AVANT PROJET SIMPLIFIE

POLAREX

POLARization of EXotic nuclei with On-Line Nuclear Orientation at ALTO
SCIENTIFIC PROJECT

1. Project description .................................................................................................. 4

2. National and international status ......................................................................... 5

3. Experimental program ............................................................................................ 6
   a. Technical specifications .................................................................................. 6
      i. Half-life limitations .................................................................................. 6
      ii. Isotopic flux and ion implantation energy required for successful OLNO experiments ................................................................................................. 6
      iii. Range of nuclei accessible to OLNO at ALTO ...................................... 6
      iv. The detected emissions ....................................................................... 7
   b. Experimental propositions ........................................................................... 8
      i. Around N=50 ............................................................................................ 8
      ii. Around N=82 .......................................................................................... 8

4. Perspectives .......................................................................................................... 9

5. General description ................................................................................................ 9
   a. $^3$He-$^4$He dilution refrigerator ................................................................ 9
   b. Beam transport line ................................................................................... 12
      i. « Horizontal » beam line ...................................................................... 13
      ii. « Vertical » beam line .......................................................................... 14
   c. System control ............................................................................................ 14
   d. Infrastructure ............................................................................................... 14

6. Manpower ............................................................................................................ 16

7. Estimated planning ............................................................................................... 17

8. Project funding .................................................................................................... 19
Abstract

The key to understanding the nuclear interaction lies with the study of exotic nuclides, which exhibit properties that are radically different from their conventional cousins along the valley of stability. Complementing the current trend of studying nuclear dynamics from reactions with exotic nuclides are the necessary, unambiguous determinations of ground-state properties such as spin, magnetic moment, half life, mass and shape. The measurement of these basic properties over a large range of the nuclear chart will permit to test the effectiveness of the theoretical models. Single-particle properties in nuclei are decisive for such determinations and a particularly powerful tool for their elucidation is the preparation of exotic nuclides in spin-oriented ensembles which can then be used to measure nuclear magnetic moments and ground-state spins. Polarized nuclei can further be used in far-reaching studies of fundamental interactions involving beta-asymmetry and isospin mixing for example.

All the efforts made in the development of next-generation facilities (SPIRAL-2, EURISOL, GSI-FAIR) need to be supported by the development of diverse experimental techniques. Our project follows this line by creating new research infrastructure for on-line orientation of exotic nuclides. The On-Line Nuclear Orientation (OLNO) method is the association of the established technique of “Low Temperature Nuclear Orientation” (to polarize nuclei) with on-line implantation of radioactive beam. The low temperature orientation will be obtained with a $^3$He - $^4$He dilution refrigerator which represents the main technical part of the system and that we inherited from TRIUMF. For the production of neutron-rich nuclides, we aim to exploit the facility newly commissioned on our own doorstep: ALTO, in Orsay. With the closure of the OSIRIS mass separator at Studsvik, and the new priority given to post-accelerated beams at TRIUMF, this new experiment - the first such activity in France - would be in competition with only the NICOLE facility at ISOLDE. Moreover, with ALTO’s original photofission production scheme, the new orientation facility would be unique worldwide for the new nuclides available for study at ALTO, and would also be used at the facility SPIRAL-2.

Résumé

La clé pour comprendre l’interaction nucléaire repose sur l’étude des noyaux exotiques qui présentent des propriétés radicalement différentes de celles de leurs cousins conventionnels le long de la vallée de la stabilité. Pour compléter la tendance actuelle sur l’étude de la dynamique nucléaire par réaction avec des noyaux exotiques, il est nécessaire et indispensable de déterminer les propriétés de l’état fondamental : spin, moment magnétique, demi-vie, masse et forme. Les mesures de ces propriétés fondamentales sur un grand domaine de la carte nucléaire permettraient de tester l’efficacité des modèles théoriques. Les propriétés des particules célibataires dans le noyau sont décisives pour de telles déterminations, et un des outils particulièrement puissant pour leur élucidation est la préparation des noyaux exotiques dans des états de spin orienté qui peuvent ensuite être utilisés pour mesurer les moments magnétiques nucléaires et le spin de l’état fondamental. Les noyaux polarisés peuvent aussi être utilisés dans des études d’interactions fondamentales mettant en jeu, par exemple, l’asymétrie bêta et le mélange d’isospin.

