EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/88－161
15 November 1988

Nuclear Orientation at ISOLDE/CERN

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Abstract

A facility for "Nuclear Implantation into Cold On-Line Equipment" (**NICOLE**) is being installed at the new on-line isotope separator ISOLDE 3 at CERN. The first on-line run was in the beginning of July 1988. The low temperature equipment has been successfully tested and first off-line experiments on various isotopes have been performed. NMR/ON has been done on various isotopes (Co, Xe, Pt, Au) in iron host. First experience with the top-loading dilution refrigerator (Oxford Instruments Limited) shows that it performs very well. The cooling power is 400 μW at 100 mK and 34 μW at 25 mK. The base temperature can be kept continuously well below 5 mK. NMR/ON can be performed at temperatures below 5.5 mK. The base temperature on-line is expected to be lower then 6 mK. The sample can be cooled down from room temperature to 10 mK within two hours, to 6 mK within 3 hours which is not only important for off-line but also for on-line experiments when samples have to be changed to remove long lived daughter activity. The latest results will be reported.

(IS120)

Paper presented at the Workshop on On－Line Nuclear Orientation－1, St. Edmund Hall, Oxford, August 31－September 4, 1988

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1. Introduction

Since nuclear orientation has been known nearly 40 years /1/ and several dilution refrigerators have been set up at isotope separators on-line to heavy ion accelerators /2, 3, 4, 5/ one could ask the question: why do we need another system ? The answer is directly given by figure 1 where a scanner picture (taken from /6/) in the focal plane of the older ISOLDE 2 separator is shown. It is a mass scan of the artificially produced mercury, which is produced by irradiation of molten lead with 600 MeV protons from the CERN-Synchro-Cyclotron. The top yields are around Hg-masses 187 – 201 with more then 10^9 atoms/s; these are easily visible on the scanners. The yield of mass 182 is still a few times 10^6 atoms/s and the one of ^{179}Hg is 10^3 atoms/s /7/. These data refer to a lead target thickness of 170 g/cm^2 and a proton beam of 0.5 μA. These yields are considerably higher than from mass separators at heavy ion accelerators (typically < 10^6 atoms/s), but sometimes the picture changes far from stability where half lives become very short. The additional experimental area which became available with the new separator ISOLDE 3 allowed the installation of a facility for:

N uclear **I** mplantation into **C** old **O** n-**L** ine **E** quipment (**NICOLE**).

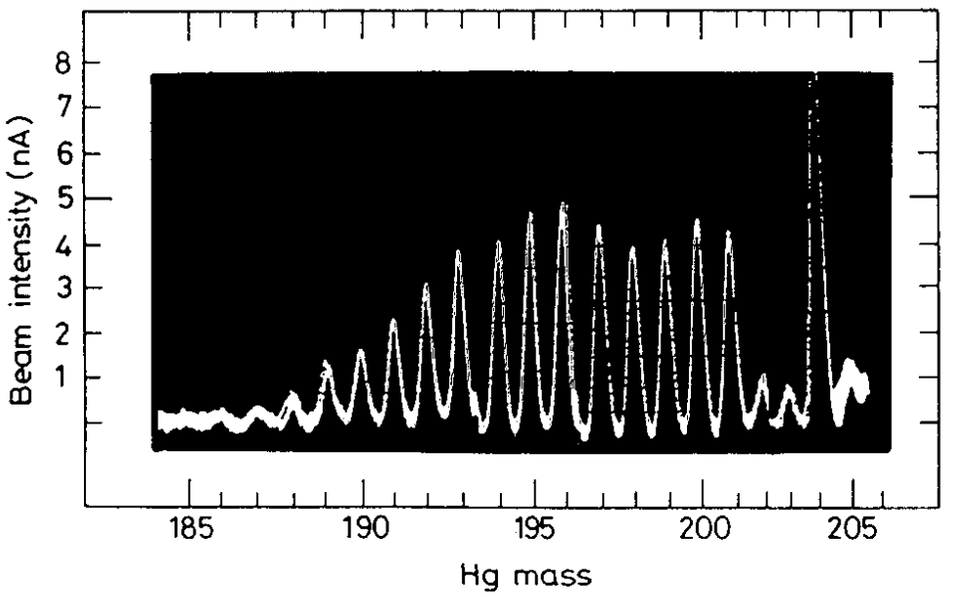

Figure 1: *Scan of Mercury beams produced at the ISOLDE 2 separator. The big peak at mass 204 is mainly lead, the target material.*

