SAND2010-5560P

Shock Compression of Liquid He and He-H Mixtures

David L. Hanson, Andrew J. Lopez, Marcus D. Knudson, Keegan P. Shelton

Sandia National Laboratories

Problem

The primary problem addressed by this LDRD is the development of a cryogenic system to generate liquid He samples for high precision EOS and isentropic compression measurements using the Z accelerator current drive.

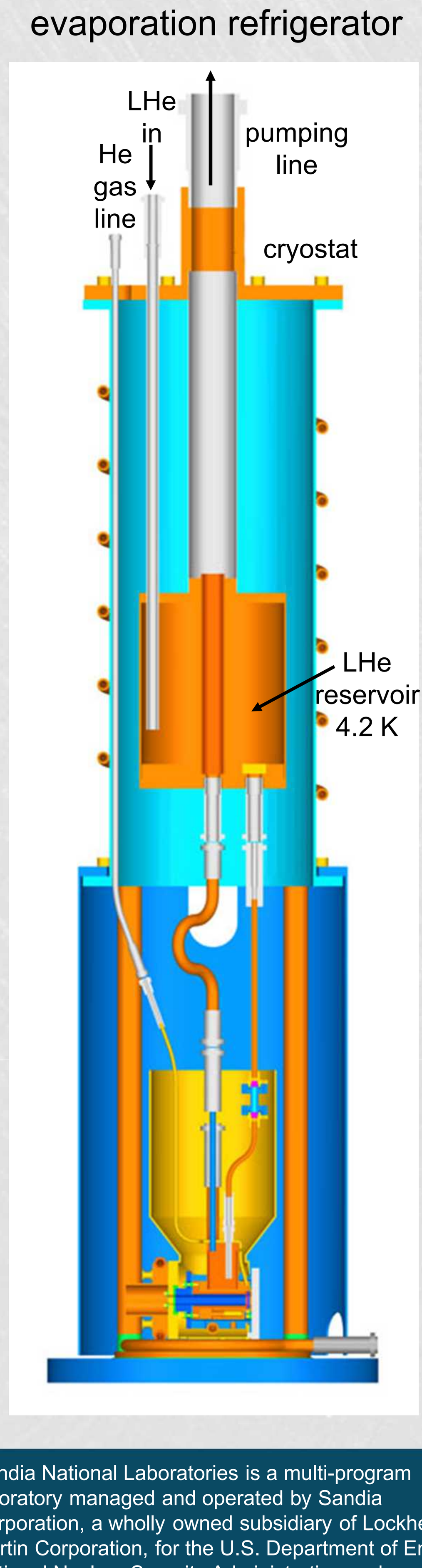
The properties of dense He and He-H mixtures in the Mbar pressure regime are critical to understanding the internal structure, origin, and evolution of the Jovian and extrasolar giant planets. Liquid He (LHe) data have been obtained at lower pressures using conventional gas gun techniques, but recent first principles calculations suggest a significant increase in compressibility (max 5.5 fold compression) just beyond the available data. More recent results using the Omega laser suggest even higher compressibility (max 7-fold at ~100 GPa). This pressure regime is well within the range of dynamic experiments at the SNL Z facility. Given the long standing controversy surrounding the compressibility of liquid D_2, it would be highly beneficial to obtain similar experimental results on LHe with the mature Z platform. Data on He-H mixtures would also provide insight into the structure of giant planetary interiors and into the proper mixing method approach for global equation of state (EOS) models.

Limited high pressure He EOS data exist because of the difficulty of condensing LHe samples at very low temperatures on gas guns, magnetic and explosive compression devices, and lasers. The present approach to condensing LD_2 samples at 20 K on Z cannot access the required temperature range of < 3.5 K because the large standoff of the cooling source from the sample holder (to allow cryostat survival) is not feasible for an ultra-low temperature system. The existing sample holder assembly also lacks adequate radiation shielding to minimize heat loading. The primary goals of this LDRD are: (1) to identify a suitable cooling method for condensing LHe samples in an appropriate geometry for high precision EOS and isentropic compression experiments on Z; and (2) to develop a detailed design and prototype test hardware to demonstrate the feasibility of generating LHe samples for Z experiments.

