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Proposal to the ISOLDE and Neutron Time-of-Flight Committee

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HIGH-PRECISION MASS MEASUREMENTS BELOW ^{48}Ca and in the RARE-EARTH REGION to INVESTIGATE the PROTON-NEUTRON INTERACTION

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Abstract

We propose to perform precision mass measurements on a series of short nuclides which contribute to the investigation of the proton-neutron interaction and its role in nuclear structure, especially deformation and collectivity. The nuclides include neutron-rich $^{39\text{-}45}$S and $^{46\text{-}48}$Ar below the doubly magic ^{48}Ca, mid-shell neutron-rich and neutron-deficient rare-earth Ce, Nd, Sm, Gd, Dy, Er, and Yb isotopes, as well as ^{186}Hf and ^{138}Te. The investigations will take place at the Penning trap mass-spectrometer ISOLTRAP which routinely reaches the required mass precision around 10 keV. The measurements are planned for a period of 2-3 years and include several target and ion-source developments.

1. Introduction and motivation

Looking at the number of valence nucleons in a nucleus is a key first and helpful step to get an idea about its structure. For even-even nuclei, the $R_{4/2}$ ratio, which is the energy of the first 4^+ excited level over the energy of the first 2^+ level, is often considered as a critical next step. The quantity $1/E(2_1^+)$is also a useful observable which reveals the same trend as $R_{4/2}$ as a function of Z and N and which is often available experimentally when $R_{4/2}$ is not. Of course, especially in medium- and heavy-mass regions, particularly in deformed nuclei, not only $R_{4/2}$ but also such quantities as the beta-band states, gamma-band states, and certain $B(E2:J_i \rightarrow J_f)$ values are naturally necessary to fully define the structure of the nucleus.

Mass measurements provide complementary information, especially, nowadays, with Penning Traps and Storage Rings which provide high accuracy mass measurements on short-lived and stable nuclides [1]. Moreover, often masses can be obtained when spectroscopic data cannot. Therefore, atomic mass measurements can often in fact give us the first information about nuclei, especially far from stability. In many cases, one can obtain the mass value for a given nucleus even if $R_{4/2}$ is unknown but, conversely, often, $R_{4/2}$ cannot be obtained when the mass is unknown.

Atomic masses allow extracting nuclear binding energies which reflect all nucleonic interactions inside the nucleus. The binding energy is given by the difference of the summed masses of all protons and neutrons inside the nucleus and the actual mass of the nucleus:

$$B.E\,(Z,N) = (Z \times m_p + N \times m_n - M(Z,N)\,) \times c^2 \qquad (1)$$

One nucleon (proton or neutron) or two nucleon separation energies can be extracted with the binding energies. Equation 2 shows one neutron and two neutron separation energies, respectively.

$$S_n(Z,N) = B(Z,N) - B(Z,N-1)\ ;\ \ S_{2n}(Z,N) = B(Z,N) - B(Z,\,N-2) \qquad (2)$$

These two observables also reveal considerable information about the structure. From S_n to S_{2n}, we can often determine shell structure or collective effect. The use of separation energies can be extended in order to extract specific interactions by exploiting double differences of binding energies [6]. One important example gives the average interaction between the last two protons and the last two neutrons, δV_{pn} [2]. Since the interactions of the protons and neutrons largely determine the character of the nucleus, the role of the proton-neutron interaction is extremely important in understanding the evolution of both single particle and collective structure: Magic numbers, single particle energies, collectivity, phase/shape transitions [3-5].

Specifically, for even-even nuclei δV_{pn} is the difference of two neutron (or two proton) separation energies for consecutively numbered even nuclei with Z and Z-2 for the same neutron number (or the difference between two neutron separation between nuclei with N and N-2 for the same proton number) (Eq.3).

$$|\delta V_{pn}\,(Z,N)| = 1/4 \times [\ \{B(Z,N) - B(Z,N-2)\} - \{B(Z-2,N) - B(Z-2,N-2)\}\ ] \quad (3)$$

$$= 1/4 \times [\ S_{2n}(Z,N) - S_{2n}(Z-2,N)]$$

$$= 1/4 \times [\ S_{2p}(Z,N) - S_{2p}(Z,N-2)]$$

δV_{pn} can often be interpreted in terms of the orbit occupations of the last two protons and neutrons, by considering of the spatial overlap between the proton and neutron wave functions [2,6]. There are several areas of the nuclear chart where new information on masses can help understand anomalous or puzzling behavior of either S_{2n} or δV_{pn} values and thereby help understand the evolution of structure in these regions. They are presented briefly below:

Flattening of S_{2n} values around Z=70 and N=108

In terms of the separation energies, an obvious example (except magic shells) of structural change is given for nuclei at critical point of quantum phase transitions. As is well known, the Nd, Sm, Gd and Dy nuclei at N=90 undergo a shape transition [7]. Deformation at N=90 for these nuclei gives increased binding energies which is seen by the flattening in S_{2n}. This flattening is clear for the rare-earth nuclei in Fig. 1 compared to a linear decrease in S_{2n} for neighbouring isotopic chains.

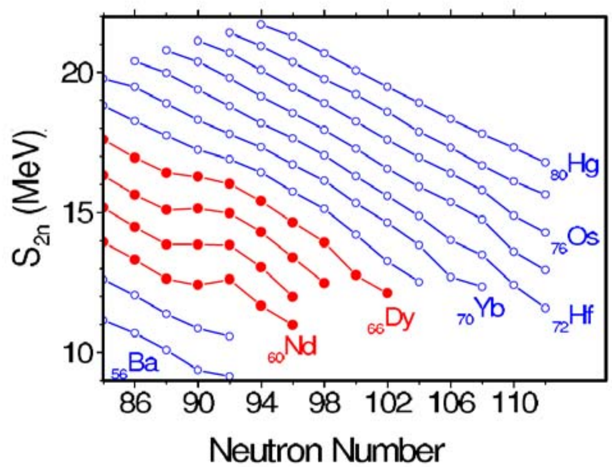

Fig. 1 The S_{2n} values as function of neutron number for the $_{56}$Ba - $_{80}$Hg nuclei between N=84 and N=112 [8]. Isotopic chains showing deformation related to the phase transition around N=90 are marked with solid circles.

Interestingly, a similar flattening in S_{2n} seems to start in the Yb chain at N=108, which might be connected to the subshell closure or other structural changes mentioned in Ref.[9]. Unfortunately there are no data for Yb beyond this point, and masses for lighter rare-earth elements beyond N=108 are also missing. In order to investigate this corner of the nuclear chart masses of Yb above N=108, Er with N>104, Dy with N>102, and more will be required. These are summarized in the first section of Table 1.

δV_{pn} values in the ^{48}Ca region

It has been stressed many times that masses of neutron-rich Hg isotopes are extremely valuable in order to derive δV_{pn} values for ^{210}Pb and heavier Pb nuclides, which would be the first δV_{pn} result south-east of doubly-magic ^{208}Pb with Z≤82 with N>126 (proton particle, neutron hole region [6]). A similar situation takes place south-east from doubly-magic ^{48}Ca, where only two δV_{pn} values (for even-Z odd-N nuclides) are known, however with large uncertainty, as seen in Fig. 2. For Ar at N=29 most of the very large uncertainty is coming from the masses of ^{45}S and ^{44}S nuclei. Ignoring the error bars in ^{45,47}Ar at N=27 and 29 the δV_{pn} values seem to indicate a clear sub-shell effect visible in a sudden drop in δV_{pn} just after N=27, in analogy with the ^{208}Pb region. The unique feature of shell structure in this region, though, is that there is no sudden change from low-j to high-j orbits when the magic number at N=28 is crossed. Therefore, opposite to the situation that occurs in the Pb region, one would not expect a sudden drop in δV_{pn} at N=29. Yet the Ar and Ca nuclei show a pattern very similar to Pb. Understanding this behavior is necessary to truly understand how the p-n interactions depend on orbit overlaps. If the δV_{pn} values for ^{45,47}Ar are confirmed with more precise mass measurements, the result may shed new light on the nature of δV_{pn} in light nuclei, and may even be a guide to understanding the nuclei in the Ca region. The required input for this study are precise masses of $^{46-48}$Ar and $^{41-45}$S, which are listed in Table 1. The same Ar isotopes are point of interest of another ISOLTRAP proposal which will be presented to the INTC, therefore no shifts are requested in Table 2.

