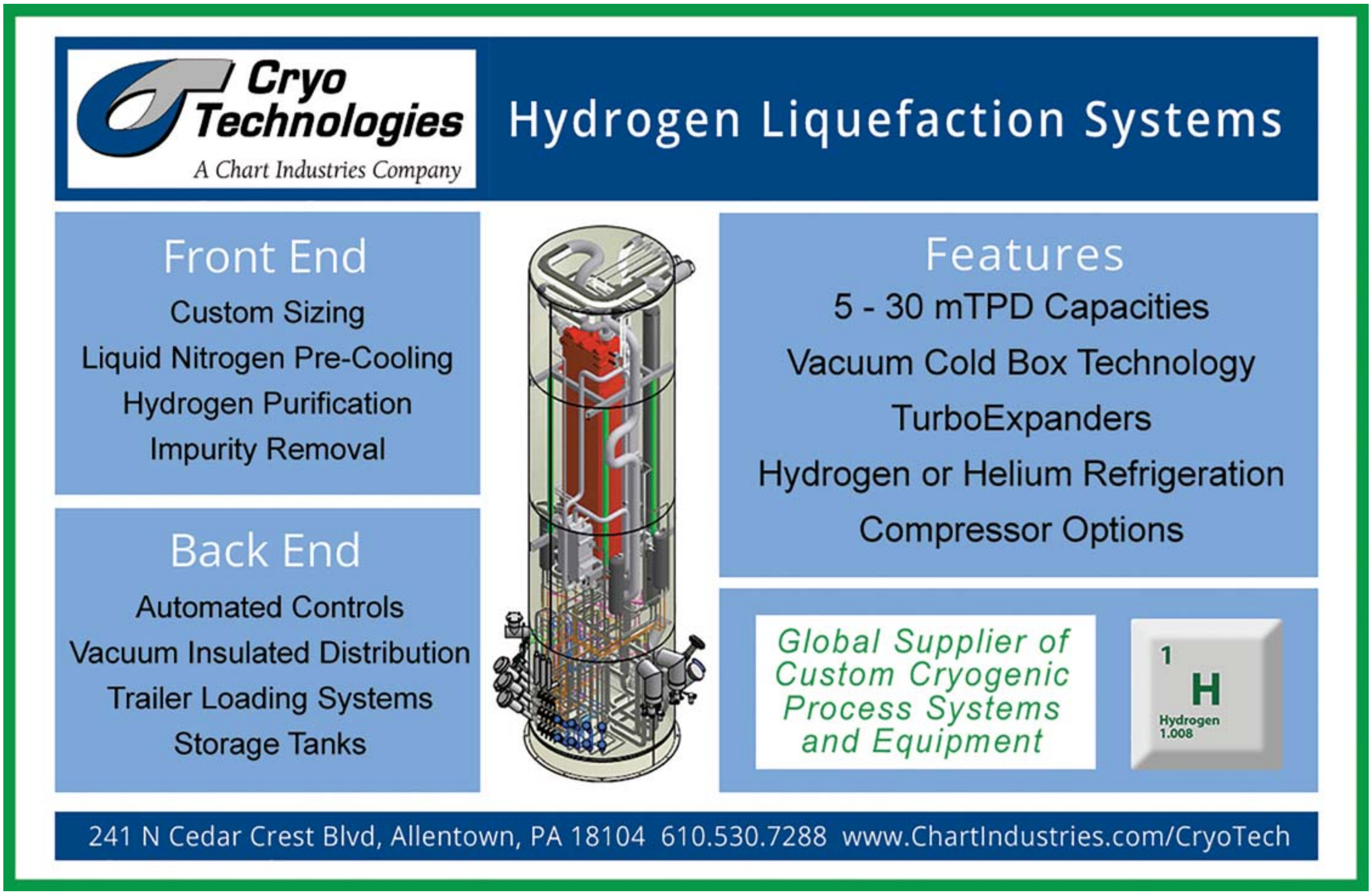
Biobank Tackles Animal Extinction 10
Revolutionizing Structural Biology 11
Temperatures Colder Than Space 15
Oxygen Deficiency Safety in Cryo Labs 20
The Study That Could Save Lives..............................24
New Company with a 25-year Lead.........................33

Cold Facts INTERNATIONAL

The Magazine of the Cryogenic Society of America, Inc.

NASA's Bubble Lab Experiments with Exotic Matter | 8

Volume 38 Number 4 2022


Cryo Technologies
A Chart Industries Company
Hydrogen Liquefaction Systems
Front End
Custom Sizing
Liquid Nitrogen Pre-Cooling
Hydrogen Purification
Impurity Removal
Back End
Automated Controls
Vacuum Insulated Distribution
Trailer Loading Systems
Storage Tanks
Features
5 - 30 mTPD Capacities
Vacuum Cold Box Technology
TurboExpanders
Hydrogen or Helium Refrigeration
Compressor Options
Global Supplier of Custom Cryogenic Process Systems and Equipment
1
H
Hydrogen
1.008
241 N Cedar Crest Blvd, Allentown, PA 18104 610.530.7288 www.ChartIndustries.com/CryoTech


PHPK TECHNOLOGIES
WHEN PERFORMANCE AND RELIABILITY MATTER
• Cold boxes
• High vacuum chambers
• Pressure vessels
• Cryostats
• Helium compressor skids
• Thermal shrouds
• Thermal conditioning units
• Vacuum insulated piping
• Valves
• Couplings
CVI Torr Master®
• Cryopumps
• Cryocoolers
Proudly Manufactured in the USA
info@phpk.com
(614) 486 4750
www.phpk.com

Strength in Numbers

A legacy of reliability. Proven performance.

For over half a century, researchers have turned to the SHI Cryogenics Group for the latest advancements in cryogenic technology. We think the numbers speak for themselves:

- Consistent reliability in **thousands of systems** worldwide
- Proven performance in **hundreds of applications**
- Over **five-hundred employees** around the world
- A full range of products, with over **forty models**
- A global installed base, supported by **twelve international offices**
- **One important customer: you**

Visit us anytime, worldwide. www.shicryogenics.com

Asia
Sumitomo Heavy Industries, Ltd.
Phone: +81 3-6737-2550 • cryo@shi.co.jp

Sumitomo (SHI) Cryogenics Shanghai, Ltd.
Phone: 86 21-54866318 • ZCryo_ChinaSales@shi.co.jp

Sumitomo (SHI) Cryogenics Korea, Co., Ltd.
Phone: +82 31 278 3050 • Won_Bum_Lee@shi.co.jp

Sumitomo (SHI) Cryogenics Taiwan Co., Ltd.
Phone: +886 3 561 2101/2557

Europe
Sumitomo (SHI) Cryogenics of Europe, Ltd.
Phone: +44(0) 1256 853333
uksales@shicryogenics.co.uk

Sumitomo (SHI) Cryogenics of Europe, GmbH
Phone: +49 (0) 6151 860 610
contact@sumitomocryo.de

United States
Sumitomo (SHI) Cryogenics of America, Inc.
Phone: +1 610-791-6700
sales@shicryogenics.com

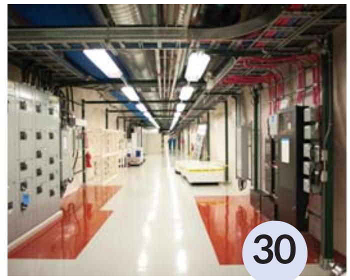
Join Our Growing Family of CSA Corporate Sustaining Members

Get connected to the cryogenic community worldwide.
Let your voice be heard and your contributions known.