Tous les efforts faits dans le développement des installations de prochaines générations (SPIRAL-2, EURISOL, GSI-FAIR) ont aussi besoin d’être soutenus par le développement de diverses techniques expérimentales. Le but de ce projet est d’y participer en créant une nouvelle infrastructure pour l’orientation en ligne de noyaux exotiques. La méthode d'Orientation Nucléaire En-Ligne (OLNO) est l’association de la technique de « Low Temperature Nuclear Orientation » (afin de polariser le noyau) avec l’implantation en ligne d’un faisceau radioactif. L’orientation à basse température est obtenue à l’aide d’un réfrigérateur à dilution $^3$He - $^4$He qui représente la partie principale du système et que TRIUMF nous a cédé. Les noyaux riches en neutrons seront produits à la nouvelle installation commissionnée au seuil de notre laboratoire : ALTO à Orsay. Avec la fermeture du séparateur de masses OSIRIS de Studsvik, et la nouvelle priorité donnée aux faisceaux post-acclérés de TRIUMF, cette nouvelle expérience - la première de la sorte en France – sera en compétition seulement avec NICOLE à ISOLDE. De plus, grâce à la méthode de production par photo-fission d’ALTO, la nouvelle installation d’orientation sera unique au monde pour ce qui est des noyaux disponibles à ALTO, et pourra aussi être utilisée à la future installation SPIRAL-2.
1. Project description

This project is a new program adopted by the group “Masses Atomiques” of the CSNSM. This program came up when G. Georgiev joined our group at the end of 2005. Up to now we have been studying nuclear properties by measuring masses of nuclei with a very short half-life with the final objective of constraining nuclear models. Therefore it was in the continuity of our goal to study another nuclear property: the nuclear magnetic moment.

The key to understanding the nuclear interaction lies with the study of exotic nuclides. These nuclides exhibit properties that are radically different from their conventional cousins along the valley of stability and therefore have strong implication in the theoretical description. Their structure cannot be understood using a direct extrapolation of the nuclear properties close to stability. The exotic nuclides are indispensable to constraint the models and test their effectiveness especially on the poorly explored, neutron-rich side of the valley of stability. Going away from this valley toward the neutron “dripline”, represents a challenge in both aspects: theoretical and experimental. Complementing the current trend of studying nuclear dynamics from reactions with exotic nuclides are the necessary, unambiguous determinations of ground-state properties such as spin, magnetic moment, half life, mass and shape. Single-particle properties in nuclei are decisive for such determinations: the magnetic nuclear moment is very sensitive to the level occupied by the unpaired nucleons, as well as ground-state spins. These two properties can be studied with a spin-oriented ensemble. Polarized nuclei can further be used in far-reaching studies of fundamental interactions involving beta-asymmetry and isospin mixing for example.

Nuclear moments have been studied since the beginning of nuclear structure physics. It started with the measurement of the nuclear moments of stable nuclei. Then, mainly moments of neutron-deficient nuclei have been measured. It is only since about 15 years that measurements have been made on neutron-rich nuclei. If this system is coupled to nuclear magnetic resonance (NMR), it can provide also a very accurate measurement of the $g$-factor of the implanted nuclei. Electric quadrupole moments of beta decaying nuclei can also be measured - the difficulty stands in the choice of the suitable single crystal host for the implantation.

We want to participate to the effort in investigation of nuclear physics at extreme condition by creating new research infrastructure for on-line orientation of exotic nuclides. The goal of this project is to develop a spin-oriented ensemble using the On-Line Nuclear Orientation (OLNO) method which associates the on-line implantation of radioactive beam of interest to the “Low Temperature Nuclear Orientation” (LTNO) technique. The polarization, needed to get a spin-oriented system, is induced by on-line implantation of the exotic nuclei on a host foil (ferromagnetic metal) cooled down to very low-temperatures and submitted to an external magnetic field (0.01-0.5 T). This field orients the internal hyperfine field (which can reach 10-100 T) which in turn orients the radioactive nuclides. The low temperatures are achieved by a $^3$He-$^4$He dilution refrigerator with a base temperature of about 6 mK [1]. The main limitation of low temperature nuclear orientation is the spin-lattice relaxation time of the impurity element (implanted nuclei) in the host. This time is of the order of seconds or more, and obviously places a lower limit on the lifetime, and, hence, accessible radioactive nuclides. This technique has the advantage to reach a high level of polarization (20-80%), but it can be only applicable to radioactive nuclei with lifetimes of the order of seconds or higher. This technique is described in details in [2].
This system requires:

- A top loading $^3$He-$^4$He dilution refrigerator to introduce the host foil (ferromagnetic metal) in which the nuclei to study will be implanted,
- Very low temperature,
- High magnetic field to orient nuclei implanted in the host foil: we use an external magnetic field and the hyperfine field that are experienced by impurities implanted in the magnetized ferromagnetic host.

The dilution refrigerator needed has been donated to us by TRIUMF, and it is right now assembled at the CSNSM.

For the production of neutron-rich nuclides, we aim to exploit the facility newly commissioned on our own doorstep: ALTO$^1$, in Orsay. Figure 1 shows the layout of the experimental hall.

![Figure 1: Layout of the experimental hall of ALTO. In red is the POLAREX structure.](http://www-csnsm.in2p3.fr/-POLAREX-.html)

2. National and international status

The new ALTO facility, based on a photo-fission source and separator, resembles closely to the one of the OSIRIS mass separator at Studsvik, where N.J. and J.R. Stone operated an on-line nuclear orientation (OLNO) facility for more than ten years. Their implication in this project is definitely essential. The suggestions which are made in this section are drawn from their experience and their knowledge of the work of the various international groups working with such a technique.

With the closure of the OSIRIS mass separator at Studsvik, and the new priority given to post-accelerated beams at TRIUMF, the new facility ALTO - the first such activity in France - would be in competition with only the NICOLE facility at ISOLDE$^2$. Moreover, with ALTO’s original

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$^2$ http://isolde.web.cern.ch/
photofission production scheme, the new orientation facility would be unique worldwide for the nuclides available for study. All these developments will serve the cause of the facility SPIRAL-2, since this infrastructure would be “easily” transportable to another site.

3. Experimental program

This set-up produces an anisotropy in the emission of the decay products which depends on nuclear structure properties like spins, multipole mixing and parity mixing. It allows to determine the nuclear magnetic moment of the implanted nuclei as well as level spins in the daughter nucleus, and gamma and beta multipolarities by counting gamma rays in singles. If this system is coupled to nuclear magnetic resonance (NMR), it can provide also very accurate measurement of the g-factor of the implanted nuclei. It can also be used for fundamental weak interaction studies.

a. Technical specifications

i. Half-life limitations
The main limitation of low temperature nuclear orientation is due to the Boltzmann distribution. The time needed to reach the Boltzmann equilibrium depends on the nuclear spin-lattice relaxation time. This time is of the order of seconds or more, thus it obviously places a strict lower limit to the lifetime. The implanted nuclides are un-oriented and cooled after implantation to the host-foil temperature at a rate determined by the spin-lattice relaxation time. This time is inversely proportional to the square of the hyperfine interaction strength (nuclear g-factor times magnetic hyperfine field strength) times the host-lattice temperature. Relevant theory is given in ref [3]. The variation of hyperfine fields and g-factors has the result that whereas for some elements the shortest orientable isotope lifetime may be in the ms range, for others it is minutes or hours.

ii. Isotopic flux and ion implantation energy required for successful OLNO experiments
Estimates of isotope range and yield of the separated beams to be available from the ALTO photofission source are used as the basis for these suggestions. To make measurements of gamma anisotropies from oriented nuclei a minimum flux of order $10^3$ ions/s or greater is needed to provide useful count rates of more than $1 \text{s}^{-1}$ with regular detector geometry and efficiency. The maximum tolerable yield is limited to about $10^7$ ions/s because of the heating effects created in the refrigerator. The ions need energy of 40 keV or above to achieve good quality implantation into a cold ferromagnetic metal host foil in which the orientation is produced. 40 keV was the acceleration energy used at Studsvik; at ISOLDE it is usually 60 keV. Both achieve implantation with high fractions of ions in substitution sites in iron, where the strength of the hyperfine field is well measured for most elements.