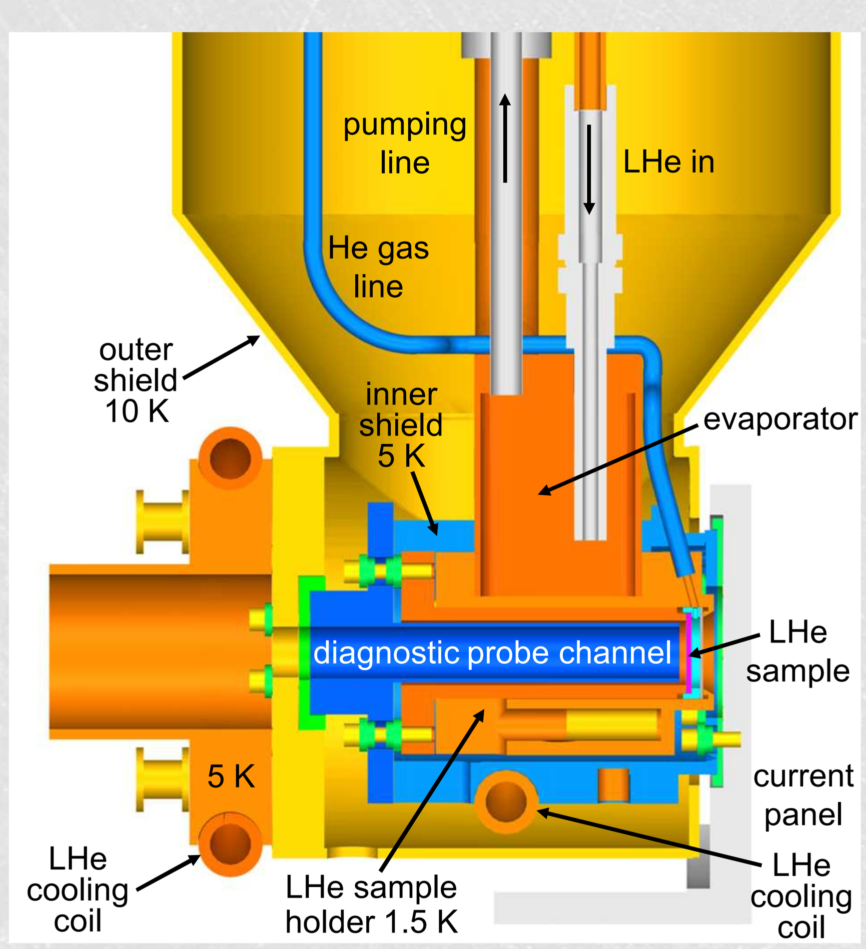
Approach

To achieve a quiescent (bubble-free) LHe sample, it is desirable to cool the liquid below the lambda point (2.176 K) for transition to the ^{4}He superfluid state. A conceptual design for an extreme low temperature (1.5 - 2 K) cryocell for the Z environment was developed by analyzing a number of cryogenic techniques for cooling objects to 1.5 K in light of the unique requirements for dynamic material experiments on Z. Because ~1.5 MJ of energy is released at the sample location during a Z shot, the cryocell and nearby components will be destroyed, and systems of high complexity or cost must be avoided. The design concept finally chosen configures the sample holder as a continuously operating, self-regulating ^{4}He evaporation refrigerator with a pumped-He bath and an independent He sample cavity fed by a gas line. This arrangement has been shown in other applications to maintain constant sample temperatures in the presence of a variable heat load for extended periods without external control. Temperatures below the normal boiling point of LHe (4.2 K) are achieved in the LHe bath by pumping on the vapor above the liquid. When the bath is pumped, LHe is drawn from the main cryostat reservoir through a flow impedance, where He gas expands into the lower pressure region, cools, and recondenses. The flow impedance maintains the pressure difference between the main reservoir (760 Torr at 4.2K) and the evaporator chamber (3.6 Torr at 1.5 K). Multiple radiation shields directly cooled by LHe and LN_2 are provided to minimize the heat load.

