ISOLDE CERN

ISOLDE Workshop and Users meeting 2007/2008

NMR/ON measurement of magnetic moments of high-spin K-isomers in Hf isotopes

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EURONS

Outline

- **Measurement Technique**
  - **The NICOLE experiment**
  - **Apparatus**
- **Motivation**
  - **Why Hafnium?**
  - **Isotopes and isomers of interest**
- **Results**
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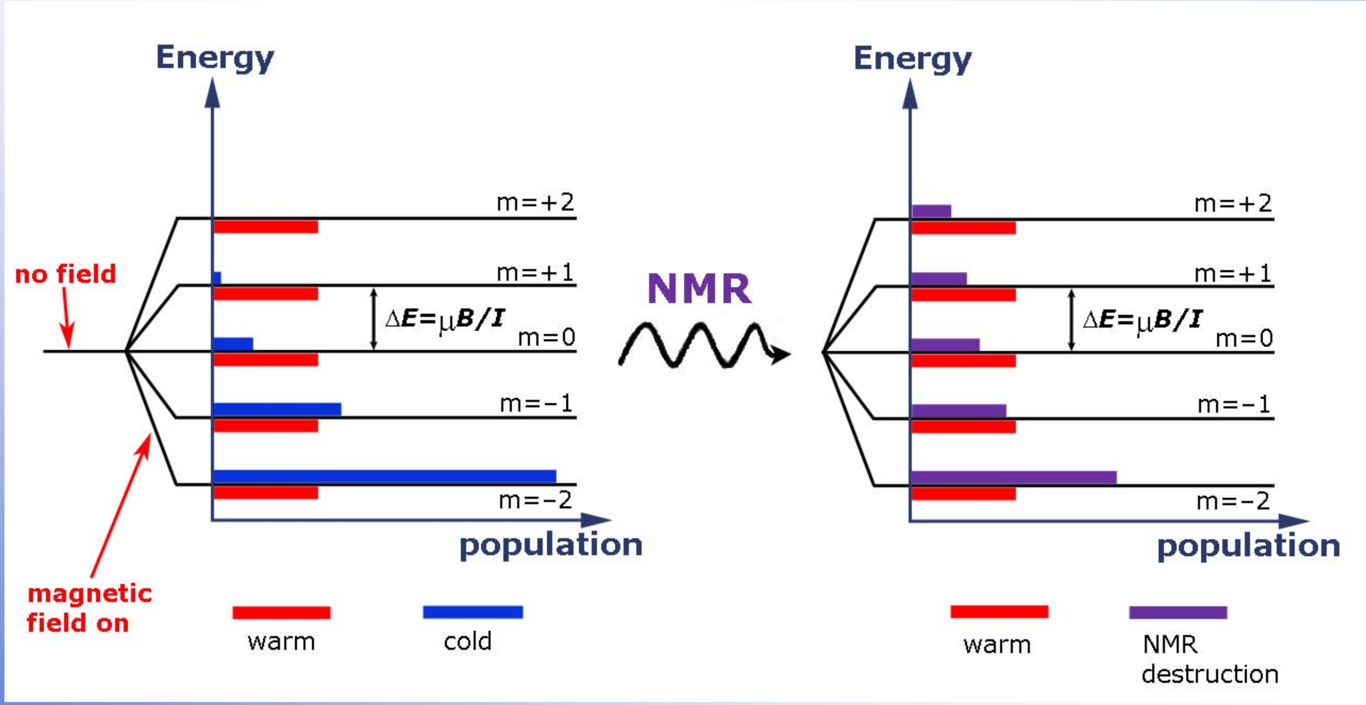
On-Line NMR/ON

