Changes of the ashes of an X-ray burst due to better known nuclear masses*

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The masses of ten proton-rich nuclides, among them the N=Z+1 nuclides ^{85}Mo and ^{87}Tc, relevant for nucleosynthesis modelling were measured with the Penning trap mass spectrometer SHIPTRAP [2]. Significant deviations in the mass values and separation energies compared to the values of the Atomic Mass Evaluation 2003 [1] (AME03) were found. The new experimental mass data were implemented in the Atomic Mass Evaluation and adjusted mass values were obtained following the procedure employed in [3]. Moreover, a new local (80$\leq A \leq$95) mass extrapolation based on the adjusted mass values was made using the methods and programs of [3]. Together with the new set of evaluated experimental data and the previously reported AME03 extrapolated mass values for A<80 and A>95 these data form a complete updated mass data set (AMEup).

To explore the impact of the new masses on the rp process in X-ray bursts reaction network calculations using the model of [4] were carried out. The baseline calculation uses the nuclear masses of the AME03 and calculated Coulomb mass shifts [5] for nuclides beyond N=Z. The results are compared to network calculations based on AMEup, combined with the same Coulomb mass shifts. The resulting final abundances show large differences between AME03 and AMEup in the region of A=86-96. The largest change is found for A=86 where the abundance increases by a factor of 20 (Fig. 1) due to an unexpectedly large decrease in S_p of ^{87}Tc. This change by a factor of 20 is by far the largest observed for abundances produced in rp process network calculations since the AME 2003 evaluation. It demonstrates that nuclear physics uncertainties can be larger than estimated and can introduce large uncertainties in nucleosynthesis model calculations.

The new results also open up the possibility for the formation of a ZrNb cycle induced by large ^{84}Mo(γ,α) or ^{83}Nb(p,α) reaction rates. For a given S_α value of ^{84}Mo the cycle will form at a sufficiently high temperature, effectively providing an upper temperature limit for any rp process along the proton drip line to produce nuclei beyond A=84, including the light p-nuclei in the A=92-98 mass region. In order to explore this temperature limit, reaction network calculations were performed using a small test network with an initial ^{82}Zr abundance. For a S_α of ^{84}Mo lowered by one standard deviation a significant cycling was found beginning at 1.5 GK. However, calculations with the full X-ray burst model, which reaches peak temperatures of 2 GK, show that a cycle does not occur, because at the required high temperatures the reaction sequence already stops at ^{56}Ni. Nucleosynthesis proceeds beyond ^{56}Ni during burst cooling only when the temperature is lower than required to form a ZrNb cycle. The formation is nevertheless a possibility in an environment where the temperature is rising slowly enough to enable the rp process to proceed past ^{56}Ni before reaching high temperatures. Another possibility would be an rp process with seed nuclei beyond ^{56}Ni.

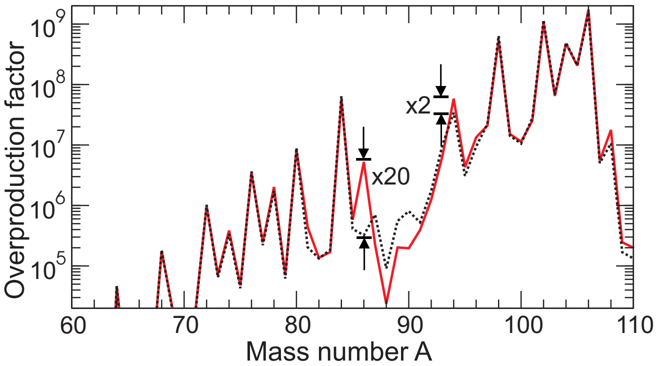

Figure 1: Calculated overproduction factors (produced abundance divided by solar system abundance) after an X-ray burst for the AME03 (dotted line) and the AMEup (solid line) mass sets.

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References

[1] G. Audi *et al.*, Nucl. Phys. A **729**, 337 (2003).

[2] E. Haettner *et al.*, GSI Scientific Report 2008 (2009) 134.

[3] A.H. Wapstra *et al.*, Nucl. Phys. A **729**, 129 (2003).

[4] H. Schatz *et al.*, Phys. Rev. Lett. **86**, 3471 (2001).

[5] B.A. Brown *et al.*, Phys. Rev. C **65**, 045802 (2002).