First results using a new technology for measuring masses of very short-lived nuclides with very high accuracy: the MISTRAL* program at ISOLDE

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Abstract : MISTRAL is an experimental program to measure masses of very short-lived nuclides ($T_{1/2}$ down to a few ms), with a very high accuracy (a few 10^{-7}). There were three data taking periods with radioactive beams and 22 masses of isotopes of Ne, Na♣, Mg, Al♣, K, Ca, and Ti were measured. The systematic errors are now under control at the level of $8\text{x}10^{-7}$, allowing to come close to the expected accuracy. Even for the very weakly produced ^{30}Na (1 ion at the detector per proton burst), the final accuracy is $7\text{x}10^{-7}$.

Mistral is a new technology for measuring masses of very short-lived nuclides with very high accuracy. Accurate measurements of atomic masses particularly far from stability are crucial to put constraints on nuclear mass models and on their parameters, especially for the description of the nucleosynthesis r-process path, and to describe new structures and properties of nuclear matter in extreme isospin conditions. Given such motivations, MISTRAL was installed at ISOLDE in CERN during the summer 1997.

MISTRAL is a transmission radiofrequency mass spectrometer based on the principle defined by L.G. Smith (2). Mass-ratios are determined through cyclotron frequency-ratio measurements. When ions A and B (A=reference and B=unknown mass) are rotating in a given homogeneous magnetic field, the product of their mass

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* **M**ass measurement at **IS**olde using a **T**ransmission **Ra**diofrequency spectrometer on-**L**ine

♣ This work is part of C. Toader's thesis (1).

and their cyclotron frequency is constant: $m_A f_{c_A} = m_B f_{c_B}$. We therefore make relative measurements. f_c is determined with the help of two radiofrequency modulations of the ion kinetic energy. Ions may only reach the final detector if this radiofrequency f_{RF} is related to f_c through $f_{RF} = (n + 1/2) \cdot f_c$ (3,4,5,6). Accurate measurements require a very homogeneous magnetic field, stable in time and a good overlap of the two beam trajectories. The total transmission from the ISOLDE focal plane to the MISTRAL detector is about 1×10^{-4} and the resolving power is around 100 000.

A measurement from MISTRAL yields a spectrum of transmission versus radiofrequency. Shown in Figure 1 is a recorded peak for ^{32}Mg from the April 1999 run. The resonance frequency is derived from a triangular fit which is the theoretically expected lineshape (7).

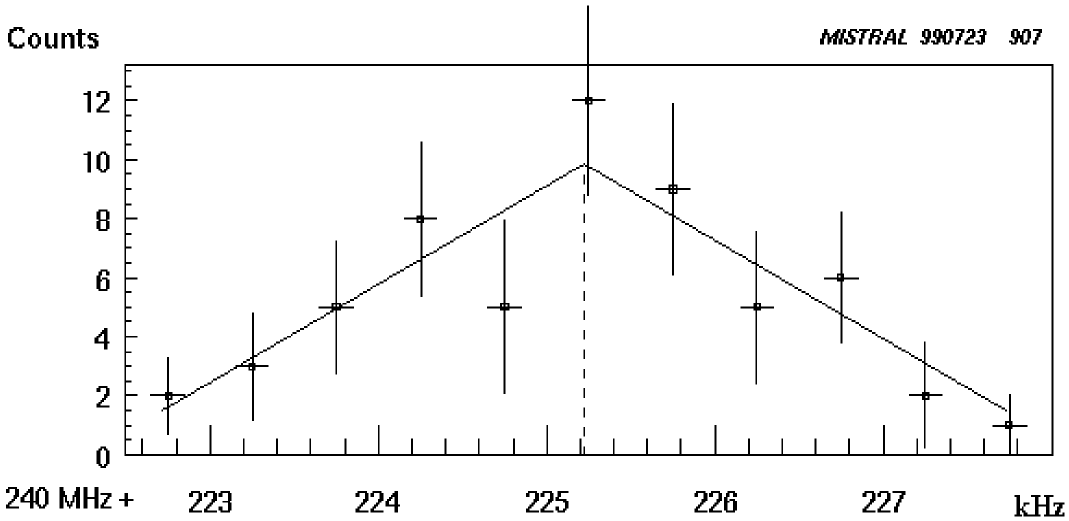

FIGURE 1. Transmission versus radiofrequency for ^{32}Mg from the April 1999 run. This nuclide is very weakly produced at ISOLDE and has a rather short half-life of only 120 ms. This measurement corresponds to 1 hour of data taking. The center accuracy is 9×10^{-7} and the resolving power is about 80 000.