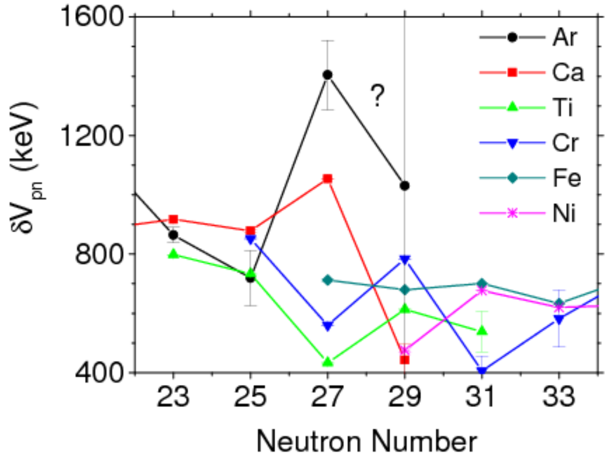

Fig.2 Empirical δV_{pn} values for even-Z odd-N nuclei in the Ca region.

δV_{pn} values in neutron-rich rare-earth nuclides

Fig.3 shows δV_{pn} values for nuclei from $_{60}$Nd to $_{70}$Yb in the rare-earth region. In the even-even cases (Fig. 3 left) for successive Z values, the δV_{pn} values increase gradually to about 350 keV followed by a sudden drop at N=Z+34. Calculations with the Nilsson model have reproduced this effect for Gd-Yb with a simple microscopic interpretation [10].

The standard interpretation of p-n interactions is that they reflect the overlaps of the wave functions of the outermost protons and neutrons, and that these should be largest when the proton and neutron shells are filled to roughly the same fractional extent. This is verified in many nuclei by large values of δV_{pn} along the diagonal joining nuclides with consecutive magic N and Z (see Fig. 4). This mechanism would explain the increases in δV_{pn} from Gd to Yb as there is a higher overlap of neutrons with mid-shell proton orbits as N increases from 92 towards the mid-neutron shell.

Yet, there appears to be an intriguing change in pattern in the heaviest isotopes of Gd to Yb. In Fig. 4 this shows up vividly in an anomalously low δV_{pn} value for ^{158}Sm (blue box at N = 96) which seems to contradict the idea of large values along the diagonal [6,11]. These two effects are in fact the same – the low value for ^{158}Sm is just a larger change in δV_{pn} than for the heavier elements. However, this unexpected δV_{pn} value has a large uncertainty.

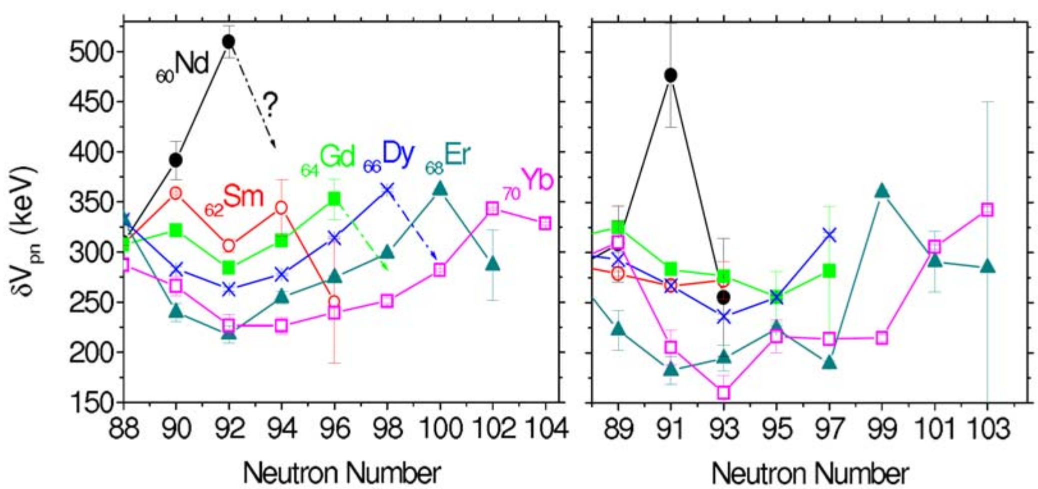

Fig. 3 Left: δV_{pn} values for even Z-even N nuclei in the rare-earth region Right: δV_{pn} for even- Z and odd-N.