NMR-ON ➔ Low temp + Magn Field ➔ Spin Preferential Orient ➔ Angular Anisotropy

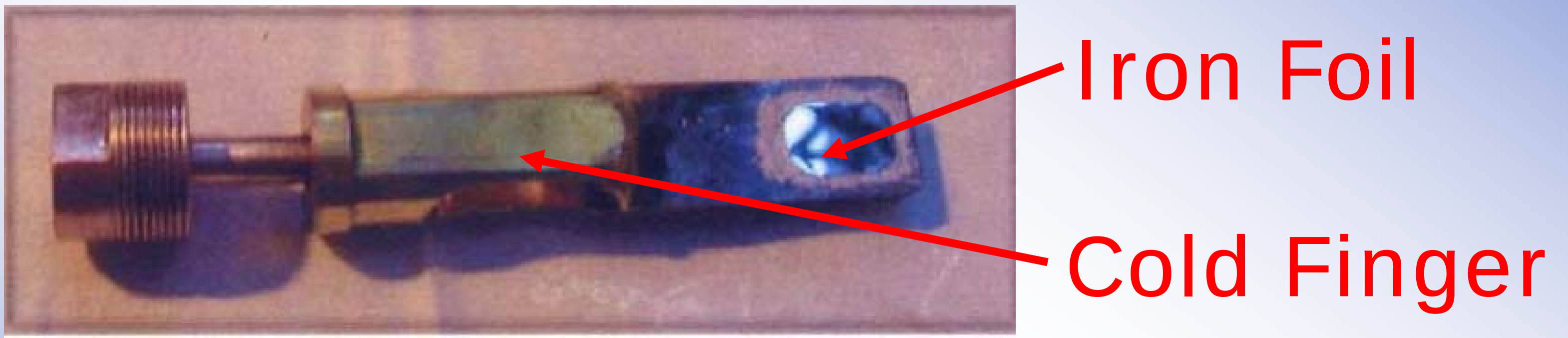
Polarised radioactive nuclei are placed in an RF field of variable frequency.

When the Zeeman splitting frequency is found ⟶ resonant absorption changes the sublevel populations and hence also the observed anisotropy ⟶ a resonance in the anisotropy versus frequency plot.



On-Line NMR/ON

^{3}He-^{4}He dilution refrigerator with a base temperature of about 6 mK (10 mK). The radioisotopes are on-line implanted into a ferromagnetic metal foil at mK temperatures magnetized by an external field of ~0.5 T. The implanted isotopes experience an internal hyperfine field (~10-100 T) which produces high degrees of nuclear polarization ⟶ nuclear resonance study.