Abbess Instruments and Systems, Inc.
Ability Engineering Technology, Inc.
Acme Cryogenics, Inc.
Ad-Vance Magnetics
Advanced Research Systems, Inc.
Advanced Valve & Instrument Inc.
Aerospace Fabrication & Materials
Air Liquide advanced Technologies
Alloy Valves and Control
American Magnetics, Inc.
Amuneal Manufacturing Corp.
API Technologies
Argonne National Laboratory
Atlas Technologies
Barber-Nichols Inc.
Beyond Gravity GMBH
Bluefors
Brugg Rohrsysteme Gmb
Canadian Nuclear Laboratories
CCH Equipment Company
Chart Inc.
Clark Industries, Inc.
Coax Co., LTD.
CoolCAD Electronics, LLC
CPC-Cryolab, an MEC Company
Creare LLC
Criotec Impianti SpA
Cryo Industries of America
Cryo Service LTDA
Cryo Technologies
Cryoco LLC
CryoCoax
Cryocomp
CryoEdge*
Cryofab, Inc.
Cryogas Tech Sdn. Bhd.
Cryogenic Control Systems, Inc.
Cryogenic Institute of New England
Cryogenic Limited
Cryogenic Machinery Corporation
Cryoguard LLC
Cryomagnetics, Inc.
Cryomech, Inc.
Cryonova Process Systems, LLC
CryoSRV, LLC
Cryotechnics LLC*
CryoVac GmbH
CryoWorks, Inc.
Cryoworld BV
CSIC Pride (Nanjing) Cryogenic Technology Co., Ltd.
Danaher Cryogenics
Demaco Holland BV
Dependable Truck & Tank Limited
DMP CryoSystems, Inc.
EPSIM Corporation
Equigas, Inc.
Essex Industries
Eta Space
Fabrum Solutions
Facility for Rare Isotope Beams—Michigan State University
Fermi National Accelerator Laboratory
Fin Tube Products, Inc.
Gardner Cryogenics
Gas Equipment Company
GasLab
GenH2
HPD–a FormFactor Company
HSR AG
IC Biomedical
ILenSys Technologies*
Imtek Cryogenics
Independence Cryogenic Engineering, LLC
Indium Wire Extrusion
JanisULT
Kelvin International Corporation
KEYCOM Corporation
kiutra GmbH
Lake Shore Cryotronics, Inc.
Lihan Cryogenics
Linde Cryogenics, Division of Linde Engineering North America Inc.
Lydall Performance Materials
Magnatrol Valve Corporation
Magnetic Shield Corporation
Marathon Products, Inc.
Meyer Tool & Mfg., Inc.
Micro Harmonics Corporation
Midalloy
Molecular Products, Inc
NASA Kennedy Cryogenics Test Laboratory
National High Magnetic Field Laboratory
Nexans Deutschland GmbH
Nikkiso Cryogenic Industries
Niowave, Inc.
Oak Ridge National Laboratory
Omegaflex
Oxford Instruments NanoScience
Paragraf Limited
PBS Velka Bites
Penflex
PHPK Technologies
Quantum Design, Inc.
Ratermann Manufacturing, Inc.
RegO
RIX Industries
Rockwood Composites
Rutherford & Titan, Inc.
Sauer Compressors USA
Scientific Instruments, Inc.
shirokuma GmbH
Sierra Lobo, Inc.
SLAC-National Accelerator Laboratory
Space Dynamics Laboratory
Spectrum Specialty Valves
SPS Cryogenics BV
STAR Cryoelectronics
Stirling Cryogenics BV
Stöhr Armaturen GmbH & Co. KG
Sumitomo (SHI) Cryogenics of America, Inc.
Sunpower, Inc.
SuperPower, Inc.
Technifab Products, Inc.
Technology Applications, Inc.
Tempshield Cryo-Protection
The Aerospace Corporation
The Phoenix Company of Chicago
Thermal Management Technologies
Thermal Space
Thomas Jefferson National Accelerator Facility
TRIUMF
Turbines Inc.*
Vacuum Barrier Corporation
Vacuum Energy Inc.
Valcor Engineering Corporation
Web Industries
WEKA AG
West Coast Solutions
XMA Corporation

* New member since last issue

Inside This Issue



FEATURES

8 NASA's Cold Atom Lab Experiments with Exotic State of Matter

10 Living Biobank Could Revive Species Facing Extinction

11 Cryo-EM Revolutionizes the Field of Structural Biology

14 Two Virginia Tech Research Labs Poised to Transform Society

15 Temperatures Colder Than Space, Achieved on Earth Through X-ray Laser

18 Efficiency and Safety Come First in Cryometrix Upright Liquid Nitrogen Biorepositories

20 CO2Meter Tackles Oxygen Deficiency Safety in Cryogenic Laboratories

22 AltoNovus Makes Measurement Easier with Handheld Ohmmeter

30 Extreme Cool - Making Liquid Nitrogen in a Deep Underground Clean Lab

36 Keeping Cool at ICC22– International Cryocooler Convention Recap

38 Book Announcement: *Cryogenic Heat Management–Technology and Applications for Science and Industry*

40 Book Review: *Helium: Its Creation, Discovery, History, Production, Properties and Uses*

44 A Lifetime Legacy in Space Cryogenics: Remembering Ted Nast

ON OUR COVER

Astronaut Christina Koch unloads new hardware for the Cold Atom Lab aboard the International Space Station. *Credit: NASA/JPL-Caltech*

In all instances, "CSA CSM" indicates a Corporate Sustaining Member of CSA.

COLUMNS

6 Executive Director's Letter

24 Cool Cryo Guests: Cryogenic Bubble Interaction: Challenges, Motivation and Potential Benefits in Cryosurgery

26 Cool Fuel: Hydrogen's Massive Sensing Challenges

27 Cryo Bios: Heinz London

28 Space Cryo: High Capacity 20 K Cryocooler Developments for In-Space Applications

31 Look who's NEW in the Cold Facts Buyer's Guide

SPOTLIGHTS

33 Danaher Cryogenics–A Quarter-Century Industry Experience Brings About New Company

34 Space Dynamics Lab Answers Whether We Are Alone in the Cosmos

35 iLenSys Technologies Shares Engineering Design and Digital Services with the Cryo Industry

39 Fabrum Solutions and AFCryo Merge to Create Fabrum

42 PRODUCT SHOWCASE

45 PEOPLE & COMPANIES

45 CALENDAR

Cold Facts

Cold Facts Magazine

Editor
Anne DiPaola

Advertising Coordinator
Joe Sullivan

Online Marketing Manager
Jo Snyder

Graphic Designer
Israel Reza

Cold Facts (ISSN 1085-5262) is published six times per year by the Cryogenic Society of America, Inc.

From the Executive Director

Here we are – another month has passed, and it's already almost fall. It never ceases to amaze me how quickly the warm summer weather comes and goes! I hope you all had a wonderful summer and found some time to relax with family and friends.

As the fall approaches, we are finalizing our plans to head to Honolulu for the Applied Superconductivity Conference (ASC). The program for ASC 2022 has been announced, and it looks to be jam-packed with plenty of good presentations, courses and activities. CSA will have a table at the event, so we hope you stop by to say hello! For full details on ASC 2022, visit **http://2csa.us/ko**

CSA will also be presenting the 2022 Roger W. Boom Award at ASC on Monday, October 24, after the plenary session (following the IEEE Awards). The Roger W. Boom Award is named in honor of the late emeritus professor from the University of Wisconsin. Dr. Boom's career spanned more than 30 years, during which he motivated a great number of young scientists and engineers to pursue careers in cryogenic engineering and applied superconductivity.

This award was created by CSA to be given to a young professional (under 40 years of age) who "shows promise for making significant contributions to the fields of cryogenic engineering and applied superconductivity." The spirit of the Boom Award is to recognize young people for their pursuit of excellence, demonstration of high standards and clear communications. You can find more information about the Boom Award on CSA's website at **http://2csa.us/boom**

Now on to some ***Cold Facts*** news – we recently introduced a new column titled "Cool Cryo Guests." This column features topical articles submitted by industry experts. We encourage you to consider submitting your work for possible inclusion in a future issue of ***Cold Facts***.

Some topics we'd love to feature include cryobiology/cryosurgery, superconductivity, food presentation/safety, quantum developments, LNG, industrial gases, and profiles of industry experts making a difference. If you're interested in submitting, please contact ***Cold Facts*** Editor Anne DiPaola at editor@cryogenicsociety.org. Make sure to include "submission" in the subject line.

Lastly, if you haven't had a chance to check out the new CSA Job Center, I highly encourage you to! It is the go-to hub for employers and job seekers in the cryogenics industry. CSA members can post job openings for free, and job seekers can post their resume for free too. If you aren't a member of CSA, but would like to post a job, you can do so for a nominal fee. Visit **http://2csa.us/jobs** to see what all the hype is about.

As always, I hope you enjoy this issue of ***Cold Facts***.


