old bushing from the 1 MV test bed. The connection of the transmission line and the anode to the compact bushing must then be engineered.

The progress with the construction, the experiments and their results will be described in regular progress reports.

Risks and risk mitigation: (1) the power supply can be broken beyond economical repair, in which case the program is off. (2) the cost estimates can be wrong.

3.3.3 TACHE 3 / TASK 3

Task 3 is the modelling work by LCAR. It splits into 2 sub-tasks:

Subtask 3.1 : sticking and desorption modelling

A method for doing these evaluations has been recently developed in our lab [13] and successfully applied to carbonaceous surface problems [14]. Several ingredients are necessary to perform this calculation : one is the knowledge of the gas-surface interaction potential, which is obtained from quantum chemistry calculations. In principle, this requires a well known surface state, which is not fully controlled in the present case. However, since we are primarily interested in physisorption, which is less dependent on surface details, we will work with representative model surface. Another ingredient is the local field enhancement, which is also dependant on the surface state. This input data will be defined in cooperation with LPGP.
Once these inputs are set, the model provides sticking probabilities and desorption rate as a function of surface temperature. From these data, coverage can be evaluated by assuming a steady state where adsorption is balanced by desorption (Langmuir type model).

Subtask 3.2 : electronic emission modelling
Emission is classically described in the Nordheim-Fowler model as tunnelling of electrode electrons through the potential barrier formed by the external electric field. The work function of these electrons and the surface electronic structure are key parameters which control the height and depth of this barrier. Once the surface structure is known from the previous subtask, these parameters can be evaluated from electronic structure calculations. We plan to evaluate these with the VASP (Vienna Ab-initio Simulation Package) software which is a plane wave density functional type software which we routinely use in our laboratory for surface problems. The observed trend at CEA is a reduction of electronic emission by surface adsorption, we therefore will try to identify conditions under which work function is maximized and surface electronic density minimized.

3.3.4 TÂCHE 4 / TASK 4

The first part of Task 4 consists of the development of a novel simulation code able to estimate the total current emitted by ‘artificial’ surfaces and the formation of hot spots on them. It is based on the extrapolation of the existing O-VIP1 code using simple axi-symmetric objects simulating thus the microprotrusions.
In the second part of this Task the LPGP will develop a new Particle-in-Cell (PIC) code to simulate the propagation of the surface emitted electrons through the gas filling the gap between the electrodes. This model of the micro-ionization phenomena corresponds to Townsend regimen of the discharge and should predict the conditions for the current amplification and filling gas dependency. The obtained currents will be compared with the measured ones at IRFM.

3.3.5 TACHE 5 / TASK 5

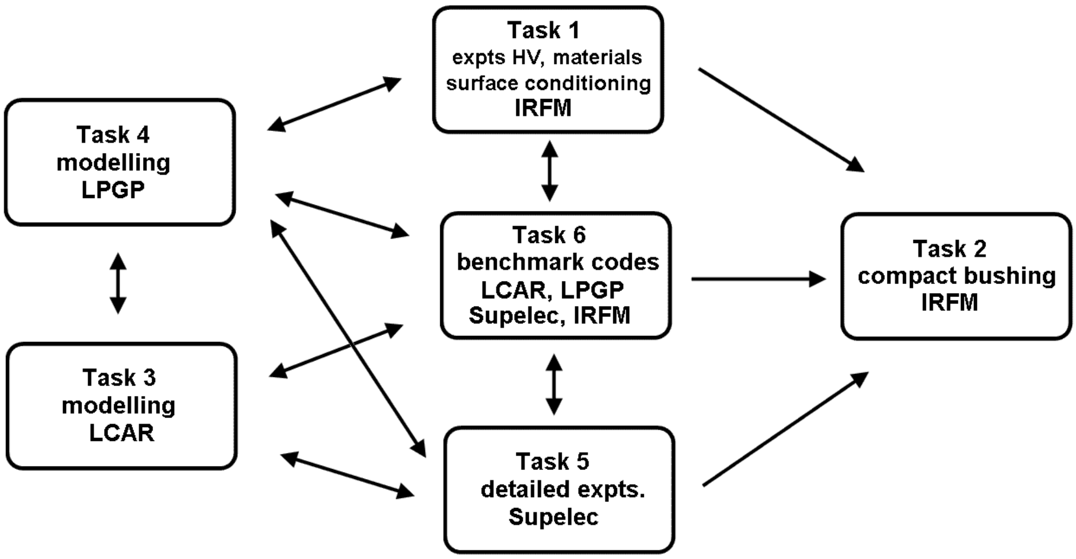
Task 5 is the experimental work by SUPELEC. The experiments and their technical preparation are to be performed by P. Testé, E. Odic and M. Kirkpatrick. The work will be done at SUPELEC on a small scale vacuum vessel in which the electrodes are suspended. Outputs from Tasks 3 and 4 will be considered, since the main objective of Task 5 is the validation of modelling results. Task 5 will be divided into two successive parts.