As a first project the proton rich Hg-Au-Pt-Ir-Os-region was chosen, which is reachable by the ISOLDE mercury beam (Au-Pt-Ir-Os as decay products). This field has been subject to nuclear structure work for many years by means of NO and other techniques. Giving a review here would go far beyond the scope of this paper but a list of references concerning NO-work can be found in /8, 9/. Otten has given a review on optical work /10/. The intense mercury beams at ISOLDE allow to complete and extend these investigations to nuclei far from stability. One of the high-lights of the first

NICOLE off-line runs is the confirmation of the long predicted oblate-prolate shape transition between ^{187}Pt and ^{185}Pt by measuring the quadrupole moments of the two isotopes /11/. The work of the Bonn group /12/ has proven that suitable samples, even for NMR/ON, can be produced by cold implantation of mercury. Other nuclei tackled so far (off-line) are light iodine isotopes /13/ and ^{37}Ar /14/.

2. The ISOLDE 3 isotope separator

In 1973, both the CERN-Synchro-Cyclotron (SC) and the ISOLDE installations (now called ISOLDE 2) were rebuilt, so that very intense radioactive beams could be produced /6/. The rapid increasing request for ISOLDE beam time lead to the decision to build a second on-line isotope separator, ISOLDE 3. This machine will not only double the beam time, but is also designed as a high resolution separator to allow direct mass measurements far from stability /15/. The first radioactive beams were produced in December 1987. The layout of the machine and the experimental area for 8 experiments is displayed in figure 2.

The unseparated beam (60 keV) from the target, which is placed in the cyclotron vault, is transported through ≈5m concrete and then separated by two magnets. All beam transport is done by electrostatic quadrupole lenses, since they are mass independent. Einzellenses have been avoided as they introduce large ion optical aberrations. The ion optics is designed to add the dispersions of the two magnets. High resolving power is achieved by high dispersion (35 mm/amu at 100 amu) and very divergent beams (FWHM≈3^0 in the final focus). These design principles cause accumulation of aberrations in such a system. To get really high resolution aberrations have to be corrected, the most important ones are the second order aberrations of the homogeneous dipole magnets. Appropriate surface coils are currently under construction. Electrostatic multipole elements allow further corrections. Once the correction elements are implemented a resolution of $m/\Delta m$ = 30000 (transmission ≈30%) is expected. This means 3.3 MeV resolution at mass 100 amu. The enhancement factor should be $\approx 10^{-8}$.

High resolution also implies more difficulties in use of the separator. A major problem is the aberrations or nonlinearities enhanced by handling very divergent beams which cause a virtual increase of the phase space volume filled by the ions. This remains true even if the corrections will be operational, because they are optimized to give a small horizontal image at the focal point of the separator. Although it was possible to design the beam lines to the experiments to be capable to transport a big phase space volume, due to phase space conservation it is not possible to form beam spots as small or beams as parallel as one is used to at ISOLDE 2 type separators.

This is in particular important for implantation via the side access of a dilution refrigerator. The long narrow side access tube, used to reduce room temperature radiation, requires a quite parallel narrow beam. For the NICOLE geometry, as a consequence, only a transmission of ≈60% (from ion source to experiment) could be achieved in beam line calculations as well as in tests.