Looking for Solenoid Valves to Handle Liquid Oxygen, Argon and Nitrogen?
Magnatrol manufactures high quality, two-way bronze and stainless steel solenoid valves designed to provide rugged, durable service over a wide range of cryogenic applications.
• Type L and M (Bronze) and Type J and K (Stainless Steel) valves to handle liquid oxygen to (-297°), argon (-303°), and nitrogen (-320°)
• Valve pipe sizes from 3/8″ up to 3″
• Continuous duty coils for all AC/DC voltages
• Wide range of options including manual override, position indicator, NEMA 4X explosion proof and watertight models, and many more
• All valves fully tested, degreased, and cleaned to keep them free of moisture
For more information, call 973-427-4341, Fax: 973-427-7611, E-mail: info@magnatrol.com or visit www.magnatrol.com.
Magnatrol VALVE CORP.
Magnatrol Valve Corporation
67 Fifth Avenue • Hawthorne, NJ 07507


AMI
AMERICAN MAGNETICS
50+ years of experience
Specializing in Cryogen Free & Custom Systems
Recipient of 2009 R&D 100 Award
15 month warranty on any system
www.americanmagnetics.com
(865)482-1056 • 112 Flint Rd., P.O. Box 2509, Oak Ridge, TN 37831


Cryogenic Valves & Vacuum Components
Large Inventory for Immediate Shipment
▼ Vacuum Jacketed Valves
▼ Vacuum Seal-Off Valves and Valve Operators
▼ Vacuum Relief Valves
▼ Coldbox Valves
▼ Vapor Vents and Heaters
▼ Pipe and Tube Sized Bayonets
Vacuum Jacketed Manifolds & Custom Fabrications
For Reliable, Long-Life Cryogenic Components Contact
sales@cryocomp.com
www.cryocomp.com
CRYOCOMP
a division of Cryofab, Inc.
+1 908.686.3643

Around the Labs

NASA's Cold Atom Lab Experiments with Exotic State of Matter

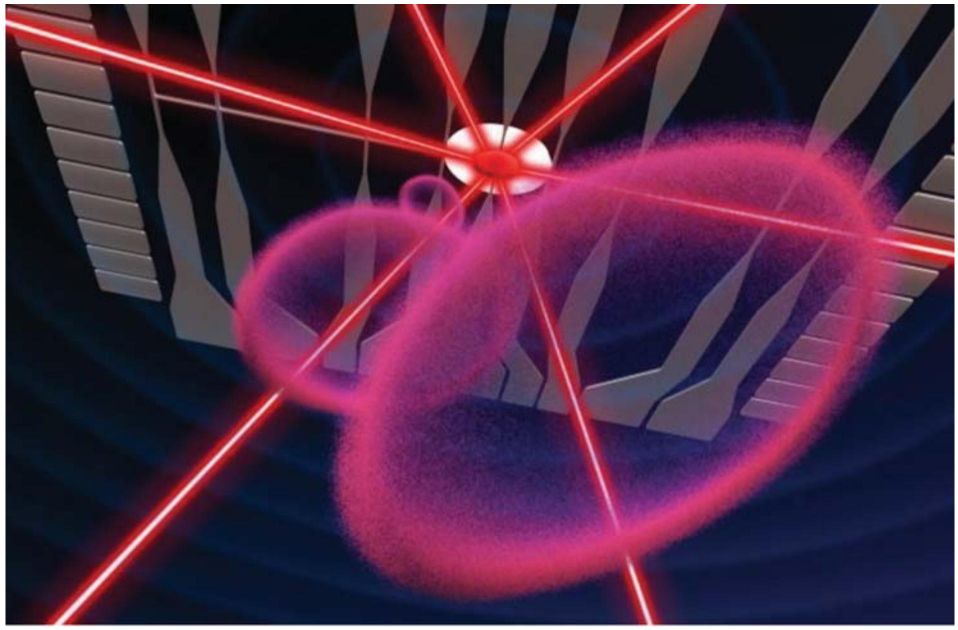
by Calla Cofield, Jet Propulsion Laboratory, Pasadena, Calif.

Since the days of NASA's Apollo program, astronauts have documented (and contended with) how liquids like water behave differently in microgravity than they do on Earth – coalescing into floating spheres instead of bottom-heavy droplets. Now, researchers have demonstrated this effect with a much more exotic material: gas cooled to nearly absolute zero (-459 °F or -273 °C), the lowest temperature matter can reach.

Using NASA's Cold Atom Lab, the first ever quantum physics facility aboard the International Space Station, researchers took samples of atoms cooled to within a millionth of a degree above absolute zero and shaped them into extremely thin, hollow spheres. The cold gas starts out in a small, round blob, like an egg yolk, and is sculpted into something more like a thin eggshell. On Earth, similar attempts fall flat: the atoms pool downward, forming something closer in shape to a contact lens than a bubble. The milestone – described in a research paper published on May 18, 2022, in the journal ***Nature*** – is only possible in the microgravity environment of the space station.

The ultracold bubbles could eventually be used in new kinds of experiments with an even more exotic material: a fifth state of matter (distinct from gases, liquids, solids and plasmas) called a Bose-Einstein condensate (BEC). In a BEC, scientists can observe the quantum properties of atoms at a scale visible to the naked eye. For instance, atoms and particles sometimes behave like solid objects and sometimes behave like waves – a quantum property called "wave-particle duality."

The work requires no astronaut assistance; the ultracold bubbles are made inside the Cold Atom Lab's tightly sealed vacuum chamber, using magnetic fields to gently

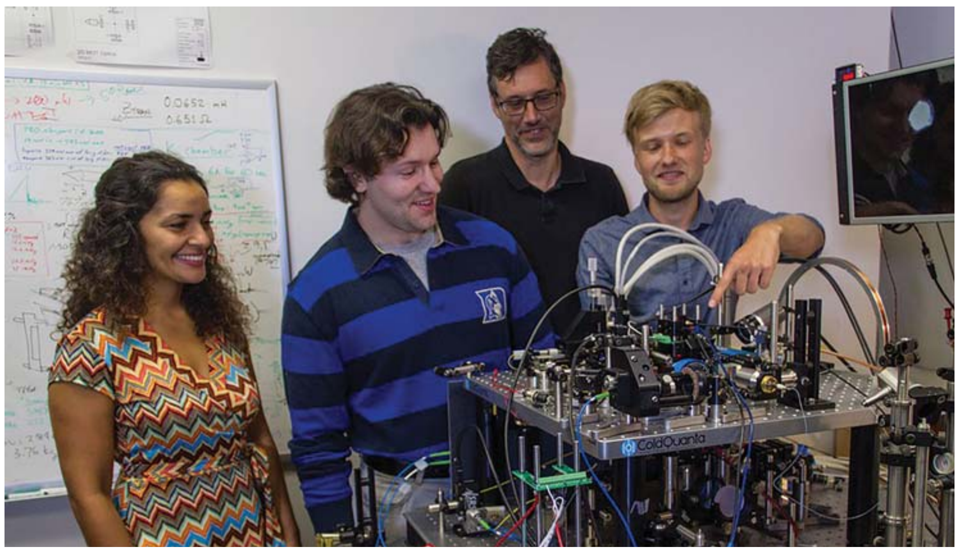


Inside NASA's Cold Atom Lab, scientists form bubbles from ultracold gas, shown in pink in this illustration. Lasers, also depicted, are used to cool the atoms, while an atom chip, illustrated in gray, generates magnetic fields to manipulate their shape in combination with radio waves. *Credit: NASA/JPL-Caltech*

Astronaut Christina Koch unloads new hardware for the Cold Atom Lab aboard the International Space Station. *Credit: NASA/JPL-Caltech* manipulate the gas into different shapes. The lab itself – which is about the size of a minifridge – is operated remotely from NASA’s Jet Propulsion Laboratory (JPL) in Southern California. The largest bubbles are about one millimeter in diameter and one micron thick. (That’s one-thousandth of a millimeter, or 0.00004 inches). They are so thin and dilute that only thousands of atoms compose them. By comparison, a cubic millimeter of air on Earth contains somewhere around a billion trillion molecules.

“These are not your average soap bubbles,” said David Aveline, lead author on the new work and a member of the Cold Atom Lab science team at JPL. “Nothing that we know of in nature gets as cold as the atomic gases produced in the Cold Atom Lab, so we start with this very unique gas and study how it behaves when shaped into fundamentally different geometries; and, historically, when a material is manipulated in this way, very interesting physics can emerge, as well as new applications.”