iii. Range of nuclei accessible to OLNO at ALTO
At ALTO over 750 neutron-rich nuclei (Figure 2) can be produced, but not all of them can be used because of production rate and lifetime acceptance. If the nuclides with a production rates $<10^4$ and lifetimes $<1 \text{s}$ are taken out, as well as the even-even nuclei, there are still about 300 candidate nuclides. Moreover if we keep only those which nuclear moments have not been measured, there are still about 200 nuclides to be studied (see Figure 3). In this chart, it can be seen that there is also a wide range of measured nuclear magnetic moments, which will allow us to test precisely the full system and to study all the systematic effects.
iv. The detected emissions
While until the last decade or so the great majority of nuclear orientation experiments were
dependent upon gamma detection, recent works have used the asymmetry of beta anisotropy
(which through its parity non-conserving terms can provide larger effects at higher temperatures)
and alpha decay anisotropy. Proving experiments have also shown that anisotropy of beta-
delayed proton emission and similar experiments on beta-delayed neutron emitters are
straightforward (since the neutrons escape the cryostat).

Figure 2: The yellow area represents the nuclides produced at ALTO.

Figure 3: Nuclei that can be measured with OLNO experiments. In blue are the ones which
nuclear magnetic moments are already known, in red the yet non-measured ones.
b. Experimental propositions

A wide range of objectives have formed the basis of OLNO work:

− level spin determination,
− aspects of nuclear structure based on gamma multi-polarity,
− sensitive tests of beta decay theory,
− parity non-conservation in nuclear gamma decay,
− nuclear magnetic dipole moments from NMR/ON,
− accurate measurements of \( g \) - factor with NMR of nuclei implanted at low temperature.

OLNO experiments yield nuclear moments of the oriented parent state, and spectroscopic data on levels of the daughter nuclei (alpha, beta, gamma transition). Following, are examples of experiments which cover these two aspects. We will mainly concentrate our efforts in studying the areas of nuclei around \( N=50 \) and \( N=82 \).

i. Around \( N=50 \)

- The parity of the ground state of \(^{72}\text{Cu}\) is not completely known. Is it a \( 2^+ \) or a \( 2^- \) state? The spectroscopy of the \(^{72}\text{Ni} \rightarrow ^{72}\text{Cu} \beta\)-decay has been studied at ISOLDE, but the remaining question is due from both proton and neutron active orbitals.
- The spin and parity of the ground state of \(^{83}\text{As}\) is not completely known. Is it a \( 3/2^- \) or a \( 5/2^- \) state? In the case where the production rate of \(^{83}\text{As}\) isotope is not sufficient at ALTO, it will be indirectly obtained after \( \beta \)-decay from the implantation of the \(^{83}\text{Ge} \) (\( T_{1/2} = 1.855\text{s} \)). This is indeed feasible due to the suitable \( T_{1/2} = 13.4 \text{s half-life of} \) \(^{83}\text{As} \). In this case the spin and parity of the ground-state entirely depend on the proton behavior.
- With the \(^{73}\text{Ga} \) and \(^{75}\text{Ga} \) isotopes, we can study the evolution of the single-particle structure of medium mass nuclides above the Ni toward the \( N=50 \) shell closure. A well known shape transition from spherical to moderate deformation occurs in the neutron-rich Ga and Ge isotopes between \( N=40-42 \), and this evolution must be characterized for more neutron-rich isotopes.
- The spin and parity of the odd-odd \(^{86}\text{Br}\) nucleus will be determined at ALTO by conventional \( \beta\gamma \) spectroscopy by the EFIX group of CSNSM [A. Astier et al., accepted proposal at the ALTO/Tandem committee, January 2006]. They will also benefit from the additional information given by a nuclear magnetic moment measurement, in order to check the validity of the model for such decays \((^{86}\text{Se}(0^+) \rightarrow ^{86}\text{Br} \rightarrow ^{86}\text{Kr}(0^+))\).

ii. Around \( N=82 \)

