NUCLEAR ORIENTATION OF ON-LINE SEPARATED ISOTOPES

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Abstract

The purpose of nuclear orientation in the study of nuclei far from stability is explained. Various methods of nuclear orientation are compared. The Leuven setup and its initial performance are described.

1. Introduction

Compared to the previously discussed techniques — optical and atomic beam — low temperature nuclear orientation is a recent addition to the study of on-line separated isotopes. First experiments of this kind were initiated about a year ago by the Leuven group: hence it is clear that we have no wealth of experimental results yet compared to the previous techniques. On the other hand we believe that our first tests show convincingly the potential of NO on-line. Before going into this, it may be useful — esp. for people not familiar with ion implantation and NO — to discuss first the principles of NO and the physics one can expect to do with it: then we will elaborate on the choice of low temperature nuclear orientation, completed by NO induced through scattering at grazing incidence.

2. Physical information that can be derived from the study of an assembly of oriented nuclei

2.1 Nuclear structure information

All information concerning this — as well as other fields of physics — is derived from the anisotropic angular distribution from an ensemble of oriented nuclei.

Several formalisms have been introduced to describe the probability \( W \) of emission at an angle \( \theta \) with a common axis of orientation (magnetic or axial quadrupolar case): the most often used formula 1) is

\[
W(\theta) = \sum_k B_k U_A P_k (\cos \theta)
\]

where \( P_k(\cos \theta) \) are the Legendre polynomials. The series is limited to even \( k \) for \( \gamma \)-emission (but not for \( \beta \)-decay). The \( B_k \) contain all the information to characterize the orientation of the parent state, e.g. internal magnetic field and temperature in the case of low temperature nuclear orientation. The \( A_k \) are angular distribution coefficients containing only nuclear parameters, such as the spins and multipolarity of the observed transition. The \( U_A \) account for unobserved preceding transitions and are also only function of nuclear parameters of these transitions.

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Hence this formalism allows easy extraction of the "nuclear" \( U_A \) products since all other orientation information is separated into the \( B_k \). It is clear that from the study of \( U_A \) "strong" arguments can be obtained to fix decay scheme parameters, by a separate analysis per transition and this only by singles counting (in contrast to angular correlation). Spins as well as multiplicities can be obtained in many cases, with no limitation to strongly converted transitions. An example is given in fig. 1.

Fig. 1 Angular distribution coefficients \( A_2 \) and \( A_4 \) for a mixed \( J + 2 \) transition as a function of the \( \frac{M_1}{E_2} \) mixing ratio

Anisotropy parameters of weak transitions can be obtained also relatively easy: it may lead to some interesting studies on relatively light isotopes not too far from stability, but is not interesting for the very complex decays of heavier isotopes. Even for these ones however the \( U_A \) parameter can be identified in many cases from study of \( \gamma \)-transitions and information obtained on the character of the \( \beta^- \) or EC-transition.

Finally, if a hyperfine interaction is used to obtain the orientation, and sufficient information is available to estimate the \( U_A \) of a particular transition in the daughter, the moments of the parent state can be deduced. For the magnetic moment this will be an easier procedure than for quadrupole moments. On the other hand there is practically no limitation to a particular element.

2.2 Implantation phenomena (location of the impurity, hyperfine field distributions)

Independently of the orientation mechanism, conservation of the orientation for a useful period of time (seconds and minutes), will mean in most cases implantation at low temperature. For the orientation mechanism itself also, some understanding of the phenomena accompanying implantation is required. We will not go deep into this subject since it belongs to
another branch of physics, mainly concerned with radition damage. It is important however to realize that even now it is difficult to predict the implantation behaviour esp. at very low temperatures. Although some cases have been well studied - mainly by Mössbauer technique - their behaviour cannot be extrapolated easily to that of other elements, certainly not in the limits of temperature and dose we are working at.

To have at least some feeling for the processes occurring during the slowdown of an ion in a metal, we refer to the very often used figure 2, which is a survey of existing techniques using or studying implantation.

![Fig. 2 Time-scale of annealing processes in metals in function of temperature.](image)

The figure displays the time scale of the most important annealing processes in function of temperature. At the same time the various techniques are indicated which allow a study of the hyperfine interaction, either to extract moments or an understanding of various processes occurring during or after implantation.