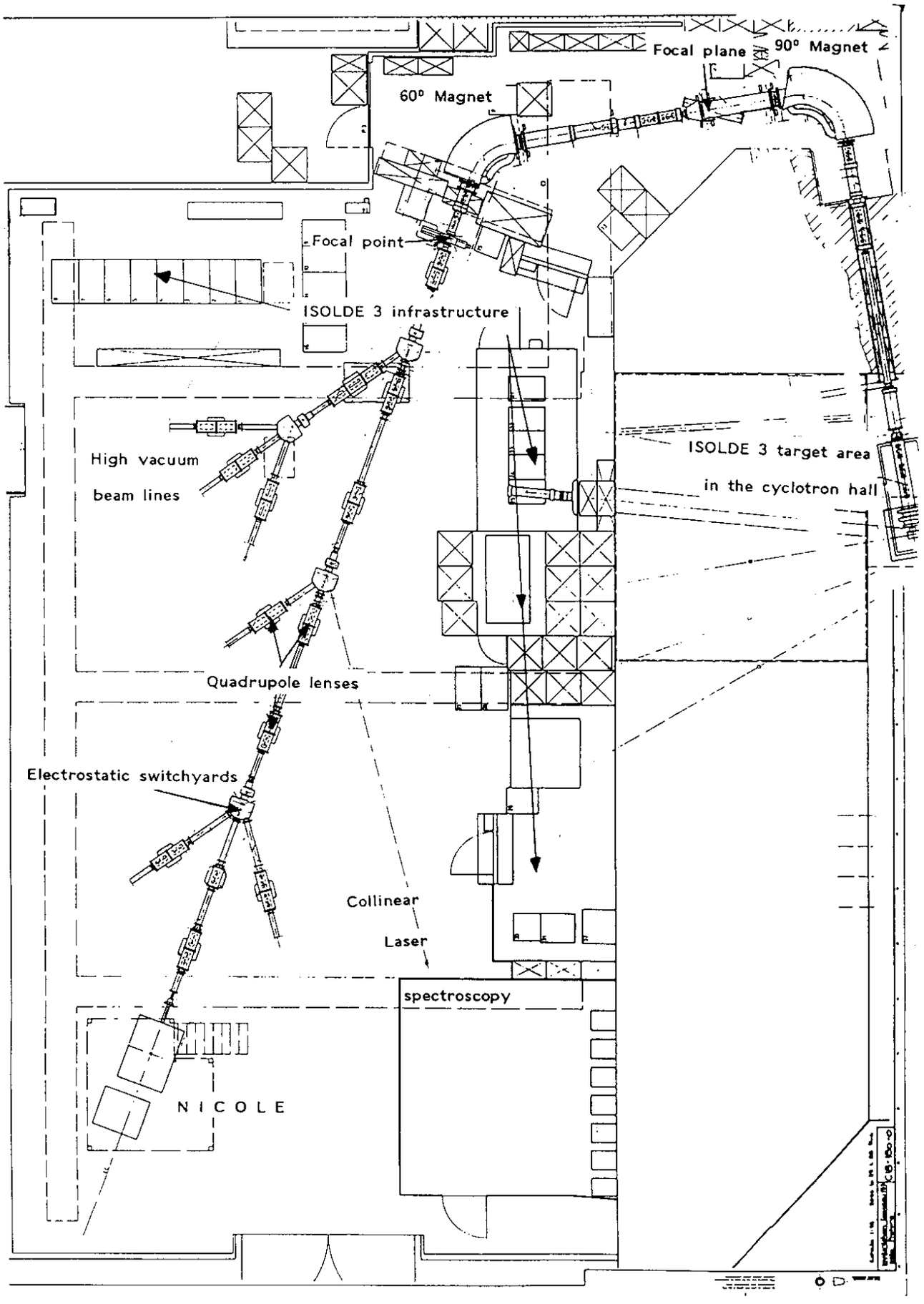

Figure 2: Layout of the ISOLDE 3 separator

3. The nuclear orientation facility

The basic principles of on-line nuclear orientation (OLNO) can be found through other contributions to this workshop and in reference /16/.