First, the electron field emission from a surface controlled cathode in high vacuum will be studied. Parametric investigations will be carried out: electric field, gap distance, electrodes nature and state of surface (ra) will be considered.
A second part will be dedicated to investigations on the field-induced gas adsorption effect on field emission: nature and pressure of the selected gas will be changed with regard to the applied voltage, electrode gap and surface conditioning.

3.3.6 TACHE 6 / TASK 6

This Task focuses on the benchmark of the novel surface code developed by the LPGP in the Task 4. Hence several materials will be tested by the project partners (IRFM, SUPELEC) and the work functions for adsorbed atoms or molecules on the surface will be calculated (LCAR). Direct comparisons will be performed between the LPGP code output and the experiments.

3.4. CALENDRIER DES TÂCHES, LIVRABLES ET JALONS / TASKS SCHEDULE, DELIVERABLES AND MILESTONES



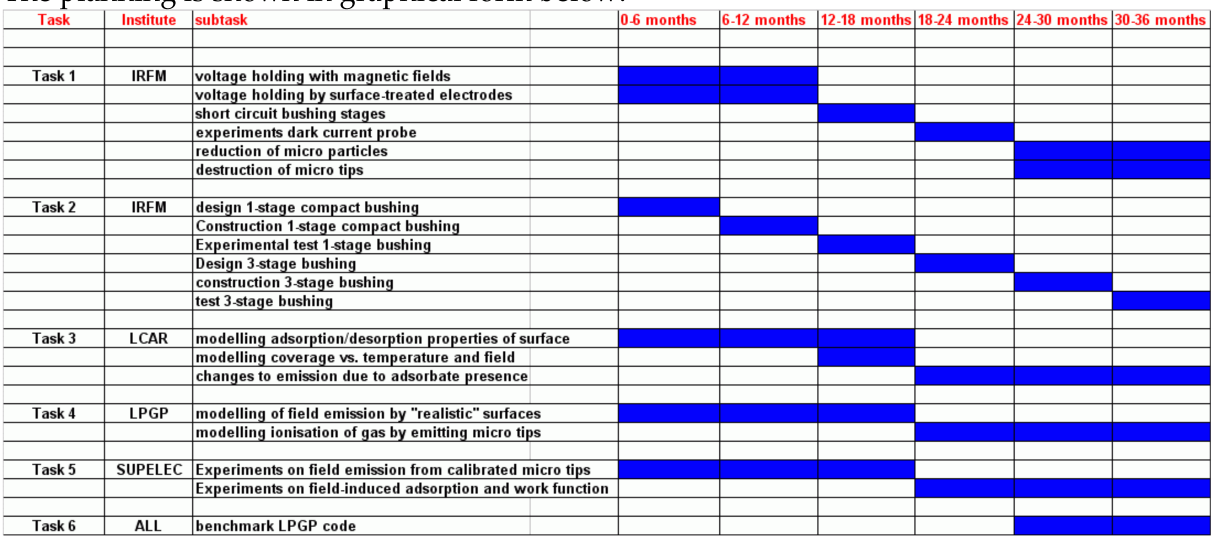
The relations between the tasks are indicated in the diagram above. Deliverables and milestones are in Table 1 below.