In connection with the study of nuclei far from instability, it is important to notice that, up to the time of conceiving this paper - no technique is workable in the time spectrum between $10^{-2}$ sec and 1 h. This is exactly the time scale where most on-line studies happen. The technique we introduce hence opens an important bridge - and a hopefully fruitful combination - between the fields of ion implantation and the study of nuclei in this time range. Moreover it is very likely that this technique uses implantation where it is most useful for study of nuclear quantities i.e. without too many complications due to the implantation itself. Although various sites cannot be excluded in principle, the presence of migration of defects can be useful in the hypothesis of substitutional landing : the latter is certainly not confirmed in all cases, but the extremely low dose reduces severely the interaction between damage created by tracks of different ions (about $10^3$ vacancy-interstitial pairs per ion of 100 keV).

It is certain that contributions to the study of implantation behaviour will be made by combination of implantation at extremely low temperatures and very low doses and subsequent NO study.

3. Schemes for orienting nuclei and keeping them oriented.

3.1 Methods

Nuclear orientation can be achieved with a large number of methods based on many different branches of physics and developed often in a very ingenious way. Comparing the large potential usefulness of NO in studying short-lived nuclei, it comes as a surprise that no previous work on NO study of nuclei far from stability has been reported - or even attempted. The main trouble is of course that it is not sufficient to induce some polarization in flight - which can be done in many ways for some elements : one must also keep the polarization during the lifetime of the isotope in order to study anisotropic emission of radiation.

The most important conditions to the choice of NO method can be listed as follows:

1) Limited (preferentially no) loss of activity by the orientation process : esp. with activities produced in heavy ion reactions (as is the case in LISOL) no serious loss can be tolerated, esp. in view of the increased distance of detectors compared to pure spectroscopy.

2) Continuous operation : in order to obtain a statistically meaningful anisotropy, an accumulation of a few $10^4$ counts is desirable in at least two directions.

3) Small delay in orientation : no method is instantaneous, but any delay should be small compared to the lifetime of the isotope.

4) Versatility : ideally any element of any isotope should be accessible.

Of the large class of dynamical methods, most fall at least on one of these criterions. Only the - in fact oldest - method using the Overhauser effect using impurities in metals shows potential, although the versatility is not proved yet. Another method, about equally old as the Overhauser scheme, has shown to the generally applicable and will be discussed in the next point.

3.2 Low temperature nuclear orientation using internal fields

This is essentially a thermal equilibrum method, i.e. it relies on making the magnetic or electric field interaction, $\mu$H resp. QV, large with respect to $KT$. In practice this means usually temperatures around 0.01 K for typical hyperfine magnetic fields available in a polarized iron matrix. If the hyperfine field has been measured for a particular element, it is often possible to measure the magnetic moment using a well known transition. The same is generally true for the qua-
The quadrupolar moment, although the study of quadrupolar interactions of impurities implanted in hexagonal crystals is still in its infancy.

The application of this technique to the orientation of short-lived isotopes easily satisfies the criteria of small charring rate and universality. The normal mounting and cooldown cycle restricts applications to lifetimes of at least 1 h; even when using a procedure for loading implanted samples onto the cold finger, this restriction is not lifted, because of the disturbance of the cooling system, normally a $^3$He-$^4$He dilution cryostat nowadays.

Direct implantation can solve this problem, although the experience with FOLBIS 2) still points to a severe perturbation of the base temperature, and still leads to a time limit of the order of 1 h. This system is not connected to an on-line separator, so no attempts were made at eliminating this restriction.

New cryogenic developments and a design adapted to the needs of on-line work made it possible to prove at LISOL that direct implantation into a cryostat operating at $0.01 K$ is possible without raising the temperature out of the region where nuclear orientation is normally observed. Continuous operation has shown to be possible, even in cases where a substantial "background" of stable beam is present. The technical developments which lead to a reduction of the normal heat input of the order $mW$ to the order $\mu W$, the cooling power regime of $^3$He-$^4$He systems around $0.01 K$ are to be published and I will not enter into details on this subject.

One last criterion however is not fully satisfied yet: a finite nuclear spin-lattice relaxation time $T_1$ is always present. In this temperature region it may vary from seconds to minutes. This is a fundamental limitation of the pure low temperature technique, which is of course conflicting with the very requirement of operating far from stability.

On the other hand it remains a fundamental advantage - when reaching lifetimes well below $T_1$ - to have an implantation foil available which will keep the orientation preserved eventually induced in flight by another mechanism.