The Cold Atom Laboratory quad locker, sitting in a fixture that will allow the hardware to be packaged for shipment to the launch facility. *Credit: NASA/JPL-Caltech*



Members of the Cold Atom Laboratory team at NASA's Jet Propulsion Laboratory are seen here with their ground-based testbed, which can reliably create a Bose-Einstein condensate. Pictured from left to right, Anita Sengupta, Ethan Elliott, Rob Thompson and Markus Krutzik. *Credit: NASA/JPL-Caltech*

Why it ‘matters’

Exposing materials to different physical conditions is central to understanding them. It’s also often the first step to finding practical applications for those materials. Conducting these types of experiments on the space station using the Cold Atom Lab enables scientists to remove the effects of gravity, which is often the dominant force impacting the motion and behavior of fluids. By doing so, scientists can better understand the other factors at play, such as a liquid’s surface tension or viscosity.

Now that scientists have created the ultracold bubbles, their next step will be to transition the ultracold gas composing the bubbles to the BEC state and see how it behaves.

“Some theoretical work suggests that if we work with one of these bubbles in the BEC state, we might be able to form vortices – basically, little whirlpools – in the quantum material,” said Nathan Lundblad, a professor of physics at Bates College in Lewiston, Maine, and the principal investigator for the new study. “That’s one example of a physical configuration that could help us understand BEC properties better and gain more insight into the nature of quantum matter.”

The field of quantum science has led to the development of modern technologies like transistors and lasers. Quantum investigations done in Earth orbit could lead to improvements in spacecraft navigation systems and sensors for studying Earth and other solar system bodies. Ultracold atom facilities have been in operation on Earth for decades; however, in space, researchers can study ultracold atoms and BECs in new ways because the effects of gravity are reduced. This enables researchers to regularly reach colder temperatures and observe phenomena longer than they can on Earth.

“Our primary goal with the Cold Atom Lab is fundamental research – we want to use the unique space environment of the space station to explore the quantum nature of matter,” said Jason Williams, project scientist for the Cold Atom Lab. “Studying ultracold atoms in new geometries is a perfect example of that.”

Reference: “Observation of Ultracold Atomic Bubbles in Orbital Microgravity” by R. A. Carollo, D. C. Aveline, B. Rhyno, S. Vishveshwara, C. Lannert, J. D. Murphree, E. R. Elliott, J. R. Williams, R. J. Thompson and N. Lundblad, May 18, 2022, ***Nature***. DOI: 10.1038/s41586-022-04639-8 **www.jpl.nasa.gov**.

Living Biobank Could Revive Species Facing Extinction

by Sue Smith, reporter

Staff at Europe's first living biobank in Shropshire are at the forefront of work to preserve endangered animals and are celebrating having banked tissue samples from 100 species. The charity, Nature's Safe, which is based in Whitchurch (Shropshire, England), is aimed at helping solve the problem of animals facing extinction by freezing samples of various species which could then be brought back to life in 10, 20, 30 or even 1,000 years' time. The charity is an offshoot of Stallion A1 Services, an organization that initially specialized in freezing sperm from prized horses from the dressage and showjumping rings, and which has been involved in helping prevent the disappearance of Suffolk Punches, an English breed of draft horse.

Members of the team of 30 at the laboratories in Whitchurch, together with volunteers, have worked with Chester Zoo, Paignton Zoo and London Zoo to transfer their skills to saving endangered animals across the planet. The scheme is the brainchild of Tullis Matson, founder of Nature's Safe, who started the charity in December 2020. Since then, the team has frozen the cells of 100 species.

"The living biobank began its work in late 2020, and acts as an insurance policy to preserve rare and threatened animals so they can be protected for generations to come. Currently, 100 species are lost each day to extinction, and as the last few species die, their genetic blueprint is removed forever from our planet," explained Matson. "[Our solution is to] collect and process tissue and reproductive cell samples from threatened and endangered species and store them in an indefinitely cryo-preserved living state at minus 196 Celsius."

"Once thawed, the stored living cells could one day be used in cell culture or assisted reproductive technologies to maintain genetic diversity in the species gene pool," he added. "I have been involved in cryobiology for 30 years, and so far we have taken samples of animals such as the southern white rhino, the Asian elephant, the Komodo dragon, and the little-known mountain chicken frog, of which there are only 100 left in the world. Without Nature's Safe, for many species near the brink of extinction, there will be no return. We know the sixth mass extinction on Earth is underway, and there will be rough times ahead. The question is what do we want to do about it; our answer is to secure future options for biodiversity by acting now."

Tullis Matson Cryopreserving a sample for storage. *Credit: Nature's Safe*

A nitrogen storage tank. *Credit: Nature's Safe*

Dr. Sue Walker, head of science at Chester Zoo and a co-founder of Nature's Safe, added to the conversation about the decreasing population of species and the urgency to preserve them. "With gene pools shrinking, cryopreservation is a critical piece of the conservation puzzle, providing a safeguard for animals the world is currently on track to lose."

Nature's Safe has cryopreserved multiple cell types from many endangered animal species. The one-hundredth species to join the living biobank is the Owston's civet, a curious-looking mammal resembling a large shrew and found throughout Southeast

▶ *continues on page 12*

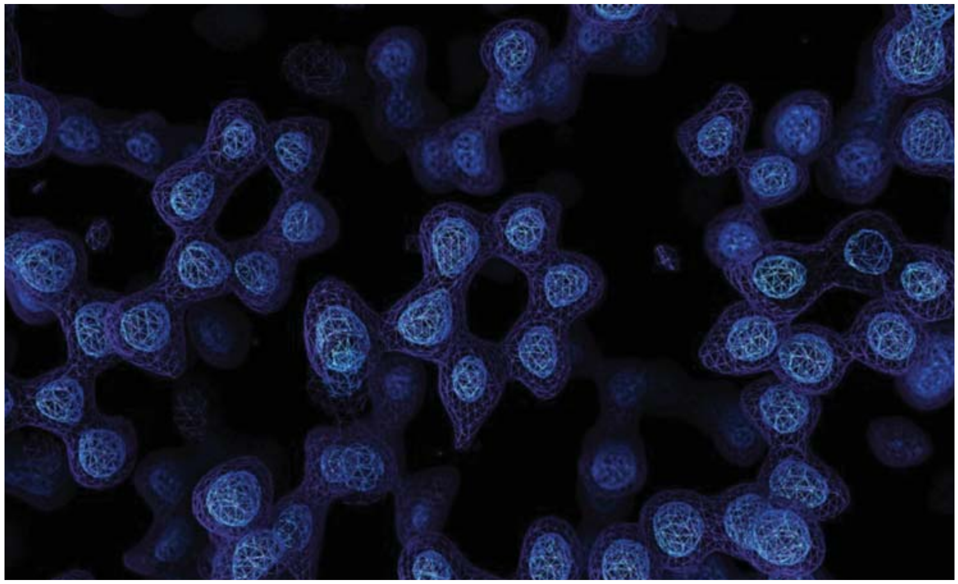
Cryo-EM Revolutionizes the Field of Structural Biology

by Mohit Sharma, freelance researcher

A revolutionary technique for determining the 3-D shape of proteins is booming. Created in the 1930s, cryogenic-electron microscopy (cryo-EM) is a version of electron microscopy. These microscopes use beams of electrons rather than light to form images of samples. Because the wavelength of an electron is much shorter than the wavelength of light, electron beams reveal much smaller things. In recent years, cryo-EM underwent the most impressive improvement compared to other techniques used in structural biology, such as X-ray crystallography and Nuclear Magnetic Resonance (NMR).

In the mid-1970s, scientists came up with the idea of freezing samples to preserve the natural structure of biological specimens and reduce damage from the electron beam. Thus, cryo-EM was born. The technology slowly evolved; however, a few years ago, it took a giant leap, thanks to dramatic advances in detectors and software. This culminated in 2017, when three scientists were awarded the Nobel Prize in chemistry for their roles in developing cryo-EM.

Cryo-EM has superseded X-ray crystallography and NMR to emerge as a popular and effective tool for structure determination. It has become indispensable for the characterization of large macromolecular assemblies, membrane proteins or samples that are limited, conformationally heterogeneous and recalcitrant to crystallization. It is also the only tool capable of elucidating high-resolution structures of macromolecules and biological assemblies in situ. A state-of-the-art electron microscope operable at cryogenic temperatures helps preserve high-resolution details of the biological sample. The structures can be determined, either in isolation via single-particle analysis or helical reconstruction, electron diffraction or within the cellular environment via cryo-electron tomography. This has resulted in breaking the boundaries with respect to both the size of the macro-molecules and assemblies whose structures could be determined, along with the visualization of atomic details at resolutions unprecedented for cryo-EM.