We therefore propose to measure the [158]Sm value with higher accuracy and to extend the systematics near the diagonal to see if the drops in δV_{pn} seen in Fig.2 are also present in heavier isotopes. This investigation is critical in order to determine the true mechanisms underlying the p-n interactions that drive the development of collectivity in these nuclei, specifically to see if they can indeed be simply understood in terms of spatial overlaps or whether other effects are also important. The nuclides for which the δV_{pn} values should be determined include neutron-rich rare-earth isotopes, as well as Hf isotopes with N> 108, W above N>112, Os with N>116, Pt with N>120, and Hg with N>122. The masses required to derive the above δV_{pn} values are listed in the second section of Table 1.

It is difficult to say if a similar trend as is even-Z rare-earth nuclides is present in odd-N isotopes (Fig. 3 right). δV_{pn} values seem to increase with N for Dy and Yb, and there is even a small peak visible for Er chain. Also for Nd a very distinct peak is visible, which is somewhat dubious considering the moderate δV_{pn} values in neighbouring chains. Thus this value requires reinvestigating. For Gd, the values might also increase, however the uncertainty is too large to draw conclusions. In order to obtain a clearer picture for these odd-N nuclides, and to compare them to their even-N neighbours, one should obtain and re-measure several δV_{pn} values in this region. Needed masses are also listed in Table 1.

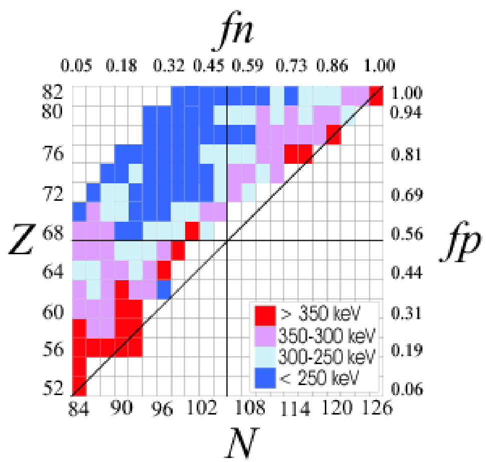

Fig.4 Empirical δV_{pn} values at the major shells Z=50-82, N=82-126 with proton and neutron fractional filling values (*fp* and *fn*, respectively) [6,11]. New data for ^{136,138}Ba are based on recent Xe mass measurements at ISOLTRAP [13].

Nuclides with unknown masses but known $R_{4/2}$ or $E(2_1^+)$ values

As mentioned in the beginning, it is generally more difficult to gain access to excited levels of a nucleus than to measure its mass. Yet, there are a number of nuclei where $R_{4/2}$ is known but not the mass. As seen in the last part of Table 1, these include mostly neutron-deficient rare-earth nuclides, many of which are known to be well deformed.

It has recently been shown that there is a much deeper link between masses and structure than previously expected and that masses can, especially in deformed nuclei, give important complementary information about structure, even concerning collective modes. That is, data such as $R_{4/2}$ and $E(2_1^+)$ are not sufficient to determine the structure. Other observables are needed. In nuclei far from stability, where other data (such as energies of excited collective modes) are not available, masses can therefore provide sensitive complementary information that can give deeper insight into the structure than heretofore thought [12].

Table 1: Nuclides of interest to investigate the proton-neutron interaction.

