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Penning-trap mass measurements on $^{92,94-98,100}_{\text{Mo}}$ with JYFLTRAP

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Abstract. Penning-trap measurements on stable $^{92,94-98,100}_{\text{Mo}}$ isotopes have been performed with relative accuracy of $1 \times 10^{-8}$ with the JYFLTRAP Penning trap mass spectrometer by using $^{85}_{\text{Rb}}$ as a reference. The Mo isotopes have been found to be about 3 keV more bound than given in the Atomic Mass Evaluation 2003 (AME03). The results confirm that the discrepancy between the ISOLTRAP and JYFLTRAP data for $^{101-105}_{\text{Cd}}$ isotopes was due to an erroneous value in the AME03 for $^{96}_{\text{Mo}}$ used as a reference at JYFLTRAP. The measured frequency ratios of Mo isotopes have been used to update mass-excess values of 30 neutron-deficient nuclides measured at JYFLTRAP.

PACS. 07.75.+h Mass spectrometers – 32.10.Bi Atomic masses, mass spectra, abundances, and isotopes

1 Introduction

Recently, a discrepancy was found between cadmium mass measurements performed at JYFLTRAP, where $^{96}_{\text{Mo}}$ was used as a reference [1], and SHIPTRAP [2] and ISOLTRAP results, where $^{85}_{\text{Rb}}$ was used as a reference ion [3]. Earlier JYFLTRAP has shown to be capable of performing very accurate mass measurements. Therefore, it was assumed that the $^{96}_{\text{Mo}}$ mass-excess value would be about 3 keV off in the Atomic Mass Evaluation 2003 (AME03) [4]. The mass evaluation done in Ref. [3] showed that there is a $-3.2$ keV shift between the AME03 value and the evaluated value for $^{96}_{\text{Mo}}$. In this work, we wanted to confirm this evaluation result by a direct mass measurement of $^{96}_{\text{Mo}}$. If the mass of $^{96}_{\text{Mo}}$ is off by 3 keV, also the neighbouring isotopes connected by $(n, \gamma)$ reactions in the AME03 are likely to be off. Thus, we decided to check the mass-excess values of all stable molybdenum isotopes and investigate where the possible 3-keV offset could come from. These measurements have a direct effect on previous JYFLTRAP results since stable molybdenum isotopes ($^{94,96,97,98}_{\text{Mo}}$) have been used as references for 30 neutron-deficient nuclides at JYFLTRAP.

2 Mass measurements

JYFLTRAP [5] is a double cylindrical Penning trap mass spectrometer for accurate mass measurements at the Ion-Guide Isotope Separator On-Line (IGISOL) facility [6, 7] in Jyväskylä, Finland. The setup consists of a Radio-Frequency Quadrupole (RFQ) cooler and buncher [8] and a double Penning-trap [9] spectrometer (see Fig. 1). In this experiment, we used an offline electric discharge ion-source at IGISOL to create singly-charged $^{85}_{\text{Rb}}$ and $^{92,94-98,100}_{\text{Mo}}$ ions.

The first trap of JYFLTRAP (purification trap) is used for the isobaric purification of the injected ion bunches by using the buffer-gas cooling technique [10]. The mass measurement is carried out in the second Penning trap (precision trap). The measurement is based on the determination of the sideband frequency of the ions of interest $\nu_{+} + \nu_{-}$, where $\nu_{+}$ and $\nu_{-}$ are the reduced cyclotron frequency and the magnetron frequency, respectively. In an ideal Penning trap this sideband frequency matches with the true cyclotron frequency $\nu_{c} = \frac{q}{2\pi m} B$ of ions with charge state $q$ and mass $m$ in the magnetic field $B$ [11]. The frequency determination was done by using the time-of-flight ion-cyclotron-resonance (TOF-ICR) technique [12]. In this method, the ion’s radial energy is increased in the trap by using an azimuthal quadrupole radio-frequency (RF) field with the cyclotron frequency of the ions. Since the radial energy of the ions is converted to axial energy in the gradient of the magnetic field when extracted from the trap, the increased energy leads to a shorter flight time to the micro-channel plate (MCP) detector. In this experiment, a Ramsey-type ion motion excitation was used [13,14] with two 25 ms long fringes.
separated by a 750 ms long waiting time. Fig. 2 shows two examples of Ramsey TOF-resonances for $^{85}$Rb$^+$ and $^{96}$Mo$^+$. The cyclotron frequency of an ion and its uncertainty are obtained from the experimental TOF data by fitting the theoretical fit function.