During three data taking periods, the masses of isotopes of Ne, Na, Mg, Al, K, Ca, and Ti were measured. These measurements extend from the valley of stability to ^{30}Na and ^{32}Mg. Eight of them have a half-life under 1s, the shortest half-life being 31ms for ^{28}Na. Only the sodium results from the two 1998 data taking periods will be discussed here; they are part of C. Toader's thesis (1).

The uncertainties of the measurements obtained with MISTRAL are the quadratic sum of three components. First, there are the classical uncertainties due to statistics. They range from 1×10^{-7} to 9×10^{-7} for the very weakly produced ^{32}Mg. Second, the measured frequencies appear to be shifted proportionally to the mass jumps between reference (^{23}Na or ^{39}K) and unknown masses (probably due to imperfect trajectories coincidence and to insufficient homogeneity of the magnetic field). These shifts are calibrated with well-known masses. This correction introduces a calibration uncertainty of $4x10^{-7}$. Third, it was also found that for different configurations of ISOLDE and MISTRAL, inconsistencies of the results exist at the level of $7x10^{-7}$. The total precision for each single measurement ranges thus from $8x10^{-7}$ to $12x10^{-7}$. Despite the systematic errors above, most masses measured with MISTRAL have been improved.

Figure 2 shows a comparison between the MISTRAL results and the AME’95 mass table (8) for sodium isotopes and ^{27}Al. The well-known masses, used as calibrators, ^{23}Na, ^{24}Na, ^{25}Na and ^{27}Al measured against ^{23}Na and ^{39}K are in very good agreement with the table. The precision for the other sodium masses ranges from 10 keV to 22 keV for ^{30}Na. The agreement with the AME’95 mass table is fair with the exception of ^{30}Na as discussed below. We improve the error on all these masses and the comparison of our results with the 1995 mass table has a consistency of 0.9 standard deviation which gives confidence in the MISTRAL measurements.

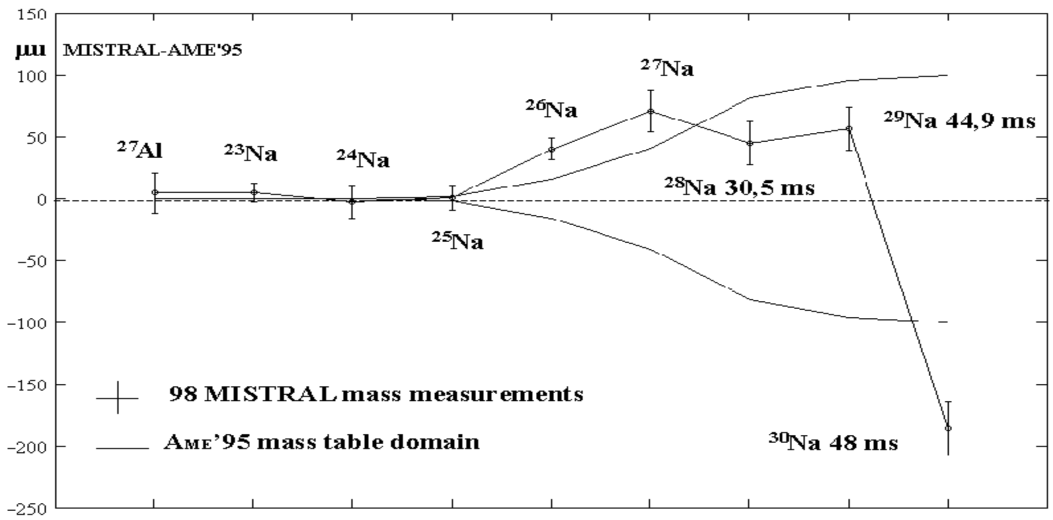

FIGURE 2. Comparison between the MISTRAL results and the AME 1995 mass table for sodium isotopes and ^{27}Al. The zero line is for the mass table values and the two symmetrical lines represent the limits of their error.