	Nuclide(s) of interest	Nuclide to study	Half life $T_{1/2}$	Mass uncert. /keV
S_{2n}	^{178}Yb	^{178}Yb	74 min.	10
	^{180}Yb	^{180}Yb	2.4 min.	400 #
	^{182}Yb	^{182}Yb *		400 #
	^{174}Er	^{174}Er	3.2 min.	300 #
δV_{pn}	^{39}S	^{39}S	11.5 s	50
	^{40}S, ^{42}Ar, ^{44}Ar	^{40}S	8.8 s	140
	^{41}S	^{41}S	1.99 s	120
	^{44}Ar, ^{46}Ar, ^{42}S,	^{42}S	1.0 s	120
	^{45}Ar, ^{43}S	^{43}S	260 ms	200
	^{46}Ar, ^{48}Ar ^{44}S	^{44}S	122 ms	300
	^{47}Ar	^{45}S	82 ms	1740
	^{46}Ar, ^{47}Ar, ^{50}Ca	^{46}Ar	8.4 s	40
	^{47}Ar	^{47}Ar	1.23 s	100
	^{50}Ca	^{48}Ar	475 ms	300 #
	^{151}Nd, ^{152}Nd	^{150}Ce	4.0 s	50
	^{153}Nd, ^{154}Nd	^{152}Ce	1.4 s	200
	^{156}Sm, ^{154}Nd	^{154}Nd	26 s	110
	^{157}Sm, ^{163}Gd	^{155}Nd	8.9 s	150 #
	^{158}Sm	^{156}Nd	5.5 s	200 #
	^{158}Sm	^{158}Sm	5.3 min.	80
	^{161}Gd	^{159}Sm	11.4 s	100
	^{162}Gd	^{160}Sm	9.6 s	200 #
	^{163}Gd	^{161}Sm	4.8 s	300 #
	^{163}Gd, ^{165}Dy	^{163}Gd	68 s	300 #
	^{166}Dy	^{164}Gd	45 s	400 #
	^{167}Dy	^{165}Gd	10.3 s	500 #
	^{171}Er	^{168}Dy	8.7 min.	140
	^{172}Er	^{170}Dy *	30 s #	200 #
	^{176}Yb	^{174}Er	3.2 min.	300 #
	^{182}Hf	^{180}Yb	2.4 min.	400 #
	^{188}W	^{186}Hf	2.6 min.	300 #
Nuclides with unknown mass but known $R_{4/2}$ or $E(2_1^+)$	^{138}Te	^{138}Te	1.4 s	210 #
		^{125}Ce	10.2 s	200 #
		^{124}Ce	6.0 s	300 #
		^{123}Ce	3.8 s	300 #
	^{124}Ce, ^{122}Ce	^{122}Ce *	2 s #	400 #
	^{128}Nd	^{129}Nd	4.9 s	200 #
		^{128}Nd	5 s	200 #
		^{134}Sm	9.5 s	200 #
		^{133}Sm	3.7 s	200 #
		^{132}Sm	4.0 s	300 #
		^{131}Sm	1.2 s	300 #
	^{134}Sm, ^{132}Sm, ^{130}Sm	^{130}Sm *	1 s #	400 #
	^{160}Sm	^{160}Sm	9.6 s	200 #
		^{139}Gd	5.8 s	200 #
		^{138}Gd	4.7 s	200 #
		^{137}Gd	2.2 s	400 #
		^{136}Gd	1 s #	400 #
		^{135}Gd	1.1 s	500 #
	^{138}Gd, ^{134}Gd	^{134}Gd *	400 ms #	400 #
		^{143}Dy	3.2 s	200 #
		^{142}Dy	2.3 s	360 #
		^{141}Dy	0.9 s	300 #
	^{142}Dy, ^{140}Dy	^{140}Dy	700 ms #	500 #
	^{148}Er	^{148}Er	4.6 s	500 #

* nuclides which have not yet been identified; # extrapolated from systematics [8]

2. Experimental setup

The presented mass measurements, especially for the δV_{pn} study, need to be performed with an uncertainty of below 10 keV, which corresponds to a relative uncertainty below $\delta m/m=10^{-7}$ in the heavy mass region around A=200. The required precision has been routinely reached by Penning trap mass spectrometers like ISOLTRAP [14].

With ISOLTRAP over 400 exotic nuclides have already been investigated, meanwhile reaching regularly a relative mass precision of the order of $\delta m/m=1\cdot 10^{-8}$ [15]. Nuclides with production rates as low as 100 ions/s and half-lives well below 100 ms can be addressed. Last year ISOLTRAP already reached a number highlights within the previous proposal devoted to the proton-neutron interaction and δV_{pn} values, P-230 [16]. During a single beamtime neutron-rich $^{136-146}$Xe and $^{223-229}$Rn were studied, with 11 out of 18 masses determined directly for the first time. In addition a new nuclide, ^{229}Rn, was identified [13], a feature which had not been achieved at a Penning trap system before.

ISOLTRAP employs three ion traps for the preparation and purification of radioactive ion bunches delivered by ISOLDE, as well as for the measurement of the atomic mass. The 60-keV ISOLDE ion beam is first stopped, cooled, and bunched in a linear radio-frequency quadrupole (RFQ). Isobaric contaminants which are still present after mass selection with either the GPS or the HRS separator magnets, can be removed in the first, cylindrically shaped Penning trap, which can reach resolving powers of up to $m/\Delta m=10^5$. The isobarically pure ion bunch is then transferred to the precision Penning trap, where possible isomeric ions can be removed using of a resonant dipolar radio-frequency (rf)-excitation.