The mass measurement in a Penning trap is based on the measurement of the frequency ratio $r$ between a reference ion with a well-known mass and an ion of interest:

$$r = \frac{\nu_{c,\text{ref}}}{\nu_c}.$$  \hspace{1cm} (1)

3 Data analysis and results

To minimize frequency shifts coming from the drifting magnetic field, the measurements were performed by running 2 scan cycles of the ion of interest (Mo$^+$) and then 2 scan cycles of the reference ion ($^{85}$Rb$^+$) and repeating this pattern. The measured data were divided into 15-cycles-long runs. A count-rate class analysis [15], where the data were divided into classes according to the number of detected ions, was applied. The frequency was extrapolated to 0.6 ions in the trap due to the 60% detection efficiency.
Different reaction studies, such as 
been several molybdenum pairs were measured in Ref. [23] but only two 98-100 were measured by comparing mass differences of 
different CH-molecules as references [22]. Masses 92-94 and 
were measured with a mass spectrometer by using dif- 
rational measurements [20,21]. Masses 92, 94, 95, 96, 98
95, 95-96, 96-97, 97-98 were linked together with (n, 
were added quadratically. 
ited uncertainty 
and a residual uncertainty 
were added quadratically. 
Measured frequency ratios and their uncertainties are 
shown in Table 1. Birge ratios 
were close to 1 in each mass measurement set. This means that the deviations 
in the data are statistical. The used atomic mass unit is 
= 931.494 099 071 keV [18], the electron mass 
= 510.998910(13) keV [19], and the value for 
mass excess ME= 82167.331(11) keV [4]. An example of the 
measured frequency ratios is shown in Fig. 3.

4 Comparison to previous measurements

In the Atomic Mass Evaluation 2003 (AME03) the molyb- 
denum masses had three main sources. Masses 92-93, 94- 
95, 95-96, 96-97, 97-98 were linked together with (n,γ) 
reaction measurements [20,21]. Masses 92, 94, 95, 96, 98 
were measured with a mass spectrometer by using dif- 
ferent CH-molecules as references [22]. Masses 92-94 and 
98-100 were measured by comparing mass differences of 
molybdenum oxide chlorides [23]. Actually, also other 
molybdenum pairs were measured in Ref. [23] but only two 
were left in the AME03 sheets. Moreover, there have 
been several β decay measurements from both sides [24– 
31]. Different reaction studies, such as (p, n) [32–34], (p, d) 
[35], (d,3He) [36], (3He, p) [37], (3He, d) [38,39], (3He,6He) 
[40], (t, p) [41], (t, α) [42], and (n, α) [43], have also yielded 
information on molybdenum isotopes. 

In Fig. 4 all the links influencing the Mo mass-excess 
values in the AME03 are shown. Since the JYFLTRAP 
values disagreed with the AME03 values (except for 92Mo), 
a thorough comparison to earlier measurements was car- 
ried out and all possible links from and to the Mo isotopes 
in the AME03 were checked out in this work. The results 
are given below nuclide by nuclide.

The main result is that the values from Bishop et al. [23] 
disagree with the JYFLTRAP values and explain 
most of the difference between the JYFLTRAP results 
and the AME03 values. Deviations were also found to 
C7H10−94Mo [22], Nb(β−)95Mo [24], 98Mo(n,γ)99Mo 
[20,21], and 106Mo(3He,p)108Tc [37]. The (n, γ) results 
between 94Mo and 98Mo agree nicely with the JYFLTRAP 
values. JYFLTRAP mass-excess values for Mo isotopes 
suggest that these Mo isotopes are systematically too 
weakly bound in the AME03. This will also have an ef- 
effect on the nuclides which have main influences coming 
from these isotopes, such as for neighbouring Nb and Tc 
uclides or 101Mo.