3.3 Reflection orientation

In the nuclear orientation setup at LISOL we incorporated therefore from the very start the possibility of inducing orientation before implantation with a much shorter relaxation time. Various methods can be proposed. Nuclear orientation achieved by scattering has been investigated intensively in the past years in many places: the energy as well as the mass range, where orientation can be observed, has increased steeply since the first reports with deuteron beams 3)4). The highest orientation degrees can be obtained by reflection at grazing incidence off ferromagnetic single crystals:

this necessitates operating at UHV conditions, and the results are not easily reproduced. Nevertheless we chose this method, although any IBSTIC mechanism (ion beam surface interaction at grazing incidence) produces some orientation degree off almost any material in normal vacuum conditions. The scattering chamber introduced in the line, has indeed the purpose of a "buffer" vacuum between the isotope separator and the implantation cryostat.

Reflection orientation works nicely esp. for light ions, where no large hyperfine fields are available for magnetic orientation. Hence the two methods - pure low temperature orientation and the combination with reflection - complement each other as well in lifetime range as in mass range.

4. The experimental setup for N.O. in LISOL

Following the principles explained previously, the Leuven on-line N.O. facility is schematically represented in fig. 3 we will not enter into technical details on solutions for various cryogenic problems.

Fig. 3 General lay-out of the experimental setup.

The essential idea is to resort to "simple" low temperature NO for $T_G > T_1$; for the cases where $T_G < T_1$ a combination of reflection orientation and low temperature implantation can be used. Starting with a separated beam of ions, either direct implantation with subsequent orientation, or first scattering with subsequent implantation is possible. The choice of implantation foils must obviously be different in both cases.

4.1 Scattering chamber

An ultra high vacuum (10$^{-10}T$) has been obtained in order to prevent oxidation of a Ni single crystal, which can be moved in and out of the beam. This crystal is mounted on a goniometer with attached magnet. Other crystals besides Ni may be used but far too little experimental work has been done using this technique up to now in order to make a definite choice.

4.2 Cryogenic connection and beam outlining

The low temperature connection to the $^3$He-$^4$He cryostat allows a solid angle
reduction of about $10^4$, depending on the opening of a diaphragm operating at liquid nitrogen temperature. Ideally focussing on an as small as possible diaphragm should give best working conditions in the cryostat. Various combinations of lens systems have been tested for this purpose.

4.3 $^3$He-$^3$He cryostat

With an improved dilution unit of the silver sintered type, developed at O.I.C., continuous temperatures below 60K can be maintained using a "He cooled baffle. Removing the baffle and opening the diaphragm raises the temperature; but even at a 5 cm opening temperatures around 15 mK can be maintained due to the high cooling power. A very compact superconducting magnet allows the installation of a detector at 0 degrees with respect to the magnetisation axis and three at 90 degrees, at distances of about 6 cm.

The efficiency of the beam transport can be measured at various points down the beam lines as well as in the cryostat during operation.

5. Initial experiments on In-isotopes

5.1 First experience

Initial experience on the behaviour of the Leuven on-line N.O. system has been gathered through a systematic study of In isotopes, produced in heavy ion reactions on polyethylene. This series provides a nice illustration of the power of N.O., notwithstanding the many development problems encountered during these first tests.

Although the proton rich indium isotopes have been studied intensively by various spectroscopic methods, the lack of spin assignments or multipolarity determinations in their decay, down to $^{112}$In is striking. The magnetic moments of these isotopes are non-existent also down from $^{109}$In. Their magnetic moments can be predicted to be largely due to the $g_9/2$ contribution. Also the internal field in $^{108}$In is reasonably large: sizable orientation effects are to be expected therefore and have been observed indeed. A series of preliminary experiments on $^{110}$In to $^{108}$In.

The magnetic moments can be extracted also from the implantations in iron, in each case at least one transition in the decay scheme is well known. A complication is due to the unknown implantation behaviour in In, which we had to clarify ourselves by experiments on $^{109}$In (with a well known magnetic moment), implanted alternately at room temperature and at 0.01K. An even larger amount of work was invested in a first attempt at extracting the quadrupole moments; on this we will elaborate in the last part of this section.

5.2 Spectroscopy problems

As explained before detectors must be used to measure the anisotropy in at least two directions. Compared to normal spec-troscopy on e.g. a tape system, these detectors have to be kept at a distance of 5 to 6 cm for two reasons. First one needs a magnet around the sample in order to polarize the iron matrix (or to keep the crystals from going superconducting when using electric field gradients). Although the magnet is extremely compact (we use currents of 60A in inductively-relatively modest field of 1T) it is difficult to reduce the dimensions below 5 cm on the outside. We chose the magnetisation axis vertical which allows us to use three Ge-Li detectors at 90° vs. one at 0°. Since the anisotropy effect is normally about half at 90° compared to the one at 0°, this allows to make the relative errors on both anisotropies comparable. Although in shown in tests, it is sufficiently high as to obtain anisotropies with accuracies of a fraction of a percent in a few hours. This is of course in the hypothesis that the configuration of cyclotron, iron source, isotope separator, beam transport and cryostat is working optimally.