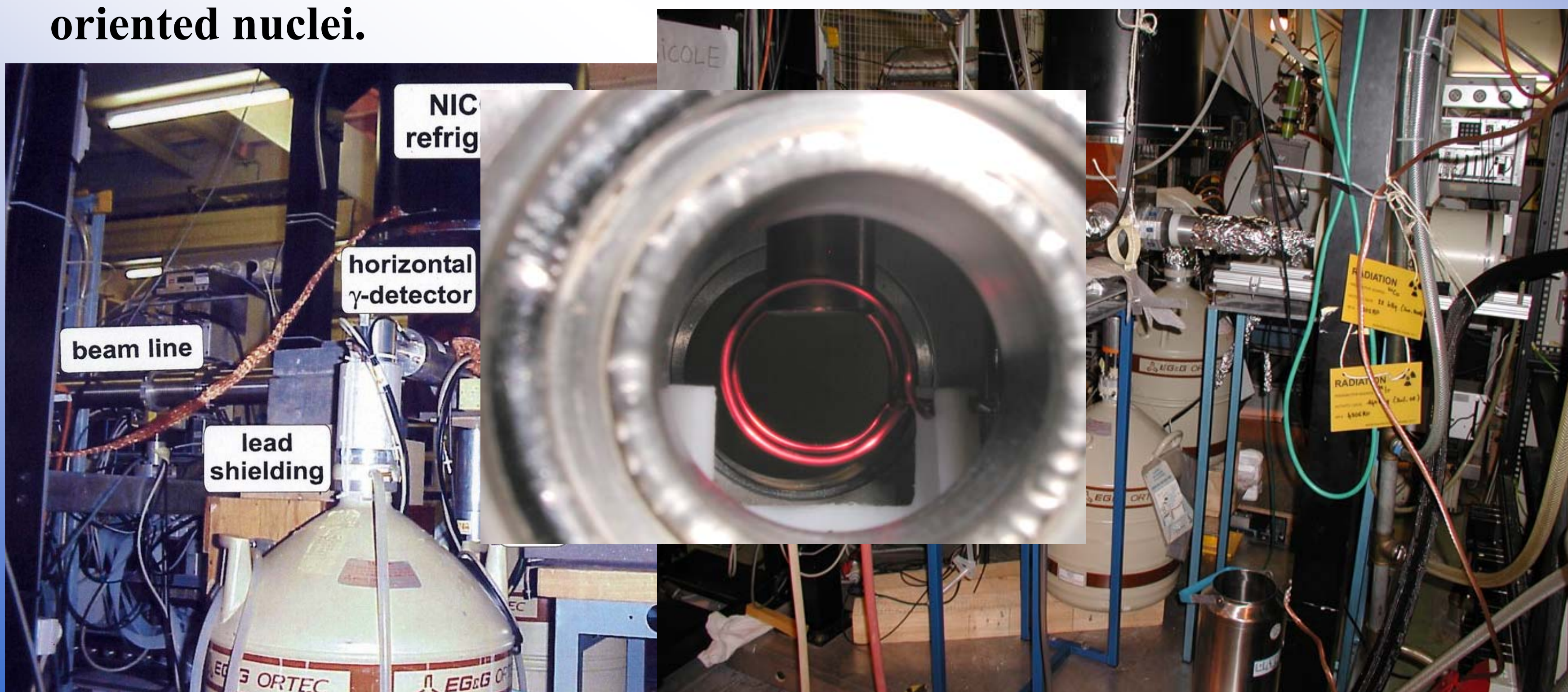


LIMITATION: the spin-lattice relaxation time of the implanted nuclei in the host. This time is of the order of second or more ⟶ lower limit on the lifetime and accessible radioactive nuclei.

NMR-NO have the ADVANTAGE to reach a high level of polarization (20-80%).

Apparatus

Four Germanium detectors (2 at 90 , 1 at 0 and 1 at 180° to the axis of orientation) for detection of the γ radiation.
A modulated RF field is produced in the iron foil with a resonance coil inside the refrigerator with axis normal to the nuclear orientation axis.
This is used to excite resonance between the hyperfine-split substates of the oriented nuclei.



Why Hafnium?

- Series of long-lived high-K isomers
- Precise measurements of the magnetic dipole moments

  information on intrinsic g_K of the isomeric states.
- Combination with independent data (rotation band of

  isomeric states) collective g-factor g_R
- Experimental data from new measurements:
- magnetic dipole moments

$$\mu = gI = g_R I + (g_K - g_R)\, K^2/(I+1)$$

- in-band quadr/dip mixing ratios for bands built (E2/M1):

$$\delta(\mathrm{E2/M1}) = \sqrt{\frac{5}{12}}\frac{1}{K}\frac{E_\gamma}{1.2x10^3}\frac{Q_0}{g_K - g_R}\frac{\langle I_f K 2 0 | I_i K\rangle}{\langle I_f K 1 0 | I_i K\rangle}$$

Why Hafnium?

Recently at ISOLDE a unique hafnium fluoride beam has been developed with high yield of isomeric states in isotopes with A around 180. Experiment aims to measure magnetic moments and decay properties of Hafnium isotopes:

A	level energy [keV]	I^π	$T_{1/2}$	suggested configuration	ISOLDE yield [ions per μC]
177	1315	$23/2^+$	1.1 s	$n7/2^-[514]$, $p7/2^+[404]$, $p9/2^-[514]$	$6.0\cdot10^5$ fed from $37/2^-$
	2740	$37/2^-$	51.4 m	$n5/2^-[512]$, $n9/2^+[624]$, $n7/2^-[514]$,$p7/2^+[404]$, $p9/2^-[514]$	$6.0\cdot10^5$
179	1106	$25/2^-$	25.1 d	$n9/2^+[624]$, $p7/2^+[404]$, $p9/2^-[514]$	$1.5\cdot10^7$
180	1183	8^-	5.5 h	$p7/2^+[512]$, $p9/2^-[514]$	$2.4\cdot10^7$
182	1173	8^-	62 m	$p7/2^+[512]$, $p9/2^-[514]$	$2\cdot10^4$

Estimated magnetic moments

For multi-quasi-particle states, using empirical g-factors, estimated moments and NMR range of resonance frequencies are given, based on the known hyperfine field of Hf in Fe of 67.4(9) T.