92Mo

The JYFLTRAP mass value for 92Mo agrees with the values 
from C7H8−92Mo [22] and 92Mo(n,γ)93Mo [20] 
experiments, which have altogether a 78.3 % influence on 
the 92Mo value in the AME03. The JYFLTRAP value 
for 92Mo agrees with the AME03 value and other experi- 
mental data except with the data from Ref. [23]. The 
JYFLTRAP mass value for 92Mo is 6.3(22) keV higher 
than the value obtained from the mass difference of 
94Mo35Cl16O−92Mo37Cl16O [23] employing the JYFL- 
TRAP mass value of 94Mo (see Fig. 5). For 92Mo, some 
(p, n), (3He, t), (p, α) and (α,3He) experiments having un- 
certainties bigger than 20 keV have been omitted from 
Fig. 5, where the deviation from different experiments 
(MELIT) to the JYFLTRAP mass-excess value (MEJYFL) 
is shown.

94Mo

The mass value measured for 94Mo at JYFLTRAP dis- 
agrees with the AME03 value by −3.0(21) keV. Similarly 
to 92Mo, there is a 6.3(22) keV difference between the 
JYFLTRAP value and the value obtained from the mass 
difference of 94Mo35Cl16O−92Mo37Cl16O [23] employing the 
JYFLTRAP value for 92Mo (see Fig. 6). Actually, even 
even bigger disagreement is found when the AME03 value for 
92Mo is used. In addition, the value from C7H10−94Mo 
[22] gives a 5.3(31) keV higher mass-excess value for 94Mo 
than measured at JYFLTRAP. The beta-decay experi- 
ments [26-28] agree with the JYFLTRAP value but the value 
from (p, n) reactions [32] disagrees with it. The 
94Mo(n,γ)95Mo [20] agrees nicely with the JYFLTRAP 
results for 94Mo and 95Mo. A shift of about 3 keV is found 
when the AME03 value for 95Mo is used instead of the 
JYFLTRAP value.
The JYFLTRAP mass value for $^{95}$Mo is 3.3(21) keV lower than the AME03 value. The AME03 value is mainly based on the $^{94}$Mo(n,γ)$^{95}$Mo [20] and $^{95}$Mo(n,γ)$^{96}$Mo [20] values, which agree well with the JYFLTRAP results for $^{94}$Mo, $^{95}$Mo, and $^{96}$Mo. A shift is observed when the AME03 value is applied for $^{94}$Mo and $^{96}$Mo, again indicating that these Mo isotopes are systematically less bound in the AME03 (see Fig. 7). Also the value based on the beta decay $^{95}$Nb($\beta^{-}$)$^{95}$Mo [24] disagreeing with the JYFLTRAP value has an influence on the $^{95}$Mo value in the AME03.

The JYFLTRAP mass-excess value for $^{96}$Mo is 2.9(22) keV lower than the AME03 value. All reaction links in the AME03 agree with the JYFLTRAP value when JYFLTRAP mass-excess values for $^{95}$Mo and $^{97}$Mo are used (see Fig. 8). The disagreement between the AME03 value and the JYFLTRAP value comes from the erroneous mass values of $^{95}$Mo and $^{97}$Mo in the AME03.

The JYFLTRAP mass-excess value for $^{97}$Mo is 2.3(22) keV lower than the AME03 value. The JYFLTRAP value agrees with all the reaction links in the AME03 except with the values from $^{97}$Nb($\beta^{-}$)$^{97}$Mo [31], $^{98}$Mo(n,γ)$^{97}$Mo and $^{97}$Mo(n,γ)$^{98}$Mo when AME03 values for $^{96}$Mo and $^{98}$Mo are applied (see Fig. 9). The $^{97}$Nb beta decay does not have an influence on the $^{97}$Mo mass value in the AME03.