5.3 Beam transport and cryogenic connection

The cold diaphragm in the cryogenic connection tube, making a transition from N$_2$ to He-temperature, is most efficient when the beam is focussed on an as small diaphragm opening as possible. On the other hand it is imperative that the beam hits the iron foil and none of the surroundings. A dual current measurement both on the sample region and on its surroundings has been installed to check this regularly.

Since we work far from stability (and have tails from neighbour stable isotopes) we expected the heating to be due only to thermal radiation, since we cannot use thermal radiation shields with these very low energy heavy ions. Unfortunately even in e.g. an isotopically enriched niobium target, traces are still present of neighbouring elements which can produce a stable contaminant in a neutron poor indium isotope, e.g. Cd in the case of $^{118}$In. Hence, at high level of heating due to the small currents asso-
cated with isotopes produced far from stability, would be negligible, are not always verified. Therefore a careful selection of materials in the manufacturing of ion sources must be made; sometimes a less ideal target and production reaction must be chosen in order to avoid excessive heating. Still, even in the case of stable contaminants we found out that our cooling power is sufficient to measure reasonably large anisotropies, at least in the magnetic case.

5.4 An example of decay scheme elucidation: $^{109}$In

$^{109}$In has been studied many times; its magnetic moment is well known and the life time is long enough to believe that the decay scheme would have been established in detail a long time ago. It turns out however that to most levels no spins have been assigned yet, and that nearly, multipolarities of transitions have been measured. We implanted a separated beam of $^{109}$In into a warm as well as a cold iron matrix. The fraction of substitutionally landing In has been studied by us in implantations of $^{111}$In and $^{141}$In (80-85 %). This served as calibration for the $\mu_A A_2^2$ parameter of the most intense transition in the decay. Comparison with the cold implantation gives the corresponding $B_2^*$. The asterisk meaning that the orientation need not be the $B_2$ of the warm implantation since different implantation sites can be involved. Using this $B_2^*$ against extracted $\mu_A A_2^2$ parameters for the majority of the other weaker $\gamma$-transitions.

Then by reasoning from up to down in the decay scheme we tried to fix unknown spins from these $A_2^2$s. The reason one likes to start from the highest level where one has the disadvantage of lowest feeding — is that no complications arise from multiple feedings. Working downwards, the reasoning becomes more complex because of the multiple feeding: on the other hand, the fact of different gamma’s desexciting from one level, leads to the possibility of combining arguments such as to emerge with a unique spin assignment.

At the same time multipolarity assignments for a large number of transitions have been extracted. Just to illustrate a "before" and "after" case we notice in fig. 4, that from a single measurement of a few hours the number of definite spin assignments is more than doubled.

Similar analysis is in progress for $^{107}$In and $^{109}$In. All these isotopes have lifetimes — although very short for classical NMR — which are considered long in the study of nuclei far from stability. We started therefore the experimental study of $^{106}$In, $^{105}$In and $^{104}$In. Here we deal with cases where relaxation time starts to be of the order of the lifetime (6.4 min. for $^{106}$In).

On the other hand an estimation of the relaxation time in normal experimental conditions, shows that corrections for relaxation are still below the 10 % level, and do not require switching to an auxiliary orientation mechanism. These corrections have been calculated in the case of $^{106}$In.

\[ \begin{array}{l}
\text{Fig. 4 Decay scheme of }^{109}\text{In (}9/2^+\text{) studied by NO.}
\end{array} \]

5.5 Magnetic moment determination:

$^{106}$In, $^{107}$In, $^{108}$In

The decay of $^{107}$In and of $^{106}$In (6+) has recently been studied by Wischnewski et al. 5). There exists another low spin isomer (1 = 3) which has however a negligible production rate in the heavy ion reactions used here. Since also in other $\gamma$-experiments have been performed on these isotopes, a relatively large number of spins is fixed.