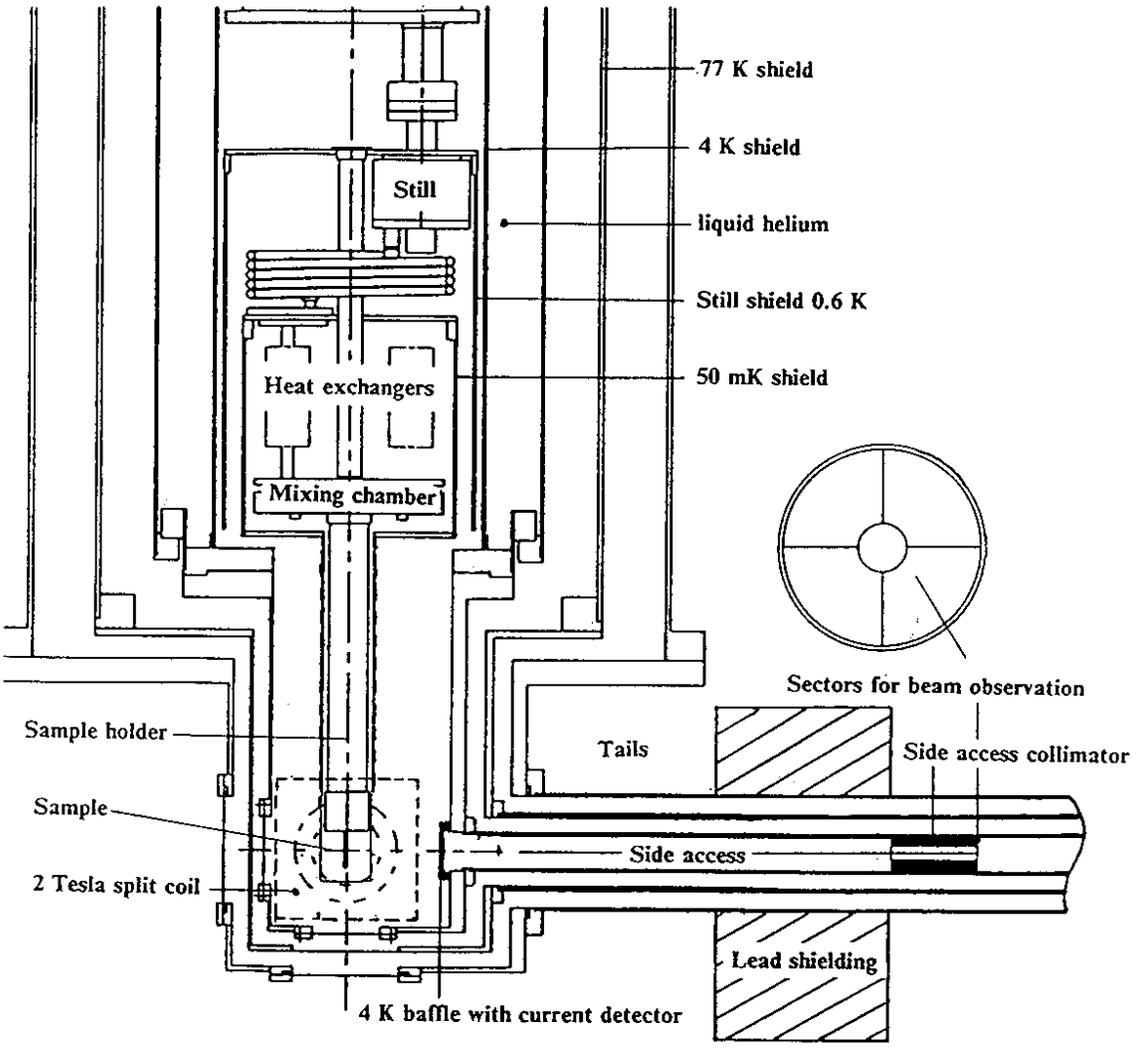

Figure 3: *Cross section through the lower part of the cryostat and the side access tube*