A	I^{π}	suggested configuration	Estimated/measured μ [n.m.]	NMR/ON ν [MHz]	T_1 at 10 mK [sec]	$T_{1/2}$
177	$23/2^+$	$n7/2^-[514], p7/2^+[512], p9/2^-[514]$	est. 8.04(6)	358.9(27)	7.5	1.1s
	$37/2^-$	$n5/2^-[512], n9/2^+[624], n7/2^-[514], p7/2^+[404], p9/2^-[514]$	est. 8.14(17)	255.8(47)	18.8	51.4m
179	$25/2^-$	$n9/2^+[624], p7/2^+[512], p9/2^-[514]$	meas. 7.43(34)	333.8(41)	8.9	25.1d
180	8^-	$p7/2^+[512], p9/2^-[514]$	est. 8.4(7)	539(45)	3.0	5.5h
182	8^-	$p7/2^+[512], p9/2^-[514]$	est. 8.4(7)	539(45)	3.0	62m

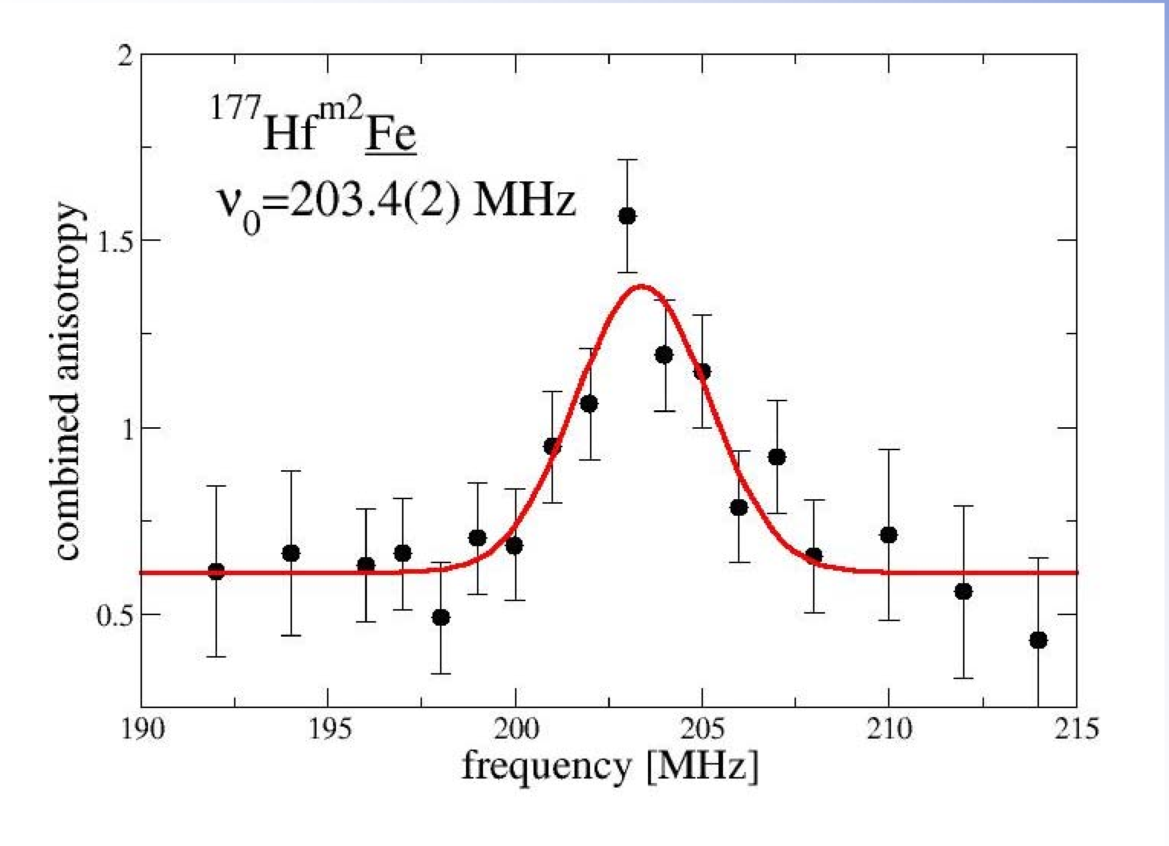
T1= spin lattice relaxation time

Data Analysis

- **Preliminary – restricted so far to data on the isomers of ^{177}Hf:**
  - **resonance of the 37/2^{-} (51 m) isomer**

    → **Magnetic moment**
  - **E2/M1 mixing ratios in bands built on the 23/2^{+} (1.1 s) isomer and the low lying 9/2^{+} [624] state**