The mass measurement is based on the very precise determination of the cyclotron frequency $\nu_c=qB/(2\pi m)$ of ions with mass m and charge q stored in a strong and homogeneous magnetic field B. With the time-of-flight cyclotron-resonance technique the gain of radial energy in the Penning trap after a quadrupolar rf-excitation is probed by monitoring the change of the time-of-flight towards an external detector after axial ejection of the ions from the trap. The magnetic field strength is determined by measuring the cyclotron frequency of a reference ion with well-known mass. The mass of the ion of interest is finally deduced from the ratio of the two cyclotron frequencies.

ISOLTRAP performance

The overall ISOLTRAP efficiency is in the percent range for longer-lived nuclides, and in the per mill range for nuclides with half-lives below 1 s, where decay losses during ion manipulation in the system are the limiting factor. Most losses are due to a limited acceptance of the ISOLTRAP buncher, which ranges from 1-10% [14].

The storage time in the traps causes decay losses which influence the shortest half-life of the investigated ions. The measurement cycle lasts usually about 1.5s, but it can be lowered (at cost of lower precision) for more exotic ions. So far, the shortest-lived nuclide investigated at ISOLTRAP was ^{74}Rb with a half-life of only 65 ms [17].

ISOLTRAP has single-ion sensitivity, therefore the minimum ISOLDE yield depends only on overall efficiency and decay losses during measurements. Assuming negligible decay losses and 1% buncher acceptance, ions with production yields as low as 100 ions/s can be and have already been addressed.

Precision achievable at ISOLTRAP is presently in most cases limited by systematic uncertainties. Using mass measurements with carbon clusters [15] a residual systematic uncertainty has been determined to be $8\text{x}10^{-9}$, to which a relative mass-dependent uncertainty has to be added [15] equal to $1.6\text{x}10^{-10}$ $*(m\text{-}m_{ref})$, where m is the mass of the reference ion. This allows to determine atomic masses below 10 keV precision, even for masses around A=200.

3. Overview on proposed beams

The nuclides proposed for mass-determination are presented in Table 1 together with their half-lives. Information on their availability and production at ISOLDE is given below:

$^{39\text{-}45}$S

The development of sulfur beams had been requested in a recent letter of intent by B. Blank et al. [18], where the precise measurement of the half-life of the superallowed 0+->0+ decaying nuclide ^{30}S was proposed.

Production of a molecular beam (SCO+) with a FEBIAD plasma ion source or negative ion beams (S-) with the recently developed ion source would be two alternatives to get pure beams. However, the Committee did not endorse the above LOI with the remark that other experimental groups should show interest in sulfur beams in order to support further development [19]. The case of ^{30}S was considered too hard to initiate the development. In this proposal, we ask for beams of neutron-rich $^{39\text{-}45}$S. In 2003, the yield of ^{38}S from a ZrO_2 target with a plasma ion source was measured to be around 8x10^3 atoms/μC [20]. This yield is more than sufficient to perform mass measurements at ISOLDE. Nevertheless, beam tests and target development is needed in order to show the feasibility for the very neutron-rich cases. While the molecular SCO beams could be readily investigated at ISOLTRAP, the negative ion beams require further technical modifications of the experimental setup at ISOLTRAP. The investigation of negative ion beams has started at ISOLTRAP and will be further pursued in order to be ready for possible beam tests.

$^{46\text{-}48}$Ar

These neutron-rich Ar beams can be reached with a new, very efficient arc-discharge (VADIS) ion source, with cooled transfer line, which was already used at ISOLTRAP in 2008 and which allowed to identify for the first time ^{229}Rn [13]. Because the same beams are included in another ISOLTRAP proposal, in the present proposal we don't ask for any Ar shifts, to avoid a double request.

^{138}Te

Neutron-rich tellurium beams have already been produced at ISOLDE, but the database doesn't include any data from the PSB. Yields of $^{131\text{-}134}$Te from a hot plasma UC_x target were recorded by the COMPLIS experiment, and all are in the 10^9-10^{10} ions/μC range [21]. Also ^{135,136}Te were studied in a later run by this experiment [22], however no yields were available to us. Proximity of ^{138}Te to the studied isotopes guarantees a production yield sufficient to perform studies at ISOLTRAP. The most abundant isobars observed during COMPLIS runs were Cs, I, and Sb, whose yields were comparable or lower than those of Te isotopes. Only for Cs the production of ^{138}Cs ($t_{1/2}$=33 min.) might be higher that in A=131-134 range. However, ISOLTRAP should be able to clean away this beam. In addition, the necessary mass resolving power $m/\Delta m$ to distinguish between ^{138}Te and ^{138}Cs is only 7500, which easily achievable in the ISOLTRAP Penning traps.