Table 1 : Deliverables and Milestones

Task	Name and title of Deliverable and Milestone	Delivery Date (months from T0)	Responsible partner
1	Report on influence of the magnetic field on the voltage holding	12	IRFM

1	Report on the influence of surface treatments on the voltage holding between two electrodes in the MV testbed.	12	IRFM
1	Report on experiment on the voltage holding when short-circuiting alternate bushing stages	18	IRFM
1	Report on the experiments with the dark current probe	24	IRFM
1	Report on the attempts to reduce the presence of micro particles on the electrodes	36	IRFM
1	Report on the effect of the different surface treatments of electrodes (high temperature baking, polishing, glow discharges, dark current in argon atmosphere)	36	IRFM
2	Design the single stage compact bushing	6	IRFM
2	Construction of the single stage compact bushing	12	IRFM
2	Experimental test single stage compact bushing	18	IRFM
2	Design the three stage compact bushing	24	IRFM
2	Construction of the three stage compact bushing	30	IRFM
2	Experimental test three stage compact bushing	36	IRFM
3	Modelling of the adsorption-desorption properties of the surface	18	LCAR
3	Evaluation of the coverage of the surface with adsorbate as a function of field enhancement conditions and surface temperature	18	LCAR
3	Modelling of the changes of the emission properties of the surface induced by adsorbate presence	36	LCAR
4	Modelling work on the field emission by "realistic" surfaces	18	LPGP
4	Modelling work on the ionisation of gas by field emitting micro tips.	36	LPGP
5	Report on the experimental study of the electron field emission from controlled surface cathode in high vacuum.	18	SUPELEC
5	Report on the field-induced adsorption process on controlled surfaces and its effect on the work function and field emission	36	SUPELEC
6	Report on the benchmarking between the code calculations by LCAR, LPGP and experimental results by IRFM and SUPELEC	36	LCAR, LPGP, SUPELEC, IRFM

The planning is shown in graphical form below.



4. STRATEGIE DE VALORISATION, DE PROTECTION ET D'EXPLOITATION DES RESULTATS / DISSEMINATION AND EXPLOITATION OF RESULTS. INTELLECTUAL PROPERTY

Dissemination of know-how generated during the project will take place by educating PhD students and postdocs, through publications in leading scientific journals, and through talks in front of the neutral beam injection community and at international conferences. The project activities will include:
- Presentations at the CCNB meetings.
- Presentations at international conferences by project members, including major conferences in quantum optics and gravitational-wave detection.
- Publications in journals with the widest possible audience and in more specialized journals in both research fields.
- Training of PhD students and postdocs.
- Active participation to networking activity in the field.

Results obtained by the partners prior to the project shall remain their respective property. Results, even those related to the purpose of the project but not directly derived from the work conducted under the project, shall belong to the partner which obtained such results. Other partners shall be entitled to no rights by virtue of the project over such patents and corresponding know-how.

The results of the project, patentable or not patentable, are the property of the partner who has obtained them. If both or all partners have participated to the elaboration of the results, partners equally own the results. If the results of the study are likely to be patented, the partners will be intended to determine the best strategy of their development.

Each partner may use the results of the project on an unrestricted and free-of-charge basis for its own research needs, excluding any commercial or industrial activity. Any commercial or industrial use by one partner of results owned by the two partners will require the agreement of the other partner and induce a financial compensation of the partner. Each partner may freely utilise the results of the project owned only by itself.

