EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

**Letter of Intent to the**
**ISOLDE and Neutron Time-of-Flight Experiments Committee**
**for experiments with HIE-ISOLDE**

# Exploration of K-isomerism using unique high-K isomeric beams

**David Jenkins**[1], Bob Wadsworth[1], Charles Barton[1], Magda Zielinska[2], **Pawel Napiorkowski**[2], Jan Kownacki[2], Marcin Palacz[2], Phil Walker[3], Kieran Flanagan[4], Sean Freeman[4], George Dracoulis[5], Ben Kay[6], Filip Kondev[6], Nigel Warr[7], Doug Cline[8], Adam Hayes[8], Thorsten Kroell[9], Norbert Pietralla[9], Nico Orce[10], Emmanuel Clement[11], Georgi Rainovski [12], M. Danchev[12], Andreas Goergen[13], Sunniva Siem[14], Dave Joss[15], Robert Page[15]

[1] University of York [2] HIL Warsaw [3] University of Surrey
[4] University of Manchester, UK [5] Australian National University
[6] Argonne National Laboratory [7] IKP Cologne [8] University of Rochester
[9] TU Darmstadt, [10] University of Western Cape [11] GANIL [12] University of Sofia
[13] CEA Saclay [14] University of Oslo [15] University of Liverpool

Spokespersons: David Jenkins (dj4@york.ac.uk), Pawel Napiorkowski (pjn@slcj.uw.edu.pl)

CERN-INTC-2010-033 / INTC-I-101
20/05/2010

**Abstract**

We propose to learn more about K-mixing and the reduced charge radius recently observed in high-K isomers by exploiting the unique high-K isomeric beams in the region around $^{178}$Hf which are available at ISOLDE. We envisage Coulomb excitation and single-particle transfer reactions of such isomeric beams for the first time.

## 1. Introduction

There is considerable topical interest in the question of to what extent the K quantum number is a good quantum number and to what extent K-mixing occurs. One of the key regions of the nuclear chart for exploring such phenomena is that around $^{178}$Hf where extremely long-lived K-isomeric states like the 31-yr $16^+$ isomer are observed. Hayes et al. have made an extremely comprehensive study of $^{178}$Hf via Coulomb excitation of the ground state [1]. They show that the $8^-$ isomer in $^{178}$Hf is populated in such a reaction but the mechanism is by no means fully clear. There are further nuclear structure puzzles associated with these isomers, for example, recent laser spectroscopy measurements which showed a reduction in the nuclear charge radius associated with $8^-$ isomers in $^{176}$Yb and $^{178}$Hf [2]. Efforts to explain this have pointed to the effects of reduced pairing but this cannot fully account for the size of the reduction which is observed. We also point out that the structure of these nuclei and their isomers are important in determining the progress of the astrophysical s-process.

## 2. Physics case

We propose to directly study the collectivity associated with the high-K isomers around $^{178}$Hf through Coulomb excitation. Uniquely, we will be able, for example, to study Coulomb excitation from the $8^-$ isomer in $^{178}$Hf. This will form a perfect complement to the very detailed studies of Coulex made by Hayes et al. starting from the ground state up [1]. Moreover, we can then directly study collectivity built on the $8^-$ (and $16^+$ isomers – we note that this latter has been studied before with an isomeric target [3]). We can look for pathways up from the isomer and down to the ground states, which again probes K-mixing and locates doorways states for de-excitation. This approach is readily applicable to neighbouring nuclei with high K-isomers such as Yb and Lu isotopes, as well as heavier Hf isotopes like $^{180}$Hf and $^{182}$Hf.

A further exciting possibility would be to carry out single-particle transfer reactions in inverse kinematics on the isomeric states. This could be used to show the extent to which high-K configurations in neighbouring nuclei are related and is something which has essentially never been attempted before (with the exception of a (p,t) reaction study on a target containing the 31-yr $^{178}$Hf isomer [4]). It would be particularly interesting to consider (t,p) reactions which might allow something to be concluded on the issue of the reduced pairing suggested for the $8^-$ isomers, for example. We can certainly extract qualitative information in this regard but theoretical support would be very helpful in this area – especially in terms of what can be learned from pair transfer reactions. Clearly, the timeline to HIE-ISOLDE gives scope to investigate these issues in much more detail than can be covered here.