A Cryo-EM map of the protein apoferritin. *Credit: Paul Emsley/MRC Laboratory of Molecular Biology*

Today, cryo-EM generates 3-D images at nearly atomic resolution of viruses, molecules and complex biological machines inside the cell, such as the ribosomes where proteins are synthesized. By flash-freezing these tiny things in their natural environments, scientists can see how they are built and what they do in much more detail than before, stringing thousands of images together to create stop-action movies and even taking virtual "slices" through cells, much like miniature CT scans. Meanwhile, cryo-EM instruments have become easier to use and much more accessible.

Subtechniques within cryo-EM

There are several subtechniques within the field of cryo-Em. They include:

- Scanning electron cryomicroscopy (cryo-SEM)
- Cryo-correlative light and electron microscopy (cryo-CLEM)
- Cryo-electron tomography (cryo-ET)
- Transmission electron cryomicroscopy (cryo-TEM)

Recent applications of Cryo-EM

The novel coronavirus, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), rose as a global pandemic affecting the respiratory system, showing acute respiratory distress syndrome. With the virus came the intense need for a therapeutic agent. In general, the continued study for therapeutic agents for SARS-CoV-2 is largely focused on large-scale screening with fragment-based drug discovery (FBDD). Recent advancements in cryo-EM have made it a widely used tool in structural biology. It is effective in investigating the structure of numerous proteins in high-resolution and has an intense influence on drug discovery, determining the binding reaction and regulation of known drugs as well as leading the design and development of new drug candidates. Here, we review the application of cryo-EM in a structure-based drug design and in silico screening of the recently acquired FBDD in SARS-CoV-2. Such insights will

▶ *continues on page 12*

Living Biobank Could Revive Species... Continued from page 10

Asia. On the brink of extinction, the species has seen a population decrease of 50% over the last three generations.

Remarking on the importance of preserving the Owston's civet's genes, Dr. Veronica Cowl, reproductive biology coordinator for Chester Zoo and the European Association for Zoos and Aquaria, said, "We have been working on understanding reproduction in the elusive Owston's civet for more than three years, and it is fantastic that we can now preserve the genes from the current zoo population through Nature's Safe. This is a great step forward in our work to prevent the extinction of this beautiful species, and it is a pleasure to work with such a passionate group of people."

This article first appeared in Shropshire Star.

Owston's civet. *Credit: Nature's Safe*

Cryo-EM Revolutionizes the Field... *Continued from page 11*

help deliver better understanding in the procurement of the effective remedial solution for the global pandemic.

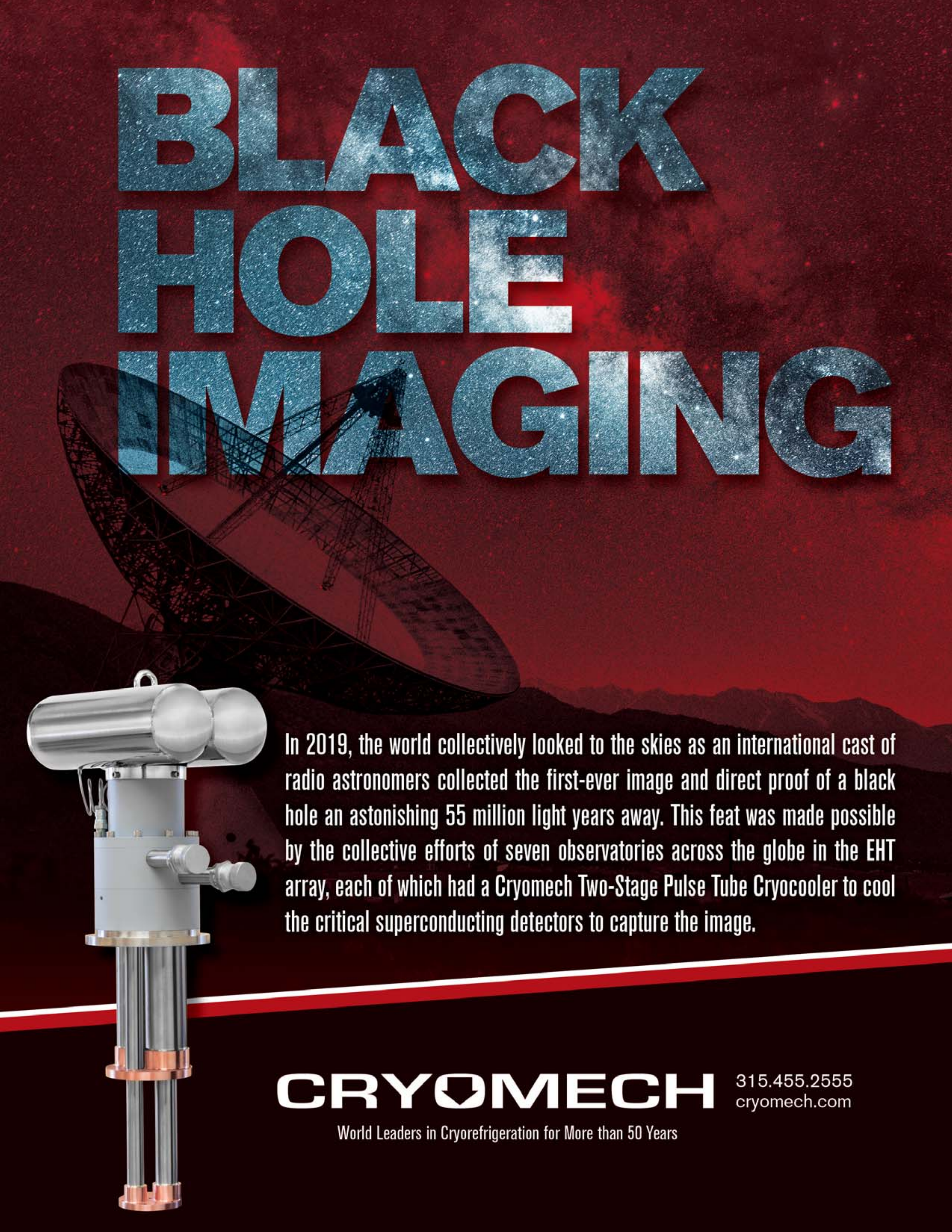
The field of Cryo-EM has gained enough popularity that only certain samples, such as viruses and ribosomes, are occasionally imaged using X-ray crystallography. Cryo-EM has now provided imaging at atomic resolution of the structural changes that occur in the p97 protein. This protein is an important target for cancer drug development as the structure and interactions of the protein are critical for cancer cell activity. Through the advanced imaging abilities of cryo-EM, the type of p97 inhibitor binding and contact sites have been observed. This study achieved resolutions of 2.3 ångströms, with the unit ångström being the equivalent of 0.1 nanometers. Cryo-EM has the potential for further improvements to resolution with advances in detector technology and sample preparation currently under way.

General significance

Previous structural biology techniques included X-ray crystallography and nuclear magnetic resonance spectroscopy. Both methods have had limited application because of the need for large sample sizes. X-ray crystallography also necessitates the crystallization of specimens, a difficult process that changes the environment to one that is non-physiological. However, cryo-EM does not require large sample sizes or crystallization; therefore, it is suited to the visualization of structures at near-atomic resolution. The method also has the advantage of not chemically fixing or staining the specimen, meaning it can be studied within the native physiological environment. Moreover, without the restriction of crystals locking the sample in a static pose, structures can be flash-frozen in several conformations to allow biological mechanisms to be deduced. The cryo-EM method can be used to determine the 3-D structure of bio-macromolecules in near native condition at close-to-atomic resolution, and it has the potential to reveal conformations of dynamic molecular complexes.

Cryo-EM is a powerful tool for the investigation of biological macromolecular structures, including analysis of their dynamics, by using advanced image processing algorithms. The method has become even more widely applicable with present-day single particle analysis and electron tomography.

This research first appeared in Daily Excelsior. The author is pursuing research in structural biology in Poland.