The JYFLTRAP mass-excess value for $^{98}$Mo disagrees with the AME03 value by 2.7(22) keV. The JYFLTRAP mass-excess result is in agreement with the results from $^{95}$H$_2$O$_2$–$^{98}$Mo [22] and $^{97}$Mo(n,γ)$^{98}$Mo [20], when JYFLTRAP value for $^{97}$Mo is applied (see Fig. 10). Here, again a disagreement is found when the AME03 values of $^{97}$Mo and $^{99}$Mo are used for the $^{97}$Mo(n,γ)$^{98}$Mo and $^{98}$Mo(n,γ)$^{99}$Mo reactions, indicating that the Mo isotopes have generally too high mass-excess values in the AME03.

The JYFLTRAP mass-excess value slightly disagrees with the AME03 value for $^{100}$Mo. An almost perfect agreement is found with the value based on $^{97}$Mo $^{99}$Mo [22].

### Table 1. Isotope, number of measurements, frequency ratio r, mass excess and the literature value [4] for the mass excess. Each measurement contains 15 scan cycles. The reference ion was $^{85}$Rb$^+$.  

<table>
<thead>
<tr>
<th>Isotope</th>
<th>#</th>
<th>r</th>
<th>ME(keV)</th>
<th>AME03(keV)</th>
<th>JYFL-AME03(keV)</th>
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<td>16</td>
<td>1082380355(10)</td>
<td>−86807.8(8)</td>
<td>−86805(4)</td>
<td>−2.8(39)</td>
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<tr>
<td>$^{94}$Mo</td>
<td>21</td>
<td>1010914072(12)</td>
<td>−88412.7(9)</td>
<td>−88410(2)</td>
<td>−3.0(21)</td>
</tr>
<tr>
<td>$^{95}$Mo</td>
<td>17</td>
<td>1117699950(12)</td>
<td>−87710.8(10)</td>
<td>−87707(2)</td>
<td>−3.3(21)</td>
</tr>
<tr>
<td>$^{96}$Mo</td>
<td>26</td>
<td>1129463266(13)</td>
<td>−88793.4(10)</td>
<td>−88790(2)</td>
<td>−2.9(22)</td>
</tr>
<tr>
<td>$^{97}$Mo</td>
<td>23</td>
<td>1141256082(14)</td>
<td>−87542.8(1.1)</td>
<td>−87540(2)</td>
<td>−2.3(22)</td>
</tr>
<tr>
<td>$^{98}$Mo</td>
<td>16</td>
<td>1153025857(15)</td>
<td>−88114.5(1.2)</td>
<td>−88112(2)</td>
<td>−2.7(23)</td>
</tr>
<tr>
<td>$^{100}$Mo</td>
<td>11</td>
<td>1176604185(16)</td>
<td>−86190.9(1.3)</td>
<td>−86184(6)</td>
<td>−6.6(60)</td>
</tr>
</tbody>
</table>

Fig. 4. Influences (%) of different reactions on the molybdenum mass-excess values in the AME03 [4]. The red arrows show the reactions which disagree with the results of this work. The masses of highlighted Mo isotopes were measured in this work.
instead of the value from this work.

Fig. 6. Mass excess of $^{92}\text{Mo}$ measured at JYFLTRAP compared to earlier experiments of C$_2$H$_6$–$^{92}\text{Mo}$ (Ries et al. [22]), $^{94}\text{Mo}$Cl$^{16}\text{O}$–$^{92}\text{Mo}$Cl$^{15}\text{O}$ (Bishop et al. [23]), $^{92}\text{Mo}(p,d)^{91}\text{Mo}$ (Kozub & Youngblood [35]), $^{92}\text{Mo}(\alpha,\alpha)^{89}\text{Mo}$ (Pardo et al. [40]), $^{93}\text{Tc}S_\beta$ value (Äystö et al. [25]), $^{92}\text{Mo}(\alpha,\gamma)^{93}\text{Mo}$ (Islam et al. [20]) and AME03 [4]. Bishop (1963)* employs the AME03 mass value [4] for $^{94}\text{Mo}$ instead of the value from this work.