Magnetic moment

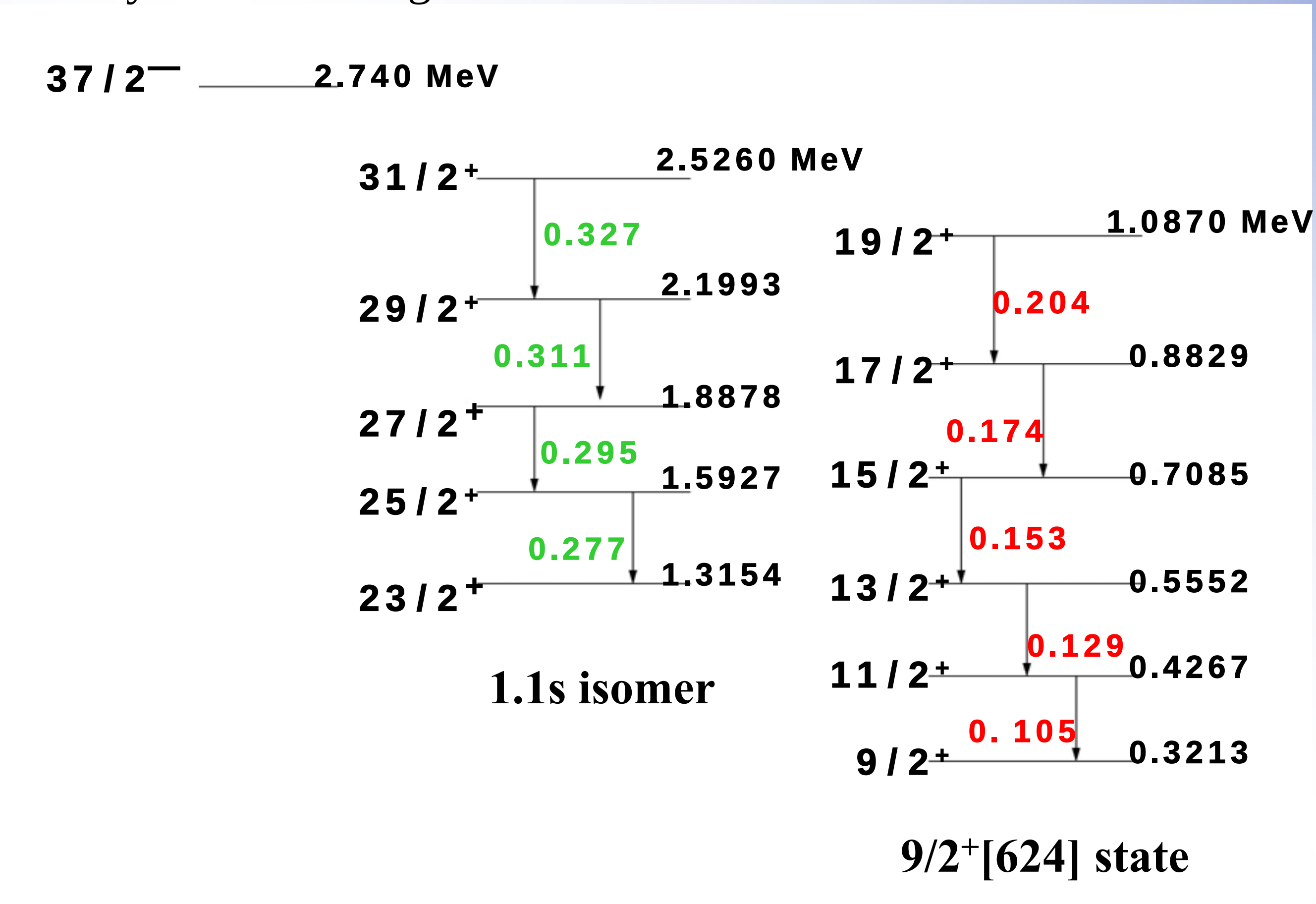


NMR/ON observed in a combined signal from several transitions from the upper, $37/2^-$ isomer.