5. DESCRIPTION DU PARTENARIAT / CONSORTIUM DESCRIPTION

5.1. DESCRIPTION, ADEQUATION ET COMPLEMENTARITE DES PARTENAIRES / PARTNERS DESCRIPTION & RELEVANCE, COMPLEMENTARITY

IRFM (Institut de Recherche sur la Fusion par confinement Magnétique), called formerly DRFC, is part of CEA Cadarache. IRFM started negative ion research for neutral beams in 1991 via a collaboration with JAERI for testing the large negative ion source, "KAMABOKO", on a negative ion injector with an energy recovery concept developed at Cadarache. In 1994, the SINGAP concept was proposed and developed as an alternative to the MAMuG accelerator for ITER. Several ITER relevant experiments have been carried out on the MANTIS and 1 MV test beds to address different issues for the ITER NBI: the test of

the KAMABOKO source in long pulses for ITER on MANTIS, or the study of the SINGAP accelerator concept with development of critical HV devices (bushing) on the 1 MV test bed.
Modelling for the ITER-NBI system is another important activity at CEA in order to promote the development of physical models accompanying experiments.
For the running of the experiments on SINGAP, IRFM has studied dark current phenomena and high voltage holding in parallel to the SINGAP experiments on the 1 MV testbed. In recent years, a collaboration between ITER and IRFM was in place to study the high voltage holding in systems with a high stored energy (up to 1000 Joule).

LCAR is a fundamental research laboratory involved in modelling of gas phase and gas surface dynamical processes at the microscopic level. It has an extensive know-how on a wide range of numerical methods encompassing purely quantum ones as well as classical or mixed quantum-classical ones. It has also developed skills in the modelling of dissipative processes, and in particular sticking of atoms or molecules on surfaces (physisorption) which is at the heart of the present project. It has been involved with CEA and LPGP in the Iternis project, looking in particular at the possibility to form vibrationally excited molecules recombining on surfaces, from which negative hydrogen ions could be formed efficiently [15]. In this frame, expertise on the use of the ab-initio density functional code VASP was developed. This will be useful in the present project to study effects of surface states on electronic emission properties.

LPGP is working from its origin in fundamental research on plasmas physics and related applications involving ionized gases and charged particles. Both, experimental and modelling approaches are currently used to describe the physical phenomena occurring in the large variety of studied plasmas, from high density ionized plasmas to very low density magnetized plasma, from large plasma volumes (m3) to micro-plasmas (< 100 μm). The know-how of numerical methods is the basement of the 'Theory and Modeling of Plasmas' team of LPGP using a large panel of methods (Boltzmann equation coupled with collisional radiative models, Monte Carlo (MC) simulations, Particle-in-Cell (PIC), PIC-MC, fluid and multifluid, etc.). It has also developed skills in the modelling of plasma-surface interaction, and in particular cold electron emission, ion assisted sputtering, plasma deposition of thin films. It has been involved together with CEA and LCAR in the ANR ITER-NIS project, contributing with the development of a new 3D numerical code (PIC-MC) for the simulation of the negative ion extraction from a low pressure electronegative plasma. In this frame, it used its expertise on the development and the exploitation of intensive parallel codes. On the other hand, LPGP develops numerical codes for the cold electron emission at microscopic scale assisted by the surface temperature. This combined knowledge considerably increases the success of the LPGP task in the present project to model the microscopic ionization effect induced by the cold emission of artificially generated surfaces on the residual gas filling the high voltage gap between cathode and anode.

An essential feature of research at the SUPELEC research groups and Laboratories (LGEP and Département Energie), whether fundamental or applied, is that it is based on the actual needs encountered in industry. It is carried out in close cooperation with industrial partners, in particular through research contracts, by the departments of education and research and by the research laboratories associated with Supélec. Fundamentals in electrical discharges (thermal and non-thermal plasmas), and applications (high current switching, electrode erosion, arc ignition, partial discharges, non-thermal processes for surface treatment and gas phase treatment) are being investigated since fifteen years. During the last four years, transition from glow discharge to arc at low pressure, was jointly studied by the two involved groups. In this domain, field emission phenomena are of high importance and are specifically considered. An experimental work was started two years ago aiming at the study of the field emission under high vacuum and intense electric field.