Fig. 7. Mass excess of $^{95}\text{Mo}$ measured at JYFLTRAP compared to earlier experiments of C$_2$H$_{11}$–$^{95}\text{Mo}$ (Ries et al. [22]), $^{95}\text{Nb}(\beta^-)^{95}\text{Mo}$ (Langer & Wortman [24]), $^{95}\text{Tc}(\beta^-)^{95}\text{Mo}$ (Cretzu et al. [29], Antoneva et al. [30]), $^{94}\text{Mo}(\alpha,\gamma)^{95}\text{Mo}$ (Islam et al. [20]), $^{95}\text{Mo}(\alpha,\beta)^{96}\text{Mo}$ (Islam et al. [20]), and AME03 [4]. The values marked with * are based on the AME03 [4] mass values of $^{94}\text{Mo}$ and $^{96}\text{Mo}$. Islam (1991)* refers to $^{94}\text{Mo}(\alpha,\gamma)^{95}\text{Mo}$ value and + to the $^{95}\text{Mo}(\alpha,\gamma)^{95}\text{Mo}$ value.

Fig. 8. Mass excess of $^{96}\text{Mo}$ measured at JYFLTRAP compared to earlier experiments of C$_2$H$_{12}$–$^{96}\text{Mo}$ (Ries et al. [22]), $^{96}\text{Mo}(p,n)^{96}\text{Tc}$ (Doukellis et al. [33], Kern et al. [34]), $^{96}\text{Mo}(\alpha,\alpha)^{96}\text{Tc}$ (Comfort et al. [38]) measured at Pittsburgh (P) and at Argonne (A), $^{95}\text{Mo}(\alpha,\beta)^{96}\text{Mo}$ (Islam et al. [20]), $^{96}\text{Ru}(\alpha,\gamma)^{96}\text{Mo}$ (Wagemans et al. [40]), $^{96}\text{Mo}(\alpha,\gamma)^{97}\text{Mo}$ (Islam et al. [20], Firestone et al. [21]), and AME03 [4]. The values marked with * are based on the AME03 [4] mass values of $^{95}\text{Mo}$ and $^{97}\text{Mo}$. The value from $^{96}\text{Nb}(\beta^-)^{96}\text{Mo}$ having an uncertainty of 20 keV has been left out.
Fig. 9. Mass excess of $^{97}$Mo measured at JYFLTRAP compared to earlier experiments of $^{97}$Mo (Ries et al. [22]), $^{97}$Nb($\beta^-$)$^{97}$Mo (Rao et al. [31]), $^{97}$Mo(p,n)$^{97}$Tc (Comfort et al. [38]), $^{97}$Mo($^3$He,d)$^{98}$Tc (Comfort et al. [38], Martin & Macphail et al. [39]), $^{97}$Mo(n,\gamma)$^{98}$Mo (Islam et al. [20]), $^{98}$Mo(n,\gamma)$^{97}$Mo (Islam et al. [20], Firestone et al. [21]), and AME03 [4]. Comfort (1974) refers to $^{97}$Mo(p,n)$^{97}$Tc and to $^{97}$Mo($^3$He,d)$^{98}$Tc. The values marked with * are based on the AME03 [4] mass values of $^{96}$Mo and $^{98}$Mo.

Fig. 10. Mass excess of $^{98}$Mo measured at JYFLTRAP compared to earlier experiments of $^{98}$Mo (Ries et al. [22]), $^{100}$Mo($^{35}$Cl,$^6$O)$^{98}$Mo$^{37}$Cl$^{16}$O (Bishop et al. [23]), $^{98}$Mo(p,n)$^{98}$Tc (Comfort et al. [38]), $^{97}$Mo(n,\gamma)$^{98}$Mo (Islam et al. [20]), $^{98}$Mo(n,\gamma)$^{99}$Mo (Islam et al. [20], Firestone et al. [21]), and AME03 [4]. The values marked with * are based on AME03 [4] mass values of $^{100}$Mo and $^{97}$Mo.