BLACK
HOLE
IMAGING
In 2019, the world collectively looked to the skies as an international cast of radio astronomers collected the first-ever image and direct proof of a black hole an astonishing 55 million light years away. This feat was made possible by the collective efforts of seven observatories across the globe in the EHT array, each of which had a Cryomech Two-Stage Pulse Tube Cryocooler to cool the critical superconducting detectors to capture the image.
CRYOMECH
315.455.2555
cryomech.com
World Leaders in Cryorefrigeration for More than 50 Years

At Two Virginia Tech Campuses, Quantum Engineering Research Labs Are Poised to Transform Society

by Emily Roediger, Virginia Tech University

Smaller isn't always better, but when it comes to quantum engineering, quantum-scale developments are ready to change the world. "Electrical and computer engineering research is critical to a global effort to advance quantum engineering research and train the new generation of quantum engineers," said Luke Lester, head of the Bradley Department of Electrical and Computer Engineering (ECE). "And our department is well positioned to be part of the quantum revolution."

Quantum engineering is poised to revolutionize society, said Lester. It could improve our communications systems, bring us new methods for securing data, make our devices more energy efficient, and, of course, make computers smaller.

According to ECE Professor Wayne Scales, who is working on the curriculum side of the department's efforts, quantum is the natural next step in computing, following mechanical switches and transistors, and the impact could be just as big.

Quantum engineering isn't just our usual engineering on a smaller scale, however. At quantum levels, different physical laws and phenomena apply than what we're used to at a larger scale. Quantum engineering requires interdisciplinary expertise, including electrical and computer engineering, materials science, computer science, physics, chemistry and math.

Two new centers for quantum research

To overcome this interdisciplinary hurdle, Virginia Tech is forming two centers for quantum engineering — one in Blacksburg and one in Alexandria. These centers will bring together researchers from multiple fields to tackle quantum challenges.

Wayne Scales (at right) and student Sefunmi Ashiru work together in the quantum lab located at Virginia Tech's Blacksburg Campus. *Credit: Chelsea Betts Seeber for Virginia Tech*

The Center of Quantum Architecture and Software Development will be part of the Virginia Tech Innovation Campus in Alexandria and is partially funded by a $12.5 million gift from Northrup Grumman. The Virginia Tech Center for Quantum Information Science and Engineering will be the Blacksburg-based complement of the Alexandria center and will tackle broad research topics from cryptography to atomic clocks.

ECE quantum research

Several ECE faculty members already have active quantum engineering research projects. Lester, along with Mantu Hudait, associate professor of ECE, are researching quantum dot devices — and the materials needed to create them. Their team is crafting devices such as ultrafast lasers, single photon sources and high-efficiency solar cells.

Assistant Professor Linbo Shao is investigating quantum information processing on silicon substrates. These high-performance devices use microwave, acoustic and optical devices.

Vassilios Kovanis, collegiate professor and Master of Engineering program director for Northern Virginia, is working on non-hermitian quantum mechanics, which uses a combination of dissipation and unitarity in contrast to traditional quantum mechanics. Within this context, he is developing tunable photonic oscillators and clocks as well as a variety of ultrasensitive sensors.

Finally, Collegiate Assistant Professor Ravi Ragunathan is working on a quantum key distribution testbed that can integrate with cyber and radio-frequency modalities.

Quantum education

In addition to quantum research programs, ECE is developing a new curriculum and new courses to train the next generation of quantum engineers. "It's a big debate on how to train students in quantum engineering because it's so interdisciplinary," said Scales.

▶ *continues on page 16*

The LCLS-II accelerator, where temperatures 2 K above absolute zero have been achieved. *Credit: Greg Stewart/SLAC National Accelerator Laboratory*

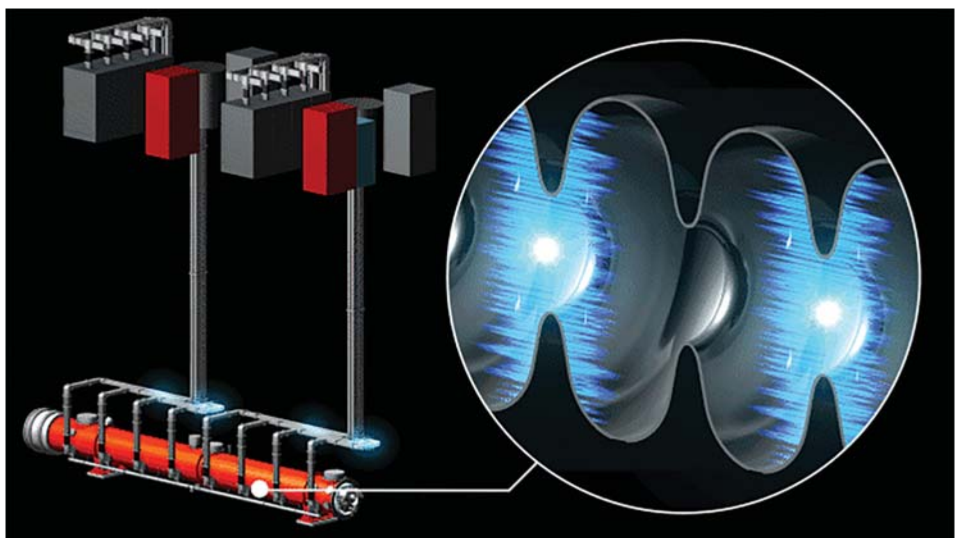
Temperatures Colder Than Space, Achieved on Earth Through X-ray Laser

by Robert Lea, science journalist

A half-mile-long tunnel under Menlo Park, Calif., has become colder than most of the universe because of a particle accelerator that slams electrons together here on Earth.

Using the X-ray free-electron laser at the Department of Energy's SLAC National Accelerator Laboratory – part of an upgrade project to the Linac Coherent Light Source (LCLS) called LCLS II – scientists chilled liquid helium to -456 °F (-271 °C). That is just 2 kelvins above absolute zero, the coldest possible temperature at which all particle movement ceases. That frosty environment is crucial for the accelerator because at such low temperatures, the machine becomes superconducting, meaning it can boost electrons through it with near zero energy loss. Even empty regions of space aren't this cold, as they are still filled with the cosmic microwave background radiation, a remnant from shortly after the Big Bang that has a uniform temperature of -454 °F (-271 °C or 3 K).

"The next-generation, superconducting accelerator of the LCLS-II X-ray free-electron laser has reached its operating temperature of two degrees above absolute zero," Andrew Burrill, director of SLAC's Accelerator Directorate, said in an interview with "Live Science."



Microwaves are pumped through the cooled cavities, accelerating electrons to near the speed of light. *Credit: Greg Stewart/ SLAC National Accelerator Laboratory*

LCLS-II can now accelerate electrons at one million pulses per second, which is a world record, Burrill added.

"This is four orders of magnitude, more pulses per second than its predecessor, LCLS, meaning that we will have sent more X-rays to users [who aim to utilize them in experiments] than LCLS has done in the past 10 years," Burrill said.

This is one of the last milestones that LCLS-II needs to achieve before it can go on to produce X-ray pulses that are, on average, 10,000 times brighter than those created by its predecessor. This should help researchers probe complex materials in unprecedented detail. The high-intensity, high-frequency laser pulses enable researchers to see how electrons and atoms in materials interact with unprecedented clarity. This will have numerous applications, from helping to reveal "how natural and man-made molecular systems convert sunlight into fuels, and thus how to control these processes, to understanding the fundamental properties of materials that will enable quantum computing," Burill said.

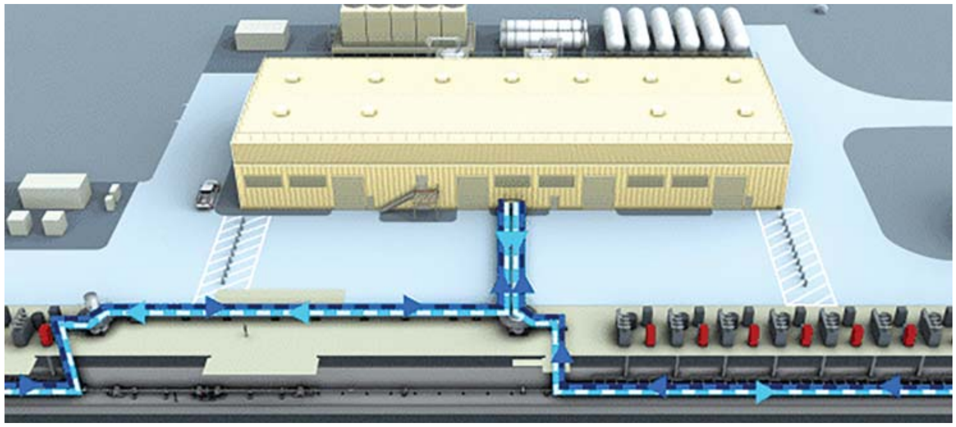
▶ *continues on page 16*

Temperatures Colder Than Space... Continued from page 15

Creating the freezing climate inside the accelerator took some work. To keep the helium from boiling away, the team needed super-low pressures. Eric Fauve, director of the cryogenic division at SLAC, told "Live Science" that at sea level, pure water boils at 212 °F (100 °C), but this boiling temperature varies with pressure. For example, in a pressure cooker, the pressure is higher, and water boils at 250 °F (121 °C), while the reverse is true at altitude, where pressure is lower and water boils at a lower temperature.