## 3. Experimental setup

The Coulomb excitation measurements will continue to require the MINIBALL array and associated CD detector. A challenge with Coulomb excitation of the high-K isomers is that both ground state and isomers are produced simultaneously. For example, in the case of $^{178}$Hf, the expectation is that the ground state, $16^+$ isomer and $8^-$ isomer would be produced from ISOLDE at a respective intensity ratio of 100:10:1 [5]. For some species, it may be possible to use laser spectroscopy to separate these different states in the manner used recently for successful studies of $^{68}$Cu at REX-ISOLDE. Laser schemes may need to be developed. Since Hf is produced as a fluoride ion, this might not be possible in that particular case. We note that, in practice, it might not be necessary to separate isomer and ground state and there may be advantages to simultaneous excitation if they can be separated experimentally following Coulomb excitation. In this regard, we propose a special approach to sensitively selecting the excitation of e.g. the $8^-$ isomers. This follows the technique of G.D. Jones [6] proposed as a means of studying high-K isomers around $^{254}$No. The idea is that heavy ions scattered into the CD detector would be in either the ground or isomeric states. In their subsequent decay, the short-lived 8- isomer would emit a flash of conversion electrons emitted. This could be used as a tag to select the Coulomb excitation of these isomers. Such an approach would entail a considerable upgrade of the existing acquisition system to allow the detection of both heavy ions with 1-GeV energies and conversion electrons summing to around 500-keV in the same pixel of the CD detector. Possible options include logarithmic preamplifiers, time-over-threshold preamplifiers and/or instrumenting the system twice with low gain and high gain. Such a system would also be of interest for alpha-tagging of heavy nuclei. Detecting delayed gamma-emission at the target and focal plane from the isomer would also serve to establish what fraction of the isomer population is de-excited [7].

Transfer reactions could either use the existing T-REX set-up or conceivably a solenoidal-field spectrometer such as the HELIOS at Argonne National Laboratory. A recoil separator may also be required. We note the existence of a letter of intent to build an electron-gamma setup at HIE-ISOLDE which could also be relevant to this case.

## 4. Beam requirements

Beams of Hafnium isomers are available at ISOLDE [5]. They are produced with Tantalum target with addition of $CF_4$. The yield of $^{178}Hf^{m1}$ is approaching $10^6/\mu C$. The yield of the $16^+$ isomer is an order of magnitude higher. The ground state is likely to be an order of magnitude higher again (extrapolated from lighter masses but not directly measured as it is stable isotope) [5].

Aside from $^{178}Hf$, potential candidates for study include the 8- isomer in $^{176}Yb$ (11.4 s) also produced at ISOLDE. A laser ion source can increase the ionization efficiency for Yb by a factor of 100. We note that a recent letter of intent to the INTC has requested development of heavier Hf beams for laser spectroscopy measurements, again with a motivation to study K isomerism.

For Coulomb excitation, we require beams of around 5 MeV/u. For transfer reactions such as (d,p), we require up to 10 MeV/u, in principle, but in some cases it may be possible to achieve something at the lower energy but probably without direct sensitivity to the l-transfer. A HELIOS-type device would place challenges on the present time structure of the beam as well as requiring a small emittance (see LoI on HELIOS-device led by Sean Freeman).

## 5. Safety aspects

There may be issues with contamination of the target chamber and apparatus with very long-lived isomers. Examples might include $^{177}Lu$ whose $23/2^-$ isomer has a 160-day half-life. In some cases, this may necessitate laser ionization schemes to remove such long-lived products.

## 6. References


1. A.B. Hayes et al., Phys. Rev. C 75, 034308 (2007).
2. M.L. Bissell et al., Phys. Lett. B 645, 330 (2007).
3. E. Lubkiewicz et al., Z. Phys. A 355, 377 (1996).
4. C. Briancon et al., Phys. Rev. C 48, R2148 (1993).
5. U. Koester et al., Eur. Phys. J. (Special Topics) 150, 293 (2007).
6. G.D. Jones, Nucl. Instrum. Meth. 488, 471 (2002).
7. H. Xie et al. Phys. Rev. C 48, 2517 (1993).