The gamma’s desexciting the highest levels are in principle most suited to fix the magnetic moment value since no complicated feedings are to be taken into consideration. Unfortunately the spins of these levels are not fixed and our statistics have not reached the point of allowing us to determine these spins. On the other hand some of the most intense gamma’s (like the 1008.9 keV gamma desexciting the 2491.6 keV level in $^{106}$In) have a strong direct feeding: moreover the $\mu_2$ of other gamma’s feeding the same level vary very little with spin.

Hence it turns out that a value for the magnetic moment can be extracted from an intense $E_2$ transition like the 1008.9 keV one. As preliminary value we extracted 4.2 (4) $\mu_N$ in the case of $^{106}$In: this must be considered a lower limit since the issue of implantation sites in very low temperature implantations is not quite settled yet.
In simple shell model description the g.s. of 106\textsuperscript{In} has the configuration \(\text{[nllg}\ 9/2\textsuperscript{-1}}\ \otimes\ \text{(v2d 5/2)}\). The \(g_{\text{eff}}\) of In isotopes has been studied intensively in the mass range 107\textsuperscript{In} to 115\textsuperscript{In} for the odd isotopes and is remarkably constant \((g_{\text{eff}} = 1.22(2))\). Using the vector addition rule and the moment of neighboring odd-neutron states of d 5/2 one derives a value of 4.83 \(\mu\text{N}\). Magnetic moment values were deduced for 107\textsuperscript{In} and 108\textsuperscript{In} as well, using in each case a well known nuclear transition. The resulting moments show reasonable agreement with the simple vector addition rule of neighbouring moments. These data as well as the moments of 113\textsuperscript{In} and 115\textsuperscript{In} – also measured by us using NMR/ON – are displayed in Table I. The superior accuracy of NMR/ON is striking compared to the commonly used "integral" NO method.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Lifetime</th>
<th>Spin</th>
<th>Experiment ((\mu\text{N}))</th>
<th>Prediction* ((\mu\text{N}))</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>115\textsuperscript{In}</td>
<td>4.5 m</td>
<td>9/2</td>
<td>5.5408</td>
<td>6)</td>
<td></td>
</tr>
<tr>
<td>114\textsuperscript{In}</td>
<td>49.5 m</td>
<td>5</td>
<td>4.658 (7)</td>
<td>6.8</td>
<td>Leuven, NMR/ON (unpublished)</td>
</tr>
<tr>
<td>113\textsuperscript{In}</td>
<td>1.6 h</td>
<td>9/2</td>
<td>5.523</td>
<td>6)</td>
<td></td>
</tr>
<tr>
<td>112\textsuperscript{In}</td>
<td>20.8 m</td>
<td>4</td>
<td>-</td>
<td>6)</td>
<td></td>
</tr>
<tr>
<td>111\textsuperscript{In}</td>
<td>2.83 d</td>
<td>9/2</td>
<td>5.497 (6)</td>
<td>Leuven, NMR/ON (unpublished)</td>
<td></td>
</tr>
<tr>
<td>110\textsuperscript{In}</td>
<td>4.9 h</td>
<td>7</td>
<td>4.728 (8)</td>
<td>4.75</td>
<td>6)</td>
</tr>
<tr>
<td>109\textsuperscript{In}</td>
<td>4.2 h</td>
<td>9/2</td>
<td>5.55</td>
<td>-</td>
<td>6)</td>
</tr>
<tr>
<td>108\textsuperscript{In}</td>
<td>58 m</td>
<td>6</td>
<td>4.5 (3)</td>
<td>4.81</td>
<td>Leuven, Integral NO (unpublished)</td>
</tr>
<tr>
<td>107\textsuperscript{In}</td>
<td>33 m</td>
<td>9/2</td>
<td>5.3 (2)</td>
<td>-</td>
<td>Leuven, Integral NO (unpublished)</td>
</tr>
<tr>
<td>106\textsuperscript{In}</td>
<td>4.4 m</td>
<td>6</td>
<td>4.2 (4)</td>
<td>4.83</td>
<td>Leuven, Integral NO (unpublished)</td>
</tr>
</tbody>
</table>

* Vector addition rule

Therefore we aim at removing any ambiguity in the moment value determination of the "Integrally" measured ones by using a combination with NMR, also for the very short-lived isotopes. In fig. 5 we display a NMR curve taken on 110\textsuperscript{In} with a count rate comparable to what can be achieved with 109\textsuperscript{In}. It seems realistic to establish the moment value of e.g. 106\textsuperscript{In} within 0.1% in the near future, since all errors due to unknown implantation-distribution disappear with this technique. We must stress however that the conclusions about decay scheme parameter are not affected by the uncertainty in implantation site distribution.