The main component of the OLNO equipment, the 400 μW top-loading ^{3}He-^{4}He dilution refrigerator, was constructed and build by Oxford Instruments Ltd. and is similar to the systems in Daresbury /3/ and Leuven /2/. The rectangular tails of the cryostat accommodate a 2 Tesla split coil magnet with horizontal field direction; see figure 3. The tails have been extended to 30 cm to allow:

- the use of anti-Compton detectors
- the installation of a nuclear cooling stage later on to reach lower temperatures. The geometry provides unshadowed positions for four γ-detectors with 5 cm diameter and 8 cm distance at angles 0^0, 90^0, 180^0 and 270^0.

A two winding copper coil mounted on a plastic former is installed in the still shield for NMR experiments. The side access to allow implantation into the cold sample is made of three concentric tubes, the inner ones connected to the Helium bath (4 K) and the nitrogen bath (77 K) and the outer one forming the eventual vacuum insulation. A variable iris diaphragm on the 77 K tube at the entrance to the 1m long side access allows to adapt the aperture of the side access to beam size while keeping the opening for room temperature radiation minimal. Experience in Daresbury /3/ has shown, that there must be a lot of thermal radiation bouncing down the 4K tube, although the 4 K tube is painted with nonreflecting (black) color. A 50 mm long lead collimator in the 4 K tube with a 5 mm diameter stops this radiation and the base temperature is now below 6 mK instead of 15 mK with the side access fully open. The collimator is also essential to make sure, that the implanted ions hit nothing but the sample so that contamination of the inner parts of the fridge is avoided.
A four sector assembly on the lead collimator forms together with an insulated metal sheet on the 4 K baffle the beam observation equipment. The five current readings are displayed on the screen of a small computer via a five channel preamplifier and an ADC plug in board. This is not as good as a beam scanner, which can not be used for obvious reasons, but allows to judge the beam size and position very rapidly. The current from the side access baffle is free of uncertainties due to secondary electron emission, since the stray field of the magnet (at B = 0.5T) bends the secondary electrons back to the current detector.
To speed up cooling the ^{3}He circuit has been fitted with two oil booster pumps in parallel. On the backing side they are pumped by a roots blower which is fitted with a rotary pump. This allows pumping with boosters already at very high still pressures (a few millibars) where the temperature is still quite high. In fact the cooling down time to 10 mK of a sample after top-loading is only little more then an hour. The cooling power P of a refrigerator is roughly given by:

$$P = c\,(T^2 - T_0^2)\,n,$$

where $T(T_0)$ is the actual (base) temperature, n the flow rate of ^{3}He, the constant c is $\approx 5 \cdot 10^{-5}$ $\mu W/(mK^2 \cdot \mu moles)$ and T_0 is 4.5 mK. Flow rates of 1000 μmoles can easily be maintained. With this formula one can estimate, that heating by room temperature radiation amounts to $\approx$ 400 nW given by the increase of base temperature from 4.5 mK to 6 mK with the side access open. The heat input corresponding to 10^7 atoms/s is only 100 nW, so that on-line temperatures of 6 mK can be expected. Unfortunately the β^+-decays in the decay chains of light mercury isotopes have Q-values of 4 – 6 MeV. Assuming a source activity of 3 MBq and a total energy deposit of 2 MeV per decay (from Hg, Au and Pt) the radioactive heat load is $\approx$1 μW and will increase the base temperature to about 8 mK which fits with the base temperatures obtained in the runs. It turned out, that these activities are about the highest the 25% HP-germanium detectors could stand.