"For helium, it is very much the same. At atmospheric pressure, helium will boil at 4.2 kelvins; however, this temperature will decrease if the pressure decreases," Fauve said. "To lower the temperature to 2 kelvin, we need to have a pressure of just 1/30 of atmospheric pressure."

To achieve these low pressures, the team uses five cryogenic centrifugal compressors, which compress the helium to cool it and then let it expand in a chamber to lower the pressure, making it one of the few places on Earth where 2 K helium can be produced on a large scale. Fauve explained that each cold compressor is a centrifugal machine equipped with a rotor/impeller, similar to the one from an engine turbo-compressor.



A still from an animation shows the linac accelerator cryoplant cooling helium gas to its liquid phase. *Credit: Greg Stewart/ SLAC National Accelerator Laboratory*

"While spinning, the impeller accelerates the helium molecules, creating a vacuum at the center of the wheel where molecules are sucked and generating pressure at the periphery of the wheel where molecules are ejected," he said.

Compression forces the helium to take its liquid state, but the helium escapes into this vacuum where it expands rapidly, cooling as it does so. In addition to its ultimate applications, the ultracold hydrogen created at LCLS-II is a scientific curiosity in itself.

"At 2.0 kelvin, helium becomes a superfluid called helium II that has extraordinary properties," Fauve said. "For instance, it conducts heat hundreds of times more efficiently than copper, and it has such low viscosity — or resistance to flow — that this can't be measured."

For LCLS-II, 2 K is as low as temperatures are expected to go.

"Lower temperatures can be achieved with very specialized cooling systems that can reach a fraction of a degree above absolute zero," Burrill said. "But this particular laser doesn't have the ability to reach those extremes."

Originally published on "Live Science."

At Two Virginia Tech Campuses... Continued from page 14

Because this curriculum has potential to impact so many technology communities, both the Commonwealth Cyber Initiative and the Institute for Critical Technology and Applied Science have helped fund the laboratory development.

One thing that is a certainty for training quantum engineers: the need for a quantum laboratory course for hands-on learning. The course — taught for the first time during the 2022 spring semester — is intended for students in both engineering and science fields. Currently, such experiential learning laboratory infrastructure is not common in the US. The course is quantum photonics-based and covers fundamental quantum science concepts, quantum communication, quantum cryptography and quantum sensing. Although the course is initially taught at the graduate level, Scales plans to offer it to undergraduates — possibly even to those in their sophomore year.

Ultimately, Scales plans to offer a virtual laboratory, as well as the in-person experience, enabling more students to gain access to this training. "You can log in remotely to the control panel and run the experiments," he said. Therefore, students on other campuses or other universities, as well as working professionals, could benefit from the Virginia Tech lab.

Scales is also building partnerships with other universities that could offer the laboratory as part of their programs — particularly universities that could help underrepresented minorities gain access to the tools. "It's an enormous educational opportunity," said Scales.

The course development doesn't stop with universities, however. "Ultimately, everything will have quantum devices, and we'll need to train people at trade schools and community colleges in quantum concepts," said Scales. "Even K-12 students... it's a completely new way of thinking for the average person."

The field is shifting, noted Scales, from being purely basic science. "It's evolving to be its own engineering discipline, with critical new applications including cybersecurity, quantum communications, quantum sensing and quantum materials."

FullX HYDROGEN VALVES

Herose's answer to the hydrogen market.

The design of the FullX Hydrogen Valve body permits an optimum installation in a vacuum-insulated system and protects cryogenically liquefied media up to -425°F against undesired rapid evaporation.

FULLY AUTOMATED PACKAGES

www.cryoorder.com sales@rmicryo.com 1-844-341-3433

reliably RATERMANN

HEROSE

Efficiency and Safety Come First in Cryometrix Upright Liquid Nitrogen Biorepositories

by Del Williams, technical writer, Torrance, Calif.

In the pharmaceutical and medical industries, cryogenic freezers are utilized as biorepositories for the long-term preservation of biospecimens such as tissue, blood, plasma or urine. These biorepositories are essentially "libraries" where biospecimens are stored for clinical or research purposes. Consequently, biorepositories are vital for understanding diseases, genetics, developing prophylactic and therapeutic agents, and monitoring human population health including outcomes related to environmental exposures.

With so much at stake, the failure of a cryogenic freezer to properly maintain biological samples at the required temperatures can be potentially catastrophic and costly. In addition, personnel need to be protected when storing or retrieving samples that are stored at extremely low, cryogenic temperatures. The challenge is that conventional options for biorepositories – traditional stainless steel vats, cryovats that contain LN_2 and compressor-based systems – pose significant disadvantages in terms of safety, reliability and temperature control.

In response, Cryometrix has developed a new category of upright liquid nitrogen freezers, improving both operator and sample safety while offering greater reliability, along with adjustable temperatures down to -160 °C and faster freeze times.

With this approach, LN_2 circulates within the walls of the freezer, keeping the contents frozen while preventing direct exposure to users. The units provide the convenience of an upright freezer with good temperature uniformity throughout. The design minimizes the need for maintenance because there are fewer moving parts and no high maintenance mechanical compressor.

Upright LN_2 freezers remove the risk of direct contact with liquid nitrogen associated with cryovats, while eliminating the need for the compressor and refrigerant design used in most biorepositories. *Credit: Cryometrix*

Overcoming conventional cryogenic freezer challenges

When using conventional cryovats, there are significant hazards in having any direct contact with LN_2, including extremely cold vapor that can rapidly freeze skin tissue and eye fluid, resulting in cold burns, frostbite, and permanent eye damage even through brief exposure. Since LN_2 is liquefied under high pressure, it can expand to a very large volume of gas. Consequently, asphyxiation caused by vaporization of liquid nitrogen can create oxygen deficiency in the immediate environment and cause unconsciousness, and even death in rare cases. In addition, pressure buildup and explosions can occur without adequate venting or pressure-relief devices that allow cryogen evaporation.

"When cooled below -150 °C, liquid nitrogen turns into a frigid vapor that keeps the samples frozen. But the liquid nitrogen can be hazardous during loading and unloading when personnel place items into vats of LN_2," says Kim Boyce, president of Reflect Scientific, Inc. (RSCF), an Orem, Utah-based manufacturer that develops and markets innovative, proprietary cryogenic cooling technologies for the biotechnology, pharmaceutical, medical and transportation markets.

Given the risks, liquid nitrogen should be handled only in well-ventilated areas when used with vats indoors, and the LN_2 should be handled slowly and carefully to minimize boiling and splashing. Tongs should be used to withdraw objects immersed in the LN_2, and personnel should never touch non-insulated vessels containing it. In many cases, personal-protective equipment is recommended, as well as extensive training.

Controlling temperature in vats is also difficult, even impossible, because there is no safe, reliable means of adjusting the temperature of the LN_2 within the vat. Cross-contamination can be an issue within vats, too, when multiple samples are stored in the same vicinity.

"Cryovats are basically passive systems that utilize LN_2 where there is really only one temperature," says Boyce.

Today, modern upright freezer designs address many of the potential safety issues associated with cryovats. “Upright liquid nitrogen freezers are designed to prevent direct contact with LN_2. The liquid nitrogen is self-contained, so there is no exposure to the user or the products,” says Boyce.

In the case of RSCF’s Cryometrix T-160 Ultra Low Temp Freezer, the unit utilizes LN_2 within but prevents user contact. The upright freezer provides adjustable temperatures from +20 °C to -160 °C, which is considerably lower than conventional upright freezer options, enabling significantly faster freeze times. The design also provides temperature uniformity ±7 °C throughout, protecting the integrity of all samples within the unit.