5.2. QUALIFICATION DU COORDINATEUR DU PROJET / QUALIFICATION OF THE PROJECT COORDINATOR

The coordinator, aged 54, has been a researcher for 30 years. He has worked in three countries on topics of Nuclear Physics, Electron Cyclotron Resonance Heating (ECRH) and Neutral Beam Injection (NBI). He obtained his Ph.D. at Utrecht University (The Netherlands) in 1985 with a thesis on proton capture reactions. Then he worked for 2 years on a project (ECRH heating on the TFR tokamak) between FOM institute (The Netherlands) and CEA – Fontenay-aux-Roses (France). At JET (UK), still the world's largest tokamak, he worked on NBI physics, tokamak plasma simulation and operated the positive-ion based injectors. In 1998 he moved to IRFM where he worked on the negative-ion based injectors for future NBI systems. This work included design and experimentation (including a stay in Japan to test the concept) on a SINGAP (single gap – single aperture) injector where pre-accelerated beams are accelerated in one single step to 1 MeV [12]. In the course of this work, experience was gained with dark current and high voltage holding phenomena. He also participated in the breakdown tests with high stored energy, performed by IRFM for ITER [19]. In addition to this work, he played a crucial role in the design of the accelerator for the diagnostic beam on ITER and he is presently working on the detailed physics design of the 5-stage 1 MeV accelerator for the ITER heating beams.

5.3. QUALIFICATION, ROLE ET IMPLICATION DES PARTICIPANTS / QUALIFICATION AND CONTRIBUTION OF EACH PARTNER

Partenaire / partner **IRFM**	Nom / Name	Prénom / First name	Emploi actuel / Position	Discipline* / Field of research	Personne. mois** / PM	Rôle/Responsabilité dans le projet / Contribution to the project 4 lignes max.
Coordinateur/responsable	De Esch	Hubert	Scientist		15	Coordinateur. Partie scientifique de la contribution IRFM
Autres membres	Villecroze	Fréderic	Engineer		27	Engineering of the IRFM contributions

* à renseigner uniquement pour les Sciences Humaines et Sociales
** à renseigner par rapport à la durée totale du projet

Partenaire / partner **LCAR**	Nom / Name	Prénom / First name	Emploi actuel / Position	Discipline* / Field of research	Personne. mois** / PM	Rôle/Responsabilité dans le projet / Contribution to the project 4 lignes max.
Coordinateur/responsable	Lepetit	Bruno	CR CNRS		12	Local coordinator, electronic and dynamical calculations
Autres membres	Lemoine	Didier	CR CNRS		6	electronic and dynamical calculations
	TBD		Post-doc		18	electronic and dynamical calculations

Partenaire / partner **LPGP**	Nom / Name	Prénom / First name	Emploi actuel / Position	Discipline* / Field of research	Personne. mois** / PM	Rôle/Responsabilité dans le projet / Contribution to the project 4 lignes max.
Coordinateur/responsable	MINEA	Tiberiu	Professor	Plasma Physics	8	Local coordinator, Plasma Modeling
Autres membres	LEROY	Olivier	Senior scientist (CNRS)	Plasma Physics	4	Plasma Modeling
Autres membres	CAILLAULT	Lise	Associated scientist (CNRS)	Plasma Physics	12	Plasma Modeling
Autres membres	TBD		Post-doc	Plasma Physics	24	Plasma Modeling

Partenaire / partner **SUPELEC**	Nom / Name	Prénom / First name	Emploi actuel / Position	Discipline* / Field of research	Personne. mois** / PM	Rôle/Responsabilité dans le projet / Contribution to the project 4 lignes max.
Coordinateur/responsable	Teste	Philippe	CR CNRS	Plasma Physics	4.5	Local coordinator, experiments design and supervision
Autres membres	Odic	Emmanuel	Professor	Plasma Physics & Chemistry	4.5	Experiments design and supervision
	Kirkpatrick	Michael	Professor	Plasma Physics & Chemistry	4.5	Experiments design and supervision
	TBD		Post-doc		12	Experimental task

Si besoin, pour chacune des personnes, leur implication dans d'autres projets (Contrats publics et privés effectués ou en cours sur les trois dernières années) sera présentée dans le tableau ci-dessous.