Rare earths: Ce, Nd, Sm, Gd, Dy, Er, Yb

Rare-earth beams have been available at ISOLDE using surface ionisation, which guarantees high efficiency. Nevertheless, this method suffers from large isobaric contamination, due to chemical proximity of neighbouring elements. ISOLTRAP can handle some isobaric contamination, as has been shown in earlier studies on neutron-deficient rare-earth nuclides and their neighbours [23]. However, the beams requested in the present proposal have unknown production yields. One can expect that when surface ionisation is used contaminants will be produced in much higher quantities than the very exotic beam of interest, and it will not be possible to clean them away using ISOLTRAP. Thus, other ion sources are required.

Pure beams of ^{150}Ce, ^{154,156}Nd, and ^{158,160}Sm were already requested in a previous ISOLTRAP proposal, P-230 [16]. Following this request the INTC committee recommended Nd and Sm beams for development (with lower priority). The present proposal, which includes more rare-earth elements than previously, is motivated by the target and ion-source development which took place since that time.

Within the new development a combination of selective laser ionisation with low work-function cavities suppressing surface ionisation has been proposed. RILIS schemes are already known for Nd, Sm, Gd, Dy, and Yb. In the case of Nd the ionisation scheme was tested in 2008 and very good results were achieved. At the end of this shutdown phase it is planned to perform similar tests for Sm. In addition, tests of the low work-function cavities will be performed by the target group during the coming online period. This would be an ideal occasion to perform production and contamination tests at ISOLTRAP.

ISOLDE production yields for these elements are available in the SC database and include isotopes closer to stability than those requested. The extrapolation is not easy, since we will use PSB and a different ionisation scheme. Therefore we would like to ask for yield tests before requesting actual shifts.

Most of the requested nuclides are rather long lived. Their half-lives are in second- and even minute-range, and only a few have ms half-lives (all above 80 ms). In this respect, the requested nuclides should be easily within reach, because For two of the listed nuclides the half-live is not known and five more nuclides haven't been yet identified. However, their half-lives are estimated to be above 500 ms [8], and ISOLTRAP has recently shown the potential to discover unknown nuclides (^{229}Rn) [13].

^{186}Hf

Hafnium yields in the ISOLDE data base come only from a Ta target (SC not PSB), but they show yields as high as $3x10^6$ for ^{180}Hf. At PSB-ISOLDE $^{177,179\text{-}184}$Hf were investigated by the NICOLE experiment, using a hot plasma Ta/W/Ir target with CF_4 in order to release the beams as a fluoride. Previously also ^{185}Hf was observed. However, no yields were given. For a more neutron-rich ^{186}Hf a target consisting of W and Ir foils might be the optimal choice.

4. Beam time request

Table 2 gives a summary of the requested beams, to be investigated over a 2-3 year period, depending on progress in target and ion-source development.

In the first part we list beams already available at ISOLDE (Hf and Te) with an estimated number of required shifts, together with a target and ion source which were already successfully used to deliver these elements.

The second part includes rare-earth beams, for which target and ion-source development has already started, and for which we request yield and contamination tests to be performed at ISOLTRAP, ideally coupled to online target tests themselves.

The last section summarises sulfur isotopes, which first require target and ion source development.

Table 2: Overview of nuclides requested in this proposal, to be investigated over a period of 2-3 years.

A	Element	Shifts	Target	Ion source
Beams available at ISOLDE: 6 shifts requested				
46-48	Ar	- *	UC_x	arc-discharge + cooled transfer line
186	Hf	3	Ta/W/Ir +CF_4	Hot plasma
138	Te	3	UC_x	Hot plasma
Rare-earth beams requiring target and ion source tests				
122-125, 150,152	Ce	-	UC_x or Ta/ low work-function cavity	RILIS
128-129, 154-156	Nd **	-		
130-134, 158-161	Sm ***	-		
134-139, 163-165	Gd	-		
140-143, 168,170	Dy	-		
148, 174	Er	-		
178,180,182	Yb	-		
Beams requiring target and ion source development				
39-45	S	-	ZrO_2 or other	FEBIAD or negative ion source

* Shifts are requested within the other ISOLTRAP proposal
** RILIS scheme tested
*** RILIS scheme to be tested during this offline period

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