At the other end are compressor-based systems that use refrigerants as an essential part of the cooling process cycle. Even though compressor-based systems allow temperature setting, mechanical compressors work constantly and have many moving parts that are susceptible to breakdown. Consequently, these systems can require significant maintenance and repair while lacking necessary reliability. A wide range of causes can contribute to compressor breakdown, such as electrical failure, insufficient lubrication, blocked condenser coils, and overheating due to dusty coils, low refrigerant levels, or inadequate insulation.

“Compressor-based systems can accommodate a wide range of temperatures but need to run 23 out of 24 hours each day and have a lot of moving parts, so they break down and require frequent maintenance,” says Boyce.

The other concern is that compressor-based systems use refrigerants, such as CFCs, which contribute to global warming as extremely potent greenhouse gases and can damage the ozone layer. In contrast, the Cryometrix upright liquid nitrogen freezers eliminate the need for a compressor and refrigerants. This eco-friendly design improves reliability and reduces maintenance due to a simplified design with minimal moving parts. The reliability of the unit enables the company to offer the industry’s longest warranty: 20-year coverage on the cooling system.

In addition, upright liquid nitrogen freezers minimize the risk of sample warming and quality deterioration due to door open-close events and offer one of the fastest recovery times in the industry. To safeguard sample integrity, state-of-the-art temperature and data logging can also be easily accessed, and multiple security levels set. The redundant cooling system and onboard seven-day battery backup further ensure that processes can continue uninterrupted even upon loss of power. The approach also uses up to 90% less energy than mechanical, compressor-based units, which significantly reduces operating costs. Unlike compressor-based systems, no heat is exhausted to the room, eliminating the need for expensive HVAC systems for cooling. The freezer has a small footprint that suits space-constrained storage environments. **www.cryometrix.com**

Upright liquid nitrogen biorepositories, like the Cryometrix ultralow temperature freezers, are now providing industry professionals with a safer, more reliable and eco-friendlier alternative that enables superior temperature control. *Credit: Cryometrix*

CO2Meter Tackles Oxygen Deficiency Safety in Cryogenic Laboratories

by Morgan Morris

For many laboratories, the use of inert gas is common, and the need for safety monitoring is vital. Worldwide, many laboratories regularly use helium, argon and oxygen to provide a stable environment during research and testing. Additionally, liquid nitrogen can be used to provide temperatures as low as -50 °C, required in cryogenics, industry freezing, cold storage and even surgical procedures. Overall, the use of inert gas is almost always found in the cryogenics industry, yet the hazards involved for those surrounded by the inert gases are critical. To that end, CO2Meter has been recognized as a leading source for gas detection solutions and works alongside many partners throughout the scientific, medical and pharmaceutical industries.

The Dangers of Inert Gas

At such specific temperatures, nitrogen, oxygen, helium, methane, and argon can all become liquids. As refrigerants, cryogenic liquids are useful in modern science. For example, at the Large Hadron Collider at CERN, they enable the superconducting operation of beam positioning devices with liquid helium at 4 K or -452 °F. However, when it comes to safety, except for oxygen, all the gases are asphyxiating. An asphyxiate gas is a nontoxic or minimally toxic gas that reduces or displaces the normal oxygen concentration in breathing air. Breathing of oxygen-depleted air can lead to death by asphyxiation or suffocation.

Small amounts of any pressurized gas are not harmful. However, a leak in a pressurized gas tank, line or fixture can easily become dangerous. For example, one volume of liquid nitrogen at its boiling temperature vaporizes to 696.5 volumes of nitrogen gas at room temperature. For most common gases, the expansion ratio from liquid to gas is between 700 and 900. This means that even a small leak can quickly lower the oxygen level in an enclosed room or area.

RAD-0002-ZR Low-Temperature Oxygen Monitor. *Credit: CO2Meter*

In order to protect lab technicians and professionals in the space, the use of CO2Meter's Oxygen Deficiency Alarm for Low Temperatures can be used to provide warning before individuals enter an area with dangerous oxygen levels that could be caused by pressurized gas leaks. The device is designed to meet OSHA confined space regulations, while offering both audible and visual alarm indicators that will be triggered in the event of a potential hazard. Paired with an easy-to-read LCD screen, which displays current oxygen levels, employees can conduct their work and research with peace of mind due to the monitor's presence and ease of readability.

In fact, The College of American Pathologists (CAP) enforces requirements that pinpoint the potential hazards related to using and storing liquid nitrogen and dry ice. In addition, associations like the Compressed Gas Association (CGA) are continually updating their CGA M-24 standards for mitigating oxygen hazards in the health and laboratory environments. These standards also provide general precautions on how to work with inert gases and list oxygen safety monitors as a key factor. All requirements apply to laboratories, clinics and reproductive facilities to ensure safety in regard to oxygen deprivation.

Mitigating gas hazards in laboratories

Some facilities depend on personal oxygen monitors to solve the problem of laboratory gas hazards. These are useful in normal operations, but what happens if the oxygen level is reduced overnight? By the time a personal alarm sounds, scientists may not be able to leave the room. Another challenge is that even the smartest and most capable person makes mistakes. No matter how much training is received, a person may walk into a potentially hazardous situation without an oxygen monitor. Oxygen safety devices prevent the dangerous repercussions that follow human error. By remotely monitoring for oxygen levels in real time, staff will be warned before they enter an area. In addition, the alarm can control ventilation fans or can be connected to a facility's HVAC and/or alarm systems.

What About Too Much Oxygen?

Tanks of liquid oxygen can also be a risk. Breathing oxygen at pressures of 0.5 bar or more (roughly two and a half times normal) for more than 16 hours can lead to irreversible lung damage and eventual death. At above 60% concentration, oxygen becomes an asphyxiate. However, even at levels above normal air (20.95%), oxygen is dangerous because it acts as an oxidizing agent. Combined with heat and fuel, oxygen promotes fire.

CO2Meter's goal is to provide best-in-class gas detection, monitoring, and analysis solutions, while ensuring education and the long-term business of its partners and customers. Incorporated in 2006, CO2Meter utilizes the latest proven gas-sensing technologies to solve the urgent needs of laboratories and facilities. By providing unique, high-quality sensors and devices, CO2Meter strives to ensure the health, welfare, and safety of the public. **www.CO2Meter.com**

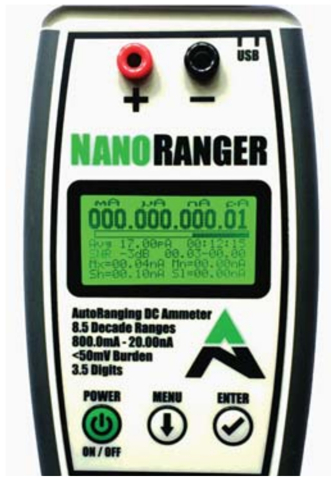
AltoNovus Makes Measurement Easier with Handheld Ohmmeter

by Geoff Dean, managing director, AltoNovus Ltd.

Measuring the resistance of delicate Josephson junctions is often problematic. The stimulus voltage applied by standard multi-meters, usually between 3-10V, will destroy the junction. Therefore, local 'DIY' low-compliance measurement devices can be necessary in the laboratory setting. ΩhmRanger-LCV, a low-compliance voltage ohmmeter designed to be 'junction-safe,' provides an easily implemented, simple measurement solution. The ΩhmRanger-LCV and NanoRanger, both from the UK's AltoNovus, are handheld meters that can be useful in any laboratory working at millikelvin temperatures, or with nanoscale devices. NanoRanger is an auto-ranging, low-stimulus voltage ammeter. Its sister meter, ΩhmRanger-LCV, is a low-compliance voltage ohmmeter, originally developed for building quantum computers using Josephson junctions.

When a team needs to characterize individual Josephson junctions at room temperature and at millikelvins, setting up and checking these experiments often calls for confirmation of electrical connectivity with junctions in place. A standard multimeter cannot be used, as it risks damaging the samples under test. Once *all* multimeters are replaced with AltoNovus meters (to ensure that a standard multimeter *cannot* be used in error), sample failure rate *decreases by 25%*. In addition, a development to automate testing, using these same meters (via the isolated USB interface), proved to be a straightforward evolution in process.

But the potential applications for AltoNovus meters are not limited to Josephson junctions. NanoRanger and ΩhmRanger-LCV can be useful in labs working at very low temperatures (