IRFM	Nom de la personne participant au projet / name	Personne. Mois / PM	Intitulé de l'appel à projets, source de financement, montant attribué / Project name, financing institution, grant allocated	Titre du projet : Project title	Nom du coordinateur / coordinator name	Date début & Date fin / Start and end dates
N°	De Esch	4	ITER	IO/11/4300000380	De Esch	04/11 02/12
N°	Villecroze	3.75	ITER	IO/IA/10/4200000283	Villecroze	01/11 03/12
N°	De Esch	1.2	ITER	IO/IA/10/4200000283	Villecroze	01/11 03/12

	Nom de la personne participant au projet / name	Personne. Mois / PM	Intitulé de l'appel à projets, source de financement, montant attribué / Project name, financing institution, grant allocated	Titre du projet : Project title	Nom du coordinateur / coordinator name	Date début & Date fin / Start and end dates
N°	Lepetit	7.2	ANR 08-BLANC-0047 / 114 k€	ITER-NIS	Simonin	01/09 05/12
N°	Lemoine	21.6	ANR 08-BLANC-0047 / 114 k€	ITER-NIS	Simonin	01/09 05/12
	Lepetit	2.4	FR-FCM+EFDA / 14 k€ HT	Production of H- ions by surface mechanims	Lemoine	01/01-31/12/2009
	Lemoine	4.8	FR-FCM+EFDA / 14 k€ HT	Production of H- ions by surface mechanims	Lemoine	01/01-31/12/2009
	Lepetit	2.4	FR-FCM+EFDA / 4 k€ HT	H atoms-gr,Ag,Ta surfaces	Lemoine	01/01-31/12/2011
	Lemoine	4.8	FR-FCM / 4 k€ HT	H atoms-gr,Ag,Ta surfaces	Lemoine	01/01-31/12/2011

LPGP	Nom de la personne participant au projet / name	Personne. Mois / PM	Intitulé de l'appel à projets, source de financement, montant attribué / Project name, financing institution, grant allocated	Titre du projet : Project title	Nom du coordinateur / coordinator name	Date début & Date fin / Start and end dates
4	MINEA	7.2	ANR08BLAN-004701	ITER-NIS	Simonin	01/09 05/12
4	MINEA	3.6	ANR ASTRID	UVfactor	F. Gérôme	12/11 11/14
4	LEROY	3.6	ANR ASTRID	UVfactor	F. Gérôme	12/11 11/14

SUPELEC	Nom de la personne participant au projet / name	Personne. Mois / PM	Intitulé de l'appel à projets, source de financement, montant attribué / Project name, financing institution, grant allocated	Titre du projet : Project title	Nom du coordinateur / coordinator name	Date début & Date fin / Start and end dates
4	Odic	7	ANR ECOTECH 2009 152 k€	PECCOVAIR	Simiand	Mars 2010- Mars 2013
4	Kirkpatrick	9	ANR ECOTECH 2009 152 k€	PECCOVAIR	Simiand	Mars 2010- Mars 2013

6. JUSTIFICATION SCIENTIFIQUE DES MOYENS DEMANDES / SCIENTIFIC JUSTIFICATION OF REQUESTED RESSOURCES

6.1. PARTENAIRE 1 / PARTNER 1 : IRFM

- *Équipement / Equipment*

Three porcelain insulators, capable of holding 200 kV, are already available at IRFM at no cost.
Construction of the small testbed including an adaptation to hold the 1-stage compact bushing: 15 k€
Construction of the three stage compact bushing : 30 k€
New flange for the MV testbed to hold the new bushing: 15 k€
Adaptation MV testbed to hold the dark current probe: 5 k€

- *Personnel / Staff*

No temporary staff is foreseen.

