CYCLOTRON INSTITUTE
TEXAS A&M UNIVERSITY

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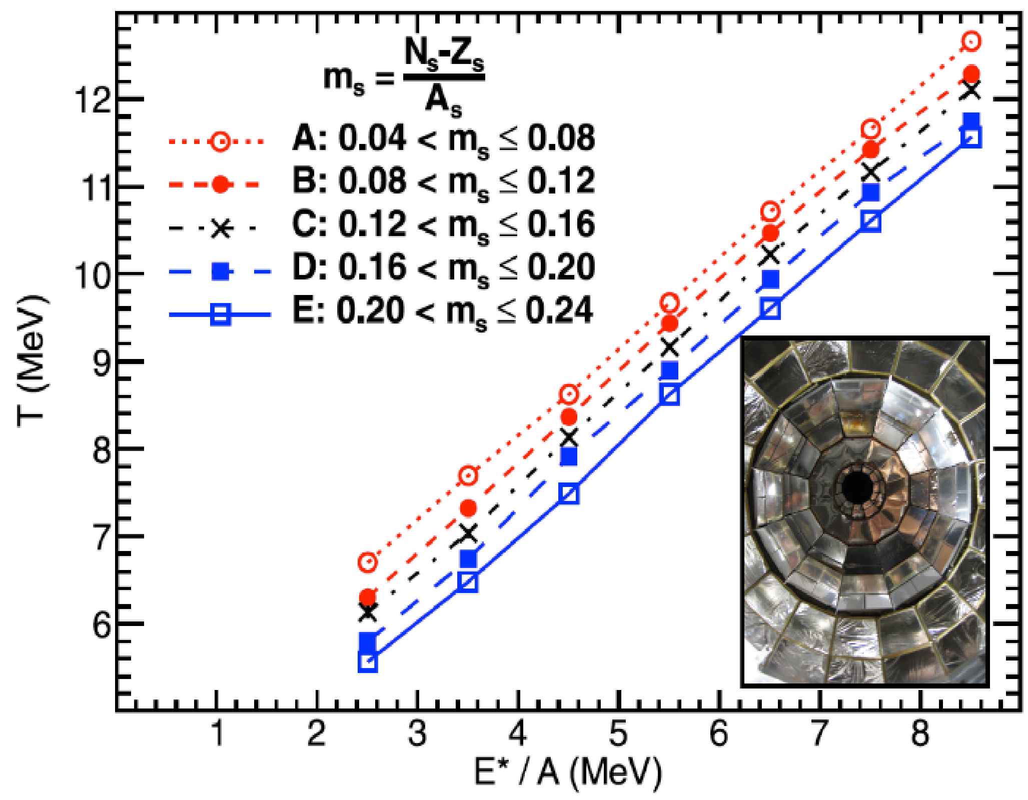
It's Cooler With More Neutrons

Observing how the thermodynamic properties of nuclei change with composition

THE SCIENCE
The nuclear equation of state describes thermodynamic relationships for extremely dense matter ($\rho > 10^{13}$ g/cm^3). Improving our knowledge of the relation between temperature, internal energy, density, pressure, and chemical potential provides insight into physical processes on the most extreme scales, from the creation of elements in supernovae to femtonova created in modern particle accelerators. The caloric curve for nuclei, the relation between temperature and internal energy, has demonstrated features suggesting a liquid-gas phase transition.

THE IMPACT
We have experimentally measured a dependence of the nuclear caloric curve on the composition of the material. Increasing the neutron content decreases the temperature observed for a given internal energy. These results can guide the development of models with more realistic equation of state.

SUMMARY
We have measured reaction products produced in collisions of nuclei in the A=70 mass range with the NIMROD-ISiS array at Texas A&M University. The complete geometric coverage, the superb isotopic resolution, and the simultaneous measurement of the free neutrons all prove crucial to our result. The reaction products are used to reconstruct the excited projectile-like fragment immediately following its collision with the target. The mass, charge, excitation energy, and temperature of this highly excited nuclear material are extracted. As we increase the internal energy of the nuclear material, the temperature rises monotonically as the nuclear material approaches its boiling point. The striking new feature we observe is that increasing the neutron content lowers the temperature significantly for a given amount of internal energy. To date, theoretical models disagree on whether the temperature should rise, fall, or remain the same. This measurement of the composition dependence of the nuclear caloric curve can constrain theoretical models and lead to an improved understanding of the nuclear equation of state.



Data Chart: We observe the caloric curve from nuclei exhibits decreasing temperatures for increasing neutron content. **Photo inset:** NIMROD Detector Array.

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PUBLICATIONS
A.B. McIntosh et al. "Asymmetry Dependence of the Nuclear Caloric Curve," Physics Letters B 719, 337 (2013).

A.B. McIntosh et al. "Using Light Charged Particles to Probe the Asymmetry Dependence of the Nuclear Caloric Curve," Phys. Rev. C 87, 034617 (2013).

A.B. McIntosh et al. "How Much Cooler would it be with Some More Neutrons? Exploring the Asymmetry Dependence of the Nuclear Caloric Curve and the Liquid-Gas Phase Transition," Euro. Phys. J. A 50, 35 (2014).

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ABOUT THE CYCLOTRON INSTITUTE: *Dedicated in 1967, the Cyclotron Institute serves as the core of Texas A&M University's accelerator-based nuclear science and technology program. Affiliated faculty members from the Department of Chemistry and Department of Physics and Astronomy conduct nuclear physics- and chemistry-based research and radiation testing within a broad-based, globally recognized interdisciplinary platform supported by the United States Department of Energy (DOE) in conjunction with the State of Texas and the Welch Foundation. The facility is one of five DOE-designated Centers of Excellence and is home to one of only five K500 or larger superconducting cyclotrons worldwide.*