Prior to our work, six other measurements of ^{30}Na were performed using various methods (Fig. 3). MISTRAL has a very small error bar of 20 keV compared to 150 keV and up for the others. Thus almost one order of magnitude has been gained, but MISTRAL seems to have a shift of –200 keV compared to the AME’95 table. Examining more closely the ^{30}Na results, it appears that the TOFI 91 measurement (9) had the most important contribution in the 1995 mass adjustment and is responsible for this disagreement. Apart from the two TOFI measurements (9,10), all data are in agreement with the MISTRAL result.

Using a RF mass spectrometrer, accurate determination of masses of very short-lived sodium nuclides were obtained. Other data are being analysed. Measurements on isotopes in the area of the next neutron shell closure at N=28 will complete this phase of the MISTRAL program at ISOLDE (11). Improvements are planned to increase sensitivity and to minimize the systematic frequency shift. The measurement program will then be focused on heavier, very short-lived, neutron-rich isotopes towards the stellar nucleosynthesis r-process path and also nuclides close to the proton dripline of interest for nuclear structure studies.

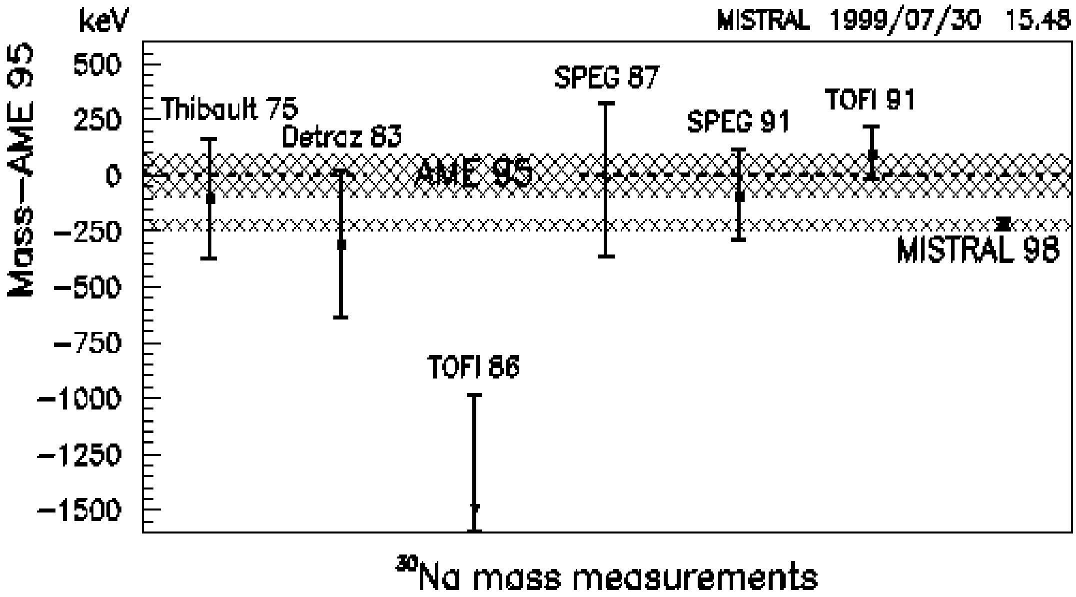

FIGURE 3. All measurements of ^{30}Na including MISTRAL value are compared to the AME'95 values (AME'95 dashed area). MISTRAL has an error bar of only 20 keV. Thibault75, mass spectrometry (12); Detraz83, Q_β (13); TOFI86, time of flight (10); SPEG87, time of flight (14); SPEG91, time of flight (15); TOFI91, time of flight (9); MISTRAL98, RF mass spectrometry (this work).

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