4. First on-line results

Masses 186,184,183 and 182 implanted into iron host have been subject to the first investigations. The data analysis is still in progress and a run in September should complete the experimental information so that only a brief overview on the Au measurements can be given here. NMR/ON was successful on ($T_{1/2}$ = 10.7 m) ^{186}Au (figure 4), but not on ($T_{1/2}$ = 53 s) ^{184}Au.
Using B = –114.5(17) Tesla /17/ as magnetic hyperfine field, the priliminary NMR result $\mu(^{186}Au)$ = ±1.278(19)nm is in agreement with laser data (–1.263(29) nm) /18/ and static NO-Data (±1.07(13) nm) /19/.

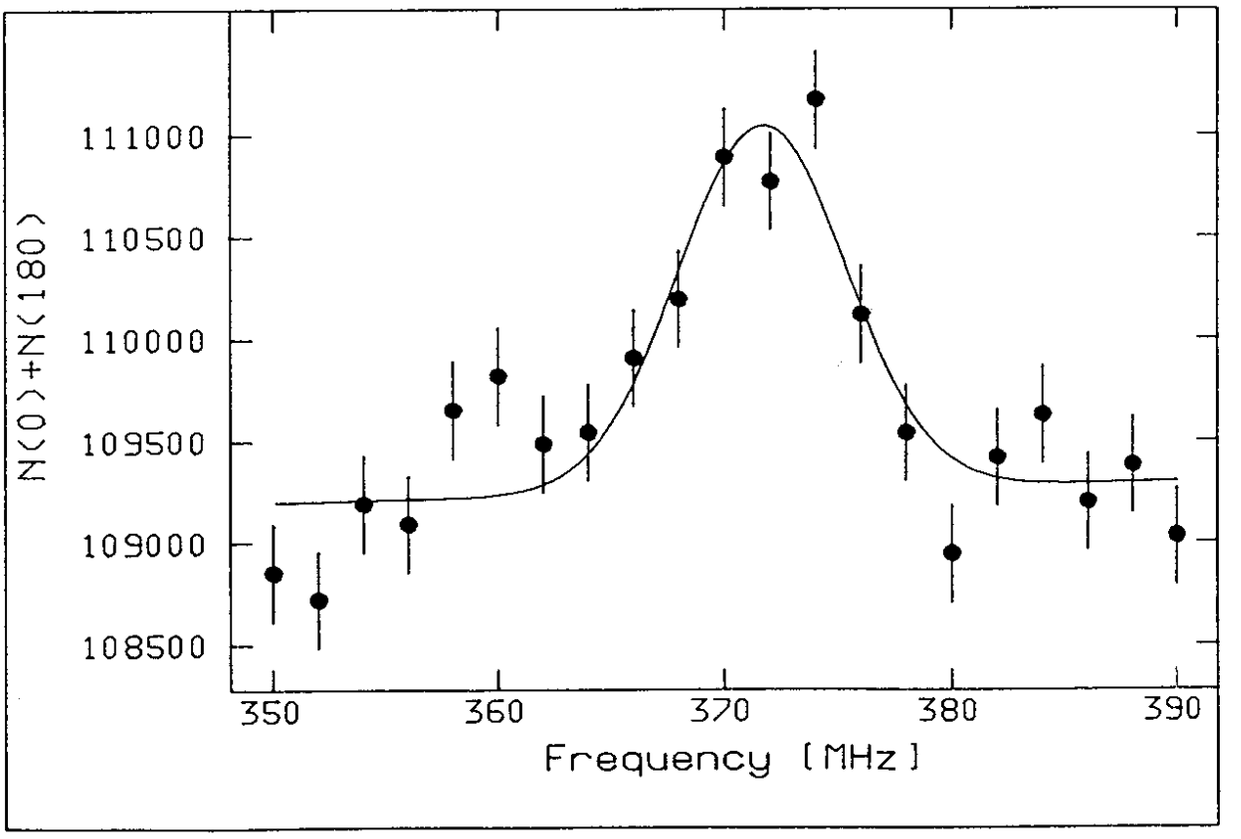

Figure 4: *Resonance of ^{186}Au in Iron detected by the change in count rate of the 192 keV γ-line. NMR parameters are: modulation ±2 MHz, FWHM = 8.7(1.5), center frequency = 371.7(6) MHz*