- *Prestation de service externe / Subcontracting*

Drawing office for the design of the bushing and the adaptation of the MV testbed to hold the new bushing : 45 k€

- *Missions / Travel*

Travel expenses (meetings and conferences): 5 k€

- *Dépenses justifiées sur une procédure de facturation interne / Costs justified by internal procedures of invoicing*

none

- *Autres dépenses de fonctionnement / Other expenses*

Operation budget of the 1 MV testbed: 30 k€

6.2. PARTENAIRE 2 / PARTNER 2 : LCAR

- *Équipement / Equipment*

20 k€ to update our local computer (linux cluster).

- *Personnel / Staff*

18 month for a post-doc who will perform electronic and dynamical calculations.

- *Prestation de service externe / Subcontracting*

none

- *Missions / Travel*

10 k€ for travels related to the coordination of the project, between Paris, Toulouse and Cadarache, as well presentation of the results to conferences.

- *Dépenses justifiées sur une procédure de facturation interne / Costs justified by internal procedures of invoicing*

none

- *Autres dépenses de fonctionnement / Other expenses*

none

6.3. PARTENAIRE 3 / PARTNER 3 : LPGP

- *Équipement / Equipment*

None.

- *Personnel / Staff*

Post-doc – plasma modeling (96 k€) :

The Theory and Modeling of Plasma group of LPGP asks ANR funding for 24 months of a post-doc starting in the first year of the project (Tasks 4 and 6). This manpower should come to enhance our modeling team, taking advantage of the prior work done to develop the O-VIP code, which is ready to run and has been validated by comparison to experiment. Hence, the post-doc will continue the work with systematic runs of O-VIP code to fill the database and further, in the second year of his work will start the development of the new simulation code of 'artificial surfaces'. She/he can thus efficiently exchange with the other project partners, receiving a feed back on the results, especially by the precious possibility to directly compare numerical and experimental results, providing the code benchmarking by the end of his work. The candidate should have a good knowledge in plasma modeling and numerical methods. Knowledge in parallel programming is highly appreciated.

- *Prestation de service externe / Subcontracting*

None.

- *Missions / Travel*

5 k€ for travels related to project meetings. Participation to international conferences to present the results.

- *Dépenses justifiées sur une procédure de facturation interne / Costs justified by internal procedures of invoicing*

None.

- *Autres dépenses de fonctionnement / Other expenses*

None.

6.4. PARTENAIRE 4 / PARTNER 4 : SUPELEC

- *Équipement / Equipment*

high voltage power supply (30kV-20mA)	5 000 €
high pressure ultrapure water rinsing apparatus	15 000 €
	20 000 €

- *Personnel / Staff*

12 months for a post-doc who will perform experiments on the small scale vacuum test bed (54 400 €).

- *Prestation de service externe / Subcontracting*

None.

- *Missions / Travel*

9 k€ for travels expenses related to the coordination of the project (Paris / Toulouse / Cadarache), as well as presentation to international conferences.

- *Dépenses justifiées sur une procédure de facturation interne / Costs justified by internal procedures of invoicing*

None.

- *Autres dépenses de fonctionnement / Other expenses*

high voltage probe P6015A Tektronix	3400 €
Current transformer probe CT1 Tektronix	2 000 €
pressure regulator	1 600 €
gas flow controllers	2 000 €
gas (He, H2, …)	4 000 €
inox tubings and connectors	1 000 €
parts and gasket / seals for the vacuum chamber	3 000 €
	17 000€

7. REFERENCES BIBLIOGRAPHIQUES / REFERENCES

[1] High voltage and Electrical Insulation Engineering, R. Arora and W. Mosch Ed., IEEE, Wiley & Sons, 2011

[2] High voltage vacuum insulation-basic concepts and technological practises, R. V. Latham Ed., Academic Press, 1995.

[3] R. Hemsworth, H. Decamps, J. Graceffa, B. Schunke, M. Tanaka, M. Dremel, A. Tanga, H.P.L. De Esch, F. Geli, J. Milnes, T. Inoue, D. Marcuzzi, P. Sonato, P. Zaccaria, *Status of the ITER heating neutral beam system*, Nucl. Fusion **49**(2009)045006

[4] L. Cranberg, *The initiation of the electrical breakdown in vacuum*, J. Appl. Phys., **23**(1952)518.