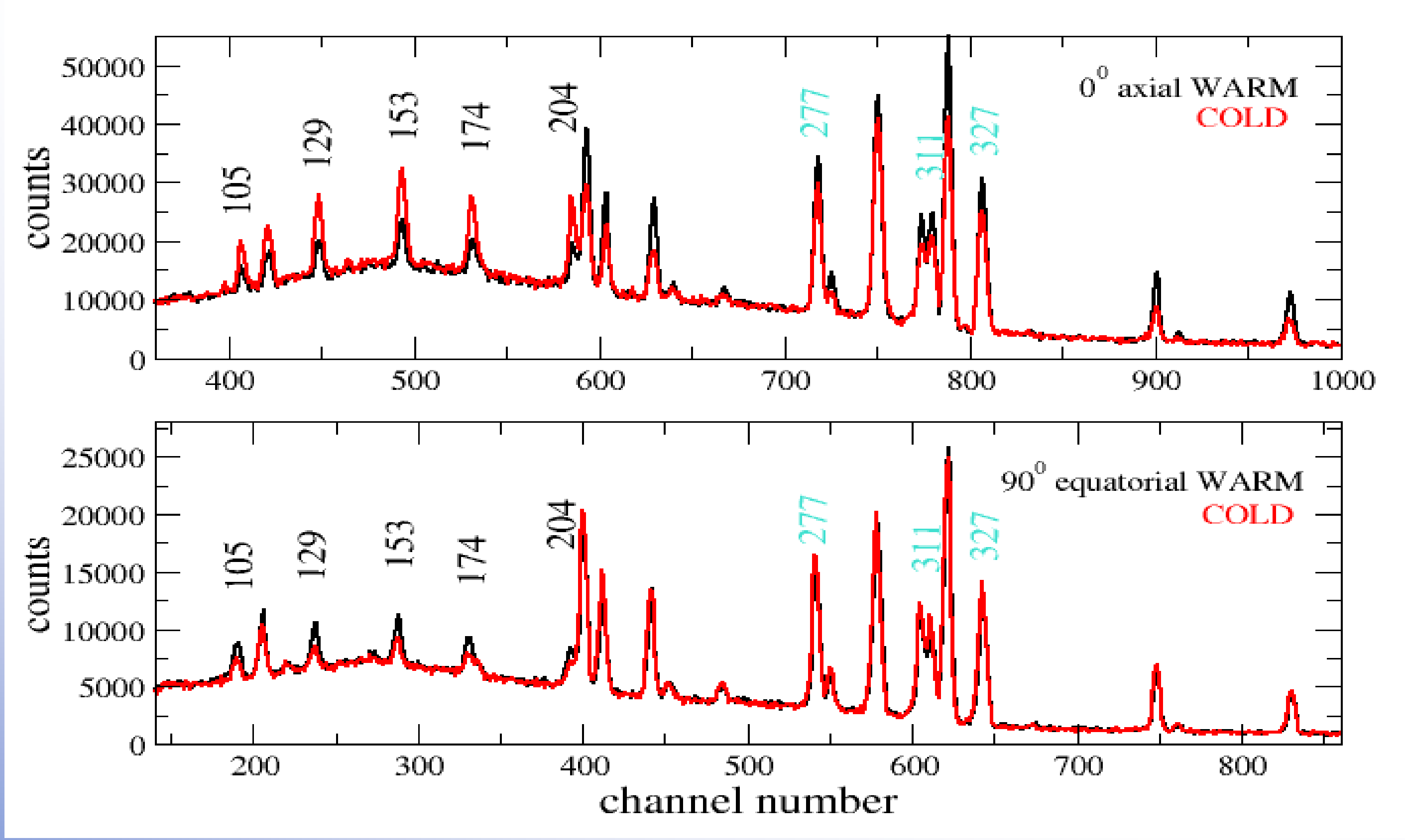
Moment value: 7.33(7) n.m. (est. 8.14(17) n.m.)

^{177}Hf Level Scheme

Simplified portion of the scheme of energy levels showing the 1.1 second isomer and the 9/2+[624] state: we determined the E2/M1 mixing ratios in bands built on these states from analysis of their angular distribution.