Fig. 11. Mass excess of $^{100}$Mo measured at JYFLTRAP compared to earlier experiments of $^{100}$Mo (Ries et al. [22]), $^{100}$Mo($^{35}$Cl,$^6$O)$^{98}$Mo$^{37}$Cl$^{16}$O (Bishop et al. [23]), $^{100}$Mo(p,$t$)$^{102}$Mo (Casten et al. [41]), $^{100}$Mo(d,$^3$He)$^{98}$Nb (Bindal et al. [36]), $^{100}$Mo($^3$He,p)$^{102}$Tc (De Gelder et al. [37]), $^{100}$Mo(t,\alpha)$^{99}$Nb (Flynn et al. [42]), $^{100}$Mo(n,\gamma)$^{101}$Mo (Seyfarth et al. [44], Firestone et al. [21]), and AME03 [4]. The value marked with * is based on the AME03 [4] mass value of $^{98}$Mo. The values from (t,$^3$He) and $^\beta^-$ experiments have been left out due to large uncertainties.

but the values from $^{100}$Mo($^{35}$Cl,$^6$O)$^{98}$Mo$^{37}$Cl$^{16}$O [23] and $^{100}$Mo(p,$^3$He,p)$^{102}$Tc [37] influencing the AME03 value of $^{100}$Mo, deviate from our Penning trap mass measurement. In addition, the value derived from the $^{100}$Mo(n,\gamma)$^{101}$Mo [44] reaction gives a similar deviation as the AME03 value. This suggests that the AME03 value for $^{101}$Mo should be about 6.6 keV lower in order to agree with the (n, \gamma) data.

5 Updated mass values of the nuclides measured at JYFLTRAP using Mo references

Up to date, 30 neutron-deficient nuclides have been measured with respect to molybdenum reference ions at JYFLTRAP (see Refs. [1, 45, 46]). Thus, the results of this paper have an effect on these mass-excess values. The values can be easily updated by multiplying the old frequency ratio measured against a molybdenum isotope (r$_{old}$) by the frequency ratio of the corresponding molybdenum ion to $^{85}$Rb$^+$ measured in this work (r$_{Mo-Rb}$):

$$m_{new} = r_{old} m_{Mo-Rb} \cdot \left[ m(85Rb^+) - m_e \right] + m_e$$

(3)

The updated values are collected in Table 2. The Y, Zr, and Nb isotopes were measured as oxides. The uncertainties due to the isomers $^{83}$Y$^m$ (E$_x$ = 61.98(11) keV [47]), $^{84}$Y$^m$ (E$_x$ = 67 keV [48]), $^{85}$Nb$^m$ (E$_x$ $\geq$ 69 keV

$\ldots$
the values from ISOLTRAP [3]. The SHIPTRAP values for new JYFLTRAP value is obtained. The new value agrees with JYFLTRAP for Cd isotopes employing Mo as a reference. The mass-excess values determined with adjusting the old mass-excess values measured against 96Cd still disagree with ISOLTRAP and SHIPTRAP. Here, the JYFLTRAP values measured against 94Mo have been updated and new weighted means of JYFLTRAP and SHIPTRAP values have been calculated for 91Tc and 91Ru. As can be seen from Table 2, the updated values are on the average about 2.8 keV lower than the old values. This is well within the error bars.

Although the 3-keV shift in the mass excesses of Mo isotopes is less than 1σ, it is important to take it into account. For example, the Cd isotopes have been measured at SHIPTRAP [2] and ISOLTRAP [3] by using 85Rb as a reference. The mass-excess values determined with JYFLTRAP for Cd isotopes employing 99Mo as a reference [1] disagreed in some cases with ISOLTRAP and SHIPTRAP (see Fig. 12). The shift from the AME03 value in the mass of 99Mo was already observed in the mass evaluation performed in Ref. [3]. In this work, we have experimentally determined this mass value. The updated Cd values (see Table 2) agree within one standard deviation with the ISOLTRAP data. However, the SHIPTRAP values for 101,102,104Cd still deviate from the ISOLTRAP and JYFLTRAP data.