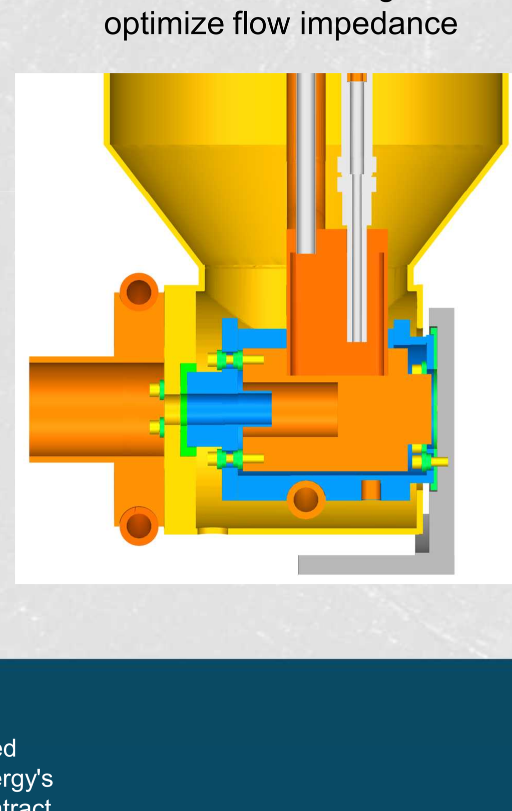
Continuously operating, self-regulating ^{4}He evaporation refrigerator



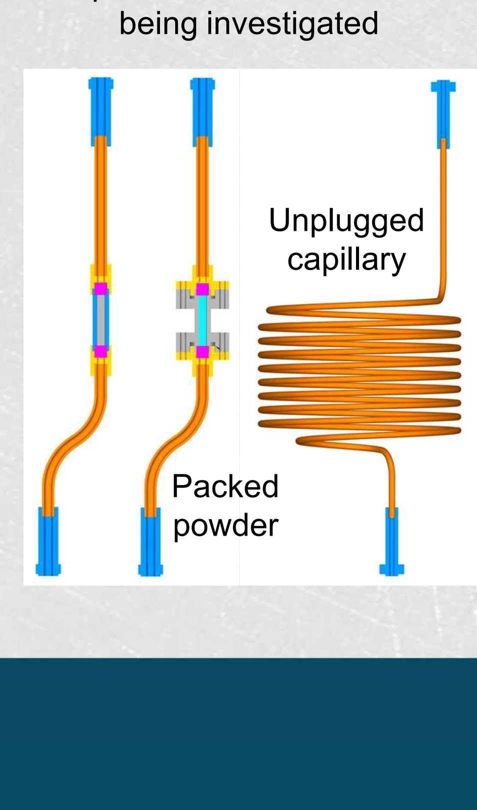
Full cryocell to demonstrate LHe sample condensation and optimize extruded Indium cryogenic vacuum seals



Simplified test cell to demonstrate cooling and optimize flow impedance



Several designs for flow impedance assemblies are being investigated



Results

The key R&D accomplishments of this LDRD include:

(1) development of a conceptual design for an expendable cryogenic system of resonable cost and complexity to condense a large area superfluid LHe sample for dynamic high pressure experiments in an EOS or isentropic compression geometry on Z;

(2) development of a detailed final design and drawing package for *basic cooling test* and *liquid sample holder* cryogenic system configurations;

(3) development and fabrication of flow impedance components structured to operate over a wide range of flow impedance values and cooling power;

(4) fabrication, assembly, and instrumentation of prototype systems for both the *basic cooling test cell* and the *liquid sample holder cryocell* configurations - testing of prototype assemblies for demonstration and optimization of LHe sample cooling is currently in progress;

(5) development and demonstration on Z of techniques for generating high pressure H fluid samples in the temperature and pressure range relevant for Z experiments with He-H mixtures.

Significance

Implementation of this new cryogenic capability on Z will: (1) impact DOE strategic needs in nuclear weapons stewardship by enabling very accurate EOS measurements of material relevant to the Nuclear Weapons program; and (2) enhance the capacity of the Z facility for world class basic research of extreme interest to both theoretical physicists and astrophysicists.

The dynamic compression capability developed on Z has become a mature platform, enabling material dynamic experiments in the Mbar pressure regime with unprecedented accuracy. Use of the extreme low temperature cryocell for condensing pure LHe samples on Z will provide additional visibility for this Z dynamic materials capability in areas of both programmatic and basic science interest.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

SAND 2010-xxxP