E2/M1 mixing ratios determine sign and magnitude of anisotropy

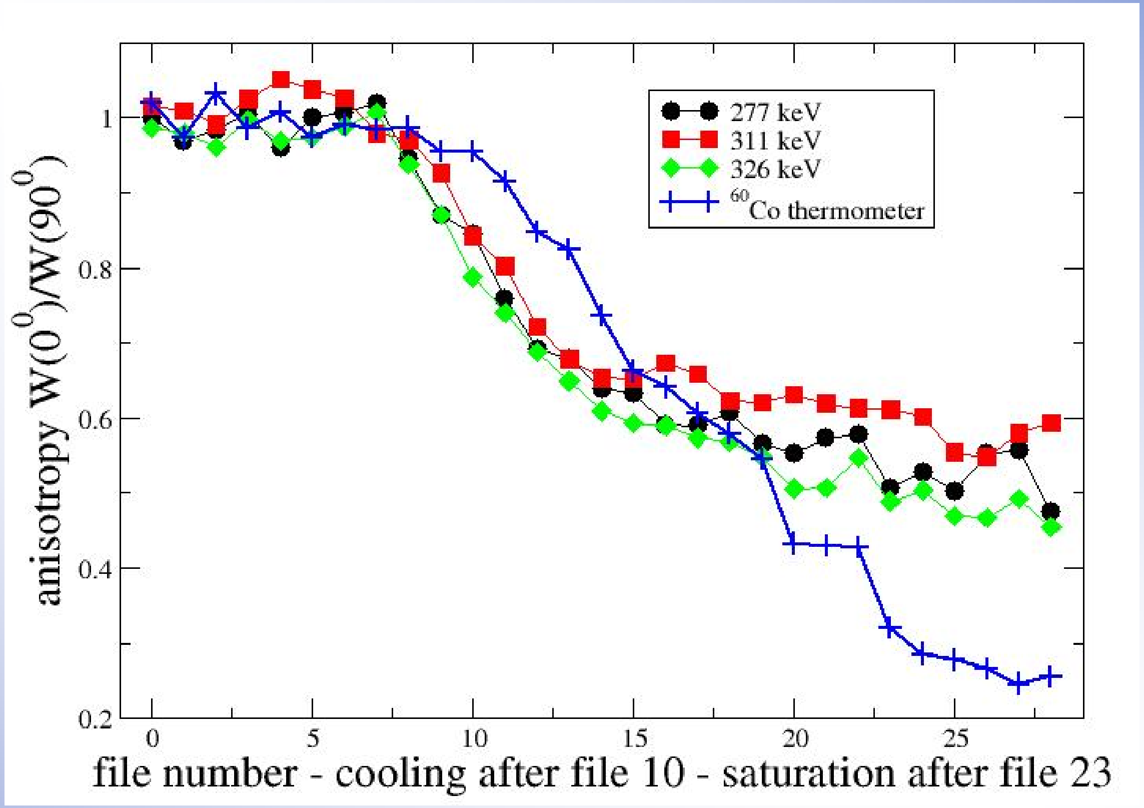


WARM and COLD spectra from 0 and 90 degree detectors two series of E2/M1 transitions

black – in band built on 9/2$^+$[624] state – n.b. increases at 0

green – in band built on 23/2$^+$ three quasi-particle 1.1s isomer – n.b decreases at 0

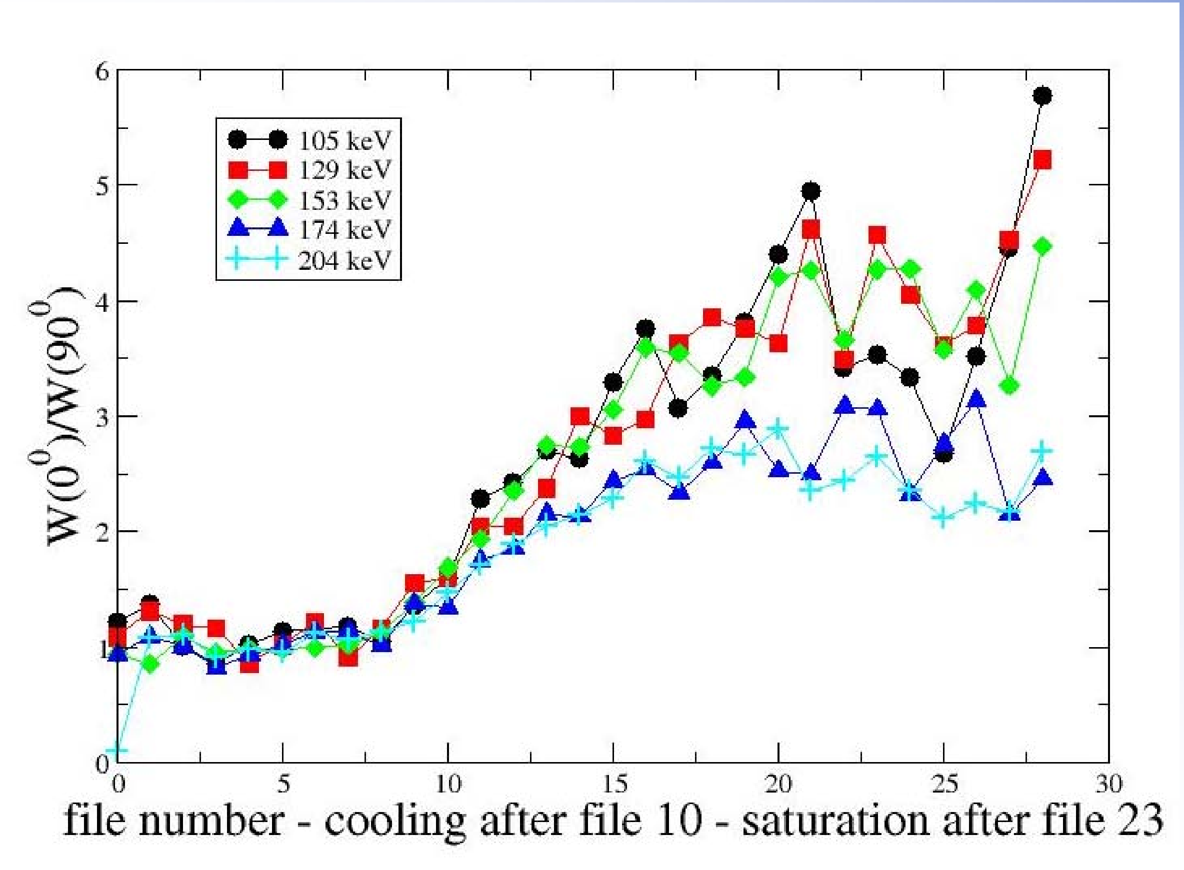
Temperature dependence of orientation of E2/M1 mixed transitions in 1.1 s isomer band