- Magnetic moment of the 3/2\(^+\) ground state of \(^{133}\text{Te}\): several publications have described work on dipole moments in the vicinity of the \(^{132}\text{Sn}\) major shell closure. In the single-proton level above the doubly magic \(^{132}\text{Sn}\) [that is \(^{133}\text{Sb}\)], these studies gave access to detailed theory of the magnetic moment operator in nuclei [3]. More extensive results on Sb, (odd-proton isotopes with \( g_{7/2} \) ground states) gave a broader testing ground for proton structures in shell model based theory [4,5]. The corresponding study of odd neutron states and of odd-odd nuclei is incomplete. Critically, the magnetic moment of the \( d_{3/2} \) odd-neutron ground state of \(^{133}\text{Te}\) is not known. This is a straightforward beta asymmetry OLNO resonance experiment, open to the new facility and should be done at the earliest opportunity.
- \(^{137}\text{I}\) has a 3-proton level structure above a closed-shell, and is in the above mentioned sequence of odd proton \( 7/2^+ \) state. The magnetic moment of its ground-state is therefore
of interest to search for analogy/differences between Sb and I. $^{137}$I is copiously produced in fission and will have a high level of orientation at accessible OLNO temperatures.

- The beta decay of $^{137}$I feeds a wide range of high lying states in $^{137}$Xe the decay of which is well studied. The levels above ~ 4 MeV excitation energy, manifest a competition between gamma decay and beta-delayed neutron emission. Two aspects of these decays are of strong interest:
  - the beta decay from the $^{137}$I $7/2^+$ ground state feeds many states of $7/2^+$ and $7/2^-$ (among others) and many of them show strong gamma decay to the $7/2^-$ ground state of $^{137}$Xe. The high density of states observed, and hence the potential for $7/2^+$ and $7/2^-$ states to be in close proximity, opens the possibility for strong parity admixture in these states. A simple search for asymmetry in the gamma emission (a 0-degree/180-degree difference with respect to the orientation axis) is an extremely sensitive test for such admixture. This experiment will require long beam times (approx. two weeks) since the gamma have high energies and relatively weak intensities.
  - Theory of the process described above is complete [5] but several aspects are uniquely open to experimental test and verification in an OLNO experiment. No such experiment has ever been done (although a pilot set-up for neutron detection outside the dilution refrigerator was successfully tested at Studsvik). Chief among the assumptions of the theory are the beta decay strength and energy dependence of the level density as function of spin and parity. These influence the average neutron anisotropy, which can be measured even with detectors with low neutron energy resolution.

Of course, no attempt is made to give an exhaustive list. The main point here is to show a wide range of experiments from classical to more complex and challenging one, and therefore to emphasize the richness in coupling a facility such as ALTO with a LTNO system. The suggestions come from the work done by the Oxford group at Studsvik, a directly comparable facility utilizing a neutron induced fission source.

4. Perspectives

The proposed experiment will be the first one of this type to be set-up in France precisely at a time when exotic nuclei producing facilities are being built. The project takes advantage of a unique opportunity to acquire a performing apparatus at minimal cost, install it at the facility ALTO which has just started and start its exploitation with the help of first class foreign competence. This will allow to acquire experience that partly lacks while doing original physics on the nuclei produced by ALTO. It also prepares the future since by that times, we will be in position to transfer the technique to the future facility at SPIRAL-2 at GANIL-Caen.

5. General description

POLAREX is an infrastructure that combines a $^3$He - $^4$He dilution refrigerator to a radioactive beam line (ALTO). In this section the different part of the system will be detailed and the characteristics given.

a. $^3$He - $^4$He dilution refrigerator

The principal part of POLAREX is the $^3$He-$^4$He dilution refrigerator. In order to have a reasonable cost for this project, we were able to negotiate with TRIUMF the transfer of such a
unit that corresponds to our requirements (the one of the ISAC facility). For information, a new equipment costs about 400 k€. This dilution refrigerator system has been manufactured and tested by Oxford Instrument, and the lowest base temperature measured was below 5.5 mK.

Here we will give a short description of the dilution refrigerator which consists of two main parts: a cold part which sits inside a liquid helium dewar, and a warm part which contains the pumps and the rest of gas handling system (called cabinet here). Both parts are connected via the pumping and gas lines.

The cold part consists of the dilution unit, the magnet, and the dewar.

- The dilution unit (Figure 4a)) consists of a still, continuous heat exchanger, cold plate, silver heat exchangers and a flat mixing chamber. An extension tube is screwed into the central hole of the mixing chamber, so that the sample holder, when loaded, sits in the field center. This dilution refrigerator is designed to allow samples to be loaded into the cryostat without warming it above approximately 2.5K. A special “top loading siphon” is used to insert the sample holder, and in conjunction with the “delivery siphon” it is also used to pre-cool the sample to liquid helium temperatures.

- The superconducting magnet is completely encapsulated in a stainless steel can which is connected to the main helium bath (Figure 4b)). The magnet hangs just inside the inner vacuum can and it is filled with liquid helium at 4.2 K. It is designed for optimum angular access in the magnetic field direction.

- The dewar is a two piece nitrogen shielded type with sliding insert seal. The top half is fixed to the support frame. (Figure 5)

The warm part consists of a cabinet that contains all the necessary pipes and valves to circulate and store the $^3$He and $^4$He and to pump the dewar. It contains also all the electrical circuits for protection of pumps and to monitor mechanical or thermal failures of the system while running. The gas handling part is split into a $^3$He part on the front panel and a high vacuum $^4$He part on the side. (Figure 6)
Figure 5: On the left is cold part of the dilution refrigerator closed inside its dewar. On the right it is fixed to its support frame.

Figure 6: Pumping cabinet / gas handling system. The $^4$He part on the front panel, and the $^3$He part is on the left side.
The dilution refrigerator is connected by the bottom to an about 2 m long beam transport line to allow implantation of the separated ion beam into the host foil. This foil is mounted on the cold finger of the refrigerator. Figure 7 shows the assembled set-up: the dilution unit, the magnet and the vertical beam line.

Figure 7: Setup of the dilution refrigerator connected to the beam line at TRIUMF

b. Beam transport line
The beam line connecting POLAREX to ALTO is made up of two parts: an horizontal part and a vertical part. The horizontal part goes from ALTO beam line to an electrostatic mirror which is located at about 2 m below the dilution unit. The vertical part goes from the electrostatic mirror to the cryostat.
i. « Horizontal » beam line

The present study (presented on Figure 8) performed a first order beam dynamics calculation to define a preliminary design of the “horizontal” beam line between the ALTO facility and the POLAREX apparatus (see Figure 1).

The initial beam conditions are from the calculated beam characteristics just after the kicker bender presented in the report ALTOφ [6]. The first order calculations have been performed using transfer matrix formalism. A genetic algorithm has been written and adapted to perform the optimization of the beam line parameters [7].

![Figure 8: Beam envelope calculation from the ALTOφ kicker-bender and the POLAREX experimental setup. ED: electrostatic deflector. QP: quadrupole triplet.](image)

The beam line is around 4.5 m long. The beam is bent by a 60° spherical electrostatic deflector. The radius of the deflector is 0.2 m. We plan to use the same electrostatic deflector as the one used in the ALTOφ beam line in order to simplify the mechanical studies and realisations. Furthermore, the conception of this deflector makes possible to let the beam pass through without any deflection. After the deflector, a faraday cup could be placed at the location of the calculated beam waist.

Then, a triplet of electrostatic quadrupoles is used to focus the beam before the Polarex experiment. The quadrupoles electrodes lengths are: 120 – 200 – 120 mm and the bore radius is 30 mm. The radius of the electrodes has to be chosen as 1.145, in units of the aperture radius, to zero the second order aberrations [8]. In our case, the voltage values used for the quadrupoles electrodes are around 900 V.

These first order calculations are useful to define the needed beam focusing and bending elements. Now, it is necessary to perform a multi-particles simulation, with the field map calculation of the deflector and the quadrupole triplet (with the SIMION [9] code, for instance) in order to validate these preliminary results.

We made an AP (Autorisation de Programme) request to the financing of this line.
ii. « Vertical » beam line
The various elements of the vertical beam line part (as shown in Figure 7) were given by TRIUMF with the dilution refrigerator. The possibility of leading the beam beyond POLAREX through the electrostatic mirror (see Figure 7) will be studied.

c. System control
The general control of the beam line will use the same program as developed for ALTO. For the data Acquisition System, almost no manpower is needed because we will purchase a PC based multichannel-analyzer from the FAST ComTec company in Germany with all the needed specificities (they have already supplied other experiments of that kind).

d. Infrastructure
As it has been shown, the top of the dilution refrigerator will be at about 5 m high. The structures to support the electrostatic mirror and the dilution unit already exist, as shown in Figure 9. The 1st floor structure is about 260 cm high. The electrostatic mirror will be inserted inside the “1st floor structure”, and the dilution unit structure (or 2nd floor structure) is about 250 cm high and goes on the top of the 1st floor one.

Actually we are working on the design of the structure that will go around this one in order to enable people to work on it. The design will optimize floor-space. On Figure 10, the structure used at TRIUMF is shown in red. This structure could not fit in the hall of ALTO and therefore was not recovered. Access to the 1st floor (where the head of the cryostat stands) will be from the already existing staircase, and access to the 2nd floor (top of the dilution unit) will be from the mezzanine. Drawings of the structure (general and detailed views) are shown in Figure 11. The conception is made in association with Jean-Marie Curreaudau to take into account all the restriction of the ALTO experimental hall. Once the final design decided, we will check the safety matters with Yves Adès.
Figure 10: In red, the structure used at TRIUMF for man access to the device.
6. Manpower

From the CSNSM we can count 1 AI (50%), 2 researchers (2 x 100%), 1 ANR 2-years postdoc (100%) involved in the setup of the apparatus. The 2-years postdoc will start working with us February 2008. For the physics studies, data taking, data analyses two more researchers will be involved at about 20% each. The knowledge of G. Georgiev in nuclear structure with radioactive beams, will be decisive to establish the physics cases and interpret the results. The involvement of A. Astier and his group (EFIX at CSNSM) who are waiting for some key nuclear moment measurements to elucidate some nuclear structure uncertainties, is also important in this context. Of course, the potential students (Ph.D., internships,…) are not included here.

The beam transport line studies are being done by engineers from the group SEMIRAMIS of CSNSM (N. Chauvin and C. Bachelet). The AI of the group MASSATOM (S. Cabaret) is working on the conception and realization of the “red” structure of POLAREX, in straight collaboration with the “service mécanique” of CSNSM.

It could be noted that expertise in dilution refrigerator and low temperature physics already exists in the laboratory (solid sate physics, bolometry), as well as a tradition of interdisciplinary cooperation. The bolometer group, member of the collaboration Edelweiss, has designed and built more than 5 refrigerators. This activity will therefore not start in a technological vacuum. We will be able to count on their experience and advice.

We are also getting precious international help such as N.J. and J.R. Stone, Nathal Severijns, Cameron Marshall. N.J. and J.R. Stone are part of this collaboration as experts of this type of method and physics, respectively. The ALTO new facility, based on a photo-fission source and separator, resembles closely to the one of the OSIRIS mass separator at Studsvik where N.J. and
J.R. Stone operated an OLNO facility for more than ten years. The presence of N.J. Stone will be of great importance in getting the project working in the best timing, to participate in the critical development and installation phase, and later in the testing phase. J.R. Stone expertise will be essential in the implementation of the control system, in on-line data analysis, and discussion about the physics involved. Both of them will give us the full autonomy needed to carry this project to success within a 3-year period. We are working in collaboration with Nathal Severijns since his device- NICOLE at ISOLDE – is the same than ours, but working in a different range of nuclei. We are also participating into the experiments using NICOLE. Cameron Marshall is a TRIUMF engineer. He is the person who was in charge of this dilution refrigerator up to now. The TRIUMF direction agreed of letting him coming to Orsay to help us get the refrigerator “debugged” and working.

7. Estimated planning
For this project we will have all the help needed from the experts in LTNO technique in order to get such a device working (the first of its kind in France) and the first measurements within a 3-year period. It will allow us to get the full autonomy needed to carry this project to success.

The estimated planning to get the first physics from this project is listed in Table 1. However, here is a summary of the main steps of the project.

- End of 2006: Shipping and handling of the dilution refrigerator from TRIUMF to Orsay. The system arrived at the CSNSM February 2007.
- 2007 – first half of 2008: Installation, modification, adaptation of the system in an “offline” mode at the CSNSM. In parallel we are working the ALTO implantation (“red” structure”).
- End 2008: Transfer of the system to ALTO experimental hall and test on site.
- 2009: Commissioning, systematic effects study.
- End 2009: First experiments.

The following planning takes into account the fact that most of the persons do not work full time on this project.
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Table 1: Estimated planning
8. Project funding

This program, POLAREX, is financed by an ANR “Programme Jeunes chercheuses et jeunes chercheurs” for the principal part of this installation: $^3$He-$^4$He dilution refrigerator part and the “vertical” beam line (Figure 7), and for a 2-years post Doc. The funding from the ANR is 150 000 €. Table 2 gives a summary of the expenses that are part of the ANR.

<table>
<thead>
<tr>
<th></th>
<th>Total H.T. (€)</th>
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<tbody>
<tr>
<td><strong>Personnal</strong></td>
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<tr>
<td>24 months postdoc</td>
<td>80 000</td>
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<tr>
<td><strong>Material</strong></td>
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<tr>
<td>Shipping and handling of the refrigerator</td>
<td>10 000</td>
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<tr>
<td>Gammas detector (for the equivalent of 6 months)</td>
<td>4 000</td>
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<tr>
<td>RF signal generator</td>
<td>8 000</td>
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<tr>
<td>RF amplifier</td>
<td>3 000</td>
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<tr>
<td><strong>Computer control</strong></td>
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<td>Pc</td>
<td>2 000</td>
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<tr>
<td>Acquisition software</td>
<td>16 000</td>
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<td>Total</td>
<td>43 000</td>
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<td><strong>Functioning</strong></td>
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<td>Liquids (He, N$_2$)</td>
<td>15 000</td>
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<td>Travel</td>
<td>12 000</td>
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<td>Total</td>
<td>27 000</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>150 000</td>
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</table>

Table 2: Summary of the financial support from ANR

For the beam transport line, we made an AP (Autorisation de Programme) request for the year 2008. The funding requested is 127 000 €.

The principal part of this installation is the $^3$He-$^4$He dilution refrigerator that we were able to negotiate with TRIUMF and which corresponds to our requirements (the one of the ISAC facility). As mentioned before a new one cost about 400 k€. We only paid for shipping and handling.

POLAREX device needs to be connected to ALTO beam line. An “AP” (Autorisation de Programme) request has been filled to finance this line. The engineers of CSNSM performed optical calculations and estimation of the cost of such line as summarized in the following table.
Prix k€

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Prix</th>
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</thead>
<tbody>
<tr>
<td>60° spherical electrostatic deflector (IPN type)</td>
<td>Deflector, settings, chamber</td>
<td>25</td>
</tr>
<tr>
<td>Triplet of electrostatic quadrupoles</td>
<td>Triplet, chamber, alim., rack, pumps</td>
<td>31</td>
</tr>
<tr>
<td>Deflectors (2 sets)</td>
<td>Deflector, alim., rack</td>
<td>12</td>
</tr>
<tr>
<td>Profilers (2 pieces) (Ganil type)</td>
<td>Mechanics + electronic</td>
<td>18</td>
</tr>
<tr>
<td>Faraday cups (3 pieces)</td>
<td>Bellows, flange, welding, insulator, alim., Kethley</td>
<td>9</td>
</tr>
<tr>
<td>Beam line stands (6 meters : 2 pieces)</td>
<td>Stands</td>
<td>6</td>
</tr>
<tr>
<td>Gauges (3 pieces)</td>
<td>Gauge + controller</td>
<td>3.9</td>
</tr>
<tr>
<td>Valves (3 pieces)</td>
<td>VAT series 14 100mm</td>
<td>6.9</td>
</tr>
<tr>
<td>Bellows (2 pieces)</td>
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<td>3</td>
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<tr>
<td>Cables</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>System control</td>
<td>PC, Labview, card, connector, rack</td>
<td>6</td>
</tr>
<tr>
<td><strong>TOTAL ESTIME (en k€)</strong></td>
<td></td>
<td><strong>127</strong></td>
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</tbody>
</table>

Table 3: Detailed table for the cost of the line going from ALTO to POLAREX

Moreover, this project is part of the scientific politic of the CSNSM, and thus we can count on the CSNSM financial help for the functioning part.

[7] N. Chauvin et al. Optics calculations and beam line design for the JANNuS facility in Orsay, accepted in NIM B.
Collaboration

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IKS, Leuven University (Belgium)  
N. Severijns

Universities of Oxford and Tennessee, USA  
J.R. Stone

Universities of Oxford and Maryland, USA  
N.J. Stone