![Fig. 12. Comparison of different Penning-trap measurements for 101−106Cd with respect to the new JYFLTRAP value. After adjusting the old mass-excess values measured against 99Mo at JYFLTRAP with the 99Mo value measured in this work, a new JYFLTRAP value is obtained. The new value agrees with the values from ISOLTRAP [3]. The SHIPTRAP values for 101,102,104Cd still disagree with JYFLTRAP but the value for 103Cd agrees well with JYFLTRAP and ISOLTRAP.](image-url)

6 Conclusions

In this paper, we have reported frequency ratios between 92,94−98,100Mo and 85Rb measured with the JYFLTRAP setup. The mass-excess values of the Mo isotopes have been determined with about 1-keV precision, which is at least by a factor of 2 more precise than in the AME03. In addition, all measured stable Mo isotopes have been found to be more bound than given in the AME03. This will also have an effect on the nuclides which have main influences coming from these Mo isotopes in the AME03, such as for neighbouring Nb, Mo and Tc nuclides. 94,96,97,98Mo have been used as references for 30 neutron-deficient nuclides measured at JYFLTRAP, and thus, these values have been updated with the new molybdenum values. Although the difference to the previous values is less than 1σ, it is worthwhile to take it into account for example when comparing to results from other facilities. In addition, proton-capture rates relevant for astrophysical rp [51,52] and vp [53,54] processes depend exponentially on proton separation energies, and already a small change will have an effect on the rate. In any case, the stable molybdenum isotopes are now more accurate references for future mass measurements of neutron-deficient nuclides.

This measurement was motivated by the discrepancy in the cadmium mass-excess values between JYFLTRAP, ISOLTRAP and SHIPTRAP. An inaccurate mass-excess value of 99Mo in the literature has now been confirmed to be the reason for the deviation. This gives a perfect example why the main result from a Penning-trap measurement should be rather the frequency ratio between the reference ion and the ion of interest and its uncertainty rather than the mass-excess value itself. This way one can always use the most accurate value for the mass of the reference ion and recalculate the mass values of ions of interest.

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References

Table 2. Old mass-excess values for several neutron-deficient nuclides measured at JYFLTRAP employing Mo isotopes as references and the new values updated with the frequency ratios measured in this work. The difference between the old and new values is also tabulated. The isomer contribution has been taken into account for $^{83,84}$Y and $^{85,87,88}$Nb.

<table>
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<th>Isotope</th>
<th>Ref.</th>
<th>$\Delta$E_{old}(keV)</th>
<th>$\Delta$E_{new}(keV)</th>
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</table>

1 The original values of $−72170(6)$ keV (old) and $−72173.2(5.6)$ keV (new) were modified for an unknown mixture of isomeric states ($^{83}$Y$^{m*}$ at 61.98(11) keV [47]).
2 The original values of $−73888.8(5.2)$ keV (old) and $−73891.2(4.9)$ keV (new) were modified for an unknown mixture of isomeric states ($^{84}$Y$^{m*}$ at 67 keV [48]).
3 The original values of $−66273(7)$ keV (old) and $−66275.4(6.0)$ keV (new) were modified for an unknown mixture of isomeric states ($^{85}$Nb$^{m*}$ at $E_x \geq 69$ keV [49]).
4 Possible contribution from an isomer at 250(160)$\#$ keV [47] has not been taken into account.
5 The original values of $−73868(7)$ keV (old) and $−73871.1(6.4)$ keV (new) were modified for an unknown mixture of isomeric states ($^{87}$Nb$^{m*}$ at 3.84(14) keV [47]).
6 The original values of $−76149(7)$ keV (old) and $−76151.5(6.1)$ keV (new) were modified for an unknown mixture of isomeric states ($^{88}$Nb$^{m*}$ at 40(140) keV [47]).
7 A weighted mean of JYFLTRAP and SHIPTRAP values (see Ref. [46]). The JYFLTRAP values with $^{94}$Mo reference are $−75983.4(45)$ keV (old) and $−75986.3(4.2)$ keV (new).
8 A weighted mean of JYFLTRAP and SHIPTRAP values (see Ref. [46]). The JYFLTRAP values with $^{94}$Mo reference are $−68235.3(48)$ keV (old) and $−68238.2(4.5)$ keV (new).
44. H. Seyfarth et al., Fizika (Croatia) 22, 183 (1990).