[5] I.N. Slivkov, Mechanism for electrical discharge in vacuum, Soviet Phys. Techn., **2**(1957)1928

[6] N. Pilan, P. Veltri, A. De Lorenzi, *Voltage Holding Prediction in Multi Electrode–multi Voltage Systems Insulated in Vacuum*, IEEE Transactions on Dielectrics and Electrical Insulation **18**(2011)553

[7] P. Massmann, D. Boilson, H. De Esch, R. Hemsworth, L. Svensson, *Voltage Holding and Dark Currents in the Cadarache 1MV Ion Beam Facility*, 20th International Symposium on Discharges and Electrical Insulation in Vacuum - Tours (France), 30/06/02 - 5/07/02

[8] R.L.C. Wang, H.J. Kreuzer, R.G. Forbes, *Field adsorption of helium and neon on metals: an integrated theory*, Surface Science **350**(1996)183

[9] T.T. Tsong, E.W. Muller, Field adsorption of inert-gas atoms on field ion emitter surfaces, Physical Review Letters **25**(1970)911

[10] W. Drachsel, J.H. Block, *field ionisation and field adsorption of hydrogen*, Journal de Physique, Colloque C6, supplement au no. ll, Tome 49, novembre 1988, C6-185

[11] S. Nicolini, *Isolation sous vide de l'accélérateur SINGAP sur le banc d'essai 1 MV. Etude du courant noir*, Rapport de Stage, Internal CEA/DRFC report: IDN/NTT-2004.003
[12] H.P.L. de Esch, L. Svensson, T.Inoue, M. Taniguchi, N. Umeda, M. Kashiwagi and G. Fubiani, *Results of the SINGAP Neutral Beam Accelerator Experiment at JAEA*, Fusion Engineering and Design **84**(2009)669
[13] B. Lepetit, D. Lemoine, Z. Medina and B. Jackson, *Sticking and desorption of hydrogen on graphite : a comparative study of different models* , J. Chem. Phys., 114705**, 134** (2011)
[14] B. Lepetit and B. Jackson, *Sticking of hydrogen on supported and suspended graphene at low temperature , Phys. Rev. Lett., 236102, **107*** (2011)
[15] S. Béchu, D. Lem**oine,** M. Bacal, A. Bès, J. Pelletier, *Production of H- by surface mechanism in Cs-free multi-polar microwave pl**asm**a,* AIP conference proceedings 1097 (2009) 74
[16] A. Maiti, J. Andzelm, N. Tanpipat and P. von Allmen, Phys. Rev. Lett. 155502, **87** (2001)
[17] C. Kim and Y. Soo Choi, S. Mi Lee, J. T. Park, B. Kim and Y. Hee, JACS, 9906 **124** (2002)
[18] M. Grujicic, G. Cao and B. Gersten, Appl. Surf. Sci., 167, **206** (2003)
[19] F. Villecroze, L. Christin, H.P.L. de Esch, A. Simonin, A. Pesce, A. De Lorenzi, *Study of large gap 200 kV breakdowns in vacuum with high stored energy for ITER neutral beam accelerator*, Fusion Engineering and Design **86** (2011) 750

Note importante : les annexes éventuelles au document scientifique doivent être déposées sur le système de soumission sous forme de documents séparés.

Annexes déposées au document scientifique

CV: H. de Esch, B. Lepetit, T. Minea, F. Villecroze, P. Teste, E. Odic

Ref. 8: P. Massmann, D. Boilson, H. De Esch, R. Hemsworth, L. Svensson, *Voltage Holding and Dark Currents in the Cadarache 1MV Ion Beam Facility*, 20th International Symposium on Discharges and Electrical Insulation in Vacuum - Tours (France), 30/06/02 - 5/07/02