Thermometric transition of ^{60}Co shows cooling of source to base temperature about 14 mK.

All isomer band mixed transitions show negative anisotropies and mixing ratios close to +0.3.

Temperature dependence of orientation of E2/M1 mixed transitions in 9/2+[624] band



All isomer band mixed transitions show strongly positive anisotropies corresponding to mixing ratios close to −0.3.

Comments

Data also taken on ^{179,180m}Hf.

Some problems with large accumulated stable Hf may have contributed to small ^{177m2}Hf NMR/ON and absence of others later in experiment.

Presence of oxygen in target led to isobaric contamination at mass 182 so not studied

^{179}Hf studied with room-temperature collection sample showed smaller than expected anisotropies – poor fraction in good sites [80% in cold on-line implanted mass 177 samples].

Future plans

- Preliminary results show the success achieved with both resonance and large anisotropies in on-line implanted sample of ^{177m2}Hf.
- Provided stable beam - contamination kept low - cold on-line implant and more frequent Fe foil change will allow resonance of ^{179,180m,182}Hf as proposed.
- NICOLE NMR line power resonances need study.
- Further beam time to be explored.

Collaboration

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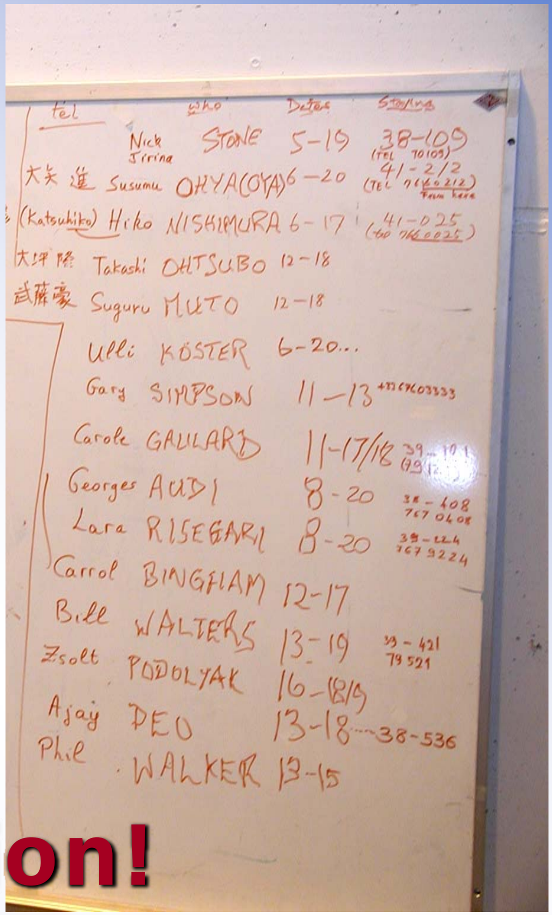

Thank you for your attention!