5.6 Quadrupolar moments of In isotopes

Quadrupolar moment measurements would be even more valuable in the study of these nuclei, since they may lead to an indication of deformation or other collective effects. The extreme constancy of \(g_{\text{eff}}\) in In makes it difficult to deduce these eventual effects from magnetic moments alone.

Environments with high electric field gradients are available (e.g. 1.2 \(10^{18}\) Vcm\(^{-2}\) in single crystals of Zn). Unfortunately room temperature implantations require annealing afterwards to obtain these gradients in Zn. We are currently studying Zn as well as Cd with cold implantations of In isotopes in order to see if annealing can be avoided. The prevalent belief is that the mobility of primary damage (holes and interstitials) will be reduced by implanting at low temperatures, and hence increase the chance of substitutional sites. Most observations made up to now lead us however to conclude a partial recrystallisation upon implantation, which again may be eliminated by implantation at low temperature with very low doses. As we mentioned before, the study of quadrupolar interactions in hexagonal crystals is far from completed and we can often not rely on previous studies. It is certain however that – prompted by "on-line" requirements – a contribution can be given to materials research with implantation at these ultra-low temperatures.

6. Conclusion

In spite of the restricted amount of experimental results we can present at this moment, we believe that the overall performance of the Leuven on-line system establishes that N.O. on-line is possible at least down to lifetimes of minutes. The first interest of this new technique lies in the easy and direct determination of anisotropy parameters from which a multitude of conclusions about the decay (both e.m. and weak) can be drawn. It is shown also that moment determinations become possible for large series of isotopes, although quadrupole moments will require a serious additional effort in many cases. The universality of low temperature NO in the magnetic case compares, in our view, favorably with other techniques; in the near future we will show whether NO is indeed competitive with optical, ABR and eventual other techniques for the determination of moments. Last but not least the implantation studies at low temperatures should make a hopefully
fruitful link with several areas of solid state research.

References


DISCUSSION

I. Berekas: For the highest isotope measured (\(^{108}\)In, 6-4 min) how did you take into account the spin-lattice relaxation time? What was the proportion of substitutional sites of In in iron for this implantation?

L. Vannevaes: An estimate was made of the relaxation time using the Korringa-relation, the calculation leads us to conclude a correction of 10%, with a relative error of about 10% also, well below the statistical error. In warm as well as cold implantations (0.01 K) the fraction of substantially implanted indium was measured using \(^{109}\)In, which has a well-known magnetic moment. In the warm implantations we deduce a substitutional landing of 85%, while in the cold ones at least 90% of the implanted isotopes vaporizes the full hyperfine field.

M. Finger: In connection with the new type of online experiments which you have described, I would like to ask you two questions: 1) What is the base temperature of your \(^{3}\)He-\(^{4}\)He refrigerator system with and without the ion beam on and how much is this base temperature dependent on fluctuation of the ion beam current during the measurement? 2) How do you monitor the fluctuation of the activity during experiment and how do you estimate from this point of view the prospects for NMR/ON experiments in such on-line nuclear orientation systems?

L. Vannevaes: To your first question the answer is that the base temperature is 5 mK with the He-beam baffle closed. Room-temperature thermal radiation alone will raise this to 10-15 mK at diaphragm openings from 5 to 10 mm. The radioactive beam heating is negligible, but stable background beams sometime have a very disturbing effect, although even in the worst case (stable \(^{186}\)Os) we could stay in the 20 mK region. As we use detectors both at 0° and 90° and compare with the "mean ratio". In NMR/ON experiments a steady monitoring of the temperature will be needed, indeed, for which several methods are in preparation.

I. Berke: In recent work with B. Benrayer and G. Marest we have prepared \(^{154}\)Mn\(_2\)Tb(3\(^+\), 9h) and \(^{154}\)Mn\(_2\)Tb(7\(^+\), 23h) in the Gd(d,2n) reaction in the Synchrocyclotron of the University of Lyon. After fusion and heat treatment the TbGd alloy has been cooled down in a dilution refrigerator. Pulse height spectra were registered at 0° and 90° with respect to the polarizing magnetic field. Preliminary evaluations show that the orientation pattern of the 3\(^+\) state can be fitted with nuclear magnetic moment \(\mu(3^+)\) and electric quadrupole moment 0(3\(^+\)) of the same order than those established for \(^{154,160}\)Tb(3\(^+\)), while the magnetic moment of the 7\(^+\) state is very low (certainly smaller than 0.5 \(\mu_N\)). Further evaluations are in progress.