THERMAL EFFECTS ON ICE OF IMPACTS ON THE LUNAR SURFACE.  J. D. Walker¹, S. Chocron¹ and W. Gray¹, ¹Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78238 jwalker@swri.edu, schocron@swri.edu and wgray@swri.edu.

Introduction: High speed impacts of celestial bodies typically involve large residual energies deposited in the impactor and the possibility of phase changes due to the residual energy. However, at lower impact speeds, there is the possibility of ice impacts not resulting in vaporization of the ice. The velocity regime where ice could be expected to survive as ice or liquid water was explored with the computational hydrocode CTH [1] using a number of different equations of state for water. The velocities are relatively low, on the order of 1 to 3 km/s, depending on various specifics. The computations include the shock loading of the ice impactors and then the subsequent adiabatic unloading leading to deposited internal energies.

The post-impact material state information is of interest in answering questions related to residual ice remaining on the Moon from historical impacts and also the possibility of engineered impacts to redirect ice-rich near-Earth objects into the Moon for human use.

Ice/Water/Vapor Equations of State: One of the difficulties in this analysis is that a wide range of material density-energy states can be accessed by the impact. Different parts of the impactor undergo different deformation histories and thus different thermal histories and residual internal energies. Computations were performed first looking at the worst case scenario – the impact of ice on a rigid surface – to understand the variability in the predications from several available equations of state. Typically equations of state for ice and water used in the impact physics community have been calibrated on one-dimensional shock data. This data does not include unloading information. For example, Fig. 1 shows temperature curves for an analytic equation of state for ice [2] assuming the ice impactor begins at 120°K for various points within an ice impactor. The ice strikes the rigid surface at 1.5 km/s. Near the impact interface, the residual temperature in the ice is such that the material in that regime would vaporize after unloading. However, for the material half way through the impactor and beyond, the material is roughly at 325°K and thus would be liquid water after the impact.

Impacting Lunar Material: Actual impacts into lunar material lead to lower impact pressures than impacts on a rigid surface. Thus, the resulting residual energies are less. As an example, Fig. 2 shows the impact of ice into lunar rock with properties of rock beneath the regolith based on information from seismic data from the Apollo program. The impact is at 2 km/s and shows material in the post-impact state at around 310°K. Thus, liquid water is expected for a lunar rock impact at 2 km/s with a lower temperature than the rigid surface impact at 1.5 km/s. For large ice impactors, impacts into the rock material are most relevant as the regolith only provides a small buffer.

The lunar surface has a regolith layer (8-12 m). Impacts into this regolith layer produce lower pressures than impact into the rock. As an example, Fig. 3 shows the impact of ice into a rough material model of the regolith at 3 km/s, and shows that after the impact there is water at 325°K. If the impactor is small compared to the regolith layer, impacts in the range of 3 km/s can lead to liquid water or ice.

Finally, Fig. 4 shows a geometry plot of the impact of an ice impactor into the lunar rock at 4 km/s showing considerable vaporization of the ice.

For low velocity impacts, experimentally when ice impacts (except at extremely low velocity) it always shatters [3]. Thus, no large contiguous original piece of ice would be expected, but the post-impact liquid water will boil due to the vacuum environment and as vapor escapes the temperature in the remaining water drops until it freezes leaving solid ice.

Figure 2: Temperature evolution of ice impacting lunar rock at 2 km/s.

Figure 3: Temperature evolution of ice impacting lunar regolith at 3 km/s.

Figure 4: Material (left, block colors) and density (right, logarithmic scale) plot 30 ms after impact of ice at 4 km/s into lunar rock, showing vaporization of the ice. The blue material is ice/water/vapor.