The nuclear spin of ^{184}Au is not known, but recent laser measurements /20/ allow the evaluation of the magnetic moment assuming a certain spin. The preliminary analysis (accounting for incomplete relaxation) of the static NO-data seems to indicate a spin of 8. The magnetic moment from NO would then be 1.78(12) nm compared with 1.707(21) form the laser experiment. This unexpected high spin could be the reason for the failure of the resonance experiment since the corresponding frequency range was not searched. Further measurements, NMR and determination of the relaxation time, are needed to clarify the situation and are scheduled for the on-line run in September.

Implantation of mass 183 yields only very little information on ^{183}Au and levels in ^{183}Pt, since the β^+-decay of ^{183}Au goes mainly to the ground state.

The temperature dependence (figure 5) of the anisotropy of ^{182}Au indicates as preliminary result a magnetic moment of 1.4(2) nm assuming I = 4 which gives the best fit to the static NO-data.

The analysis of ^{183,182}Ir anisotropies seems to indicate, that the samples show a fraction in good sites of only ≈ 50%. Although mercury implants reasonable (≈80%) into a cold iron host /12/ and gold to nearly 100% (after careful sample preparation) /19/ the low fraction could be due to a general problem when looking at daughters of cold implanted mercury.

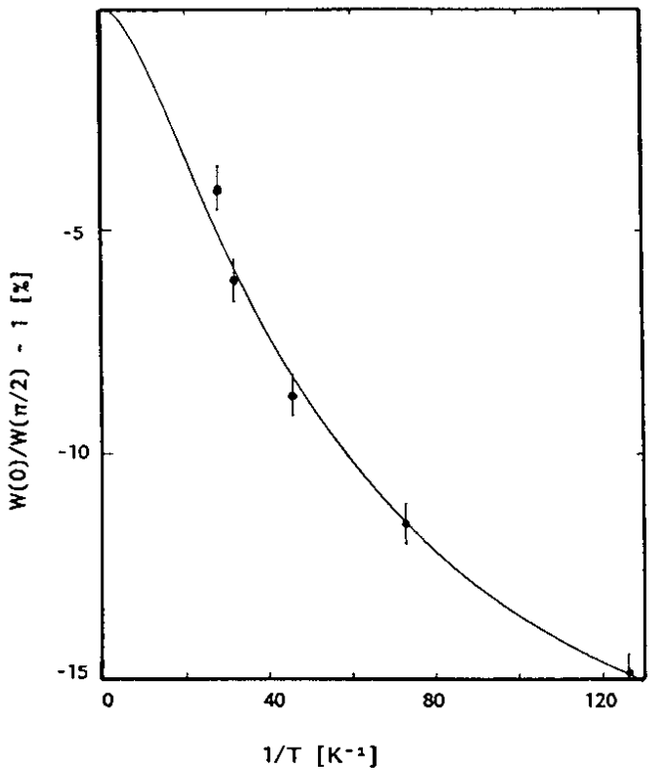

Figure 5: *Temperature dependence of the 154 keV γ-line in the decay of* ^{182}Au

Further analysis of the present data and investigations during the next run should help to clarify this question.

Acknowledgements

The authors thank all members of the ISOLDE and SC staff for their help and support in setting up the NICOLE facility. Special thanks go to H. Andreasen for help on the separator, to D.E. Brown and R. Eder for help with the data analysis, to J.-P. Hadjout for technical assistance and to many junior members of Nicole for help in running experiments. The NICOLE collaboration acknowledges with gratitude financial support from the Bundesminsterium für Forschung und Technolgie (BMFT) (D), IN2P3 (F), The Nuclear Research Committee (SERC) (GB) and the Interuniversitair Instituut voor Kernwetenschappen (B) and thanks R. Coussement and E. Bodenstedt for their assistance in obtaining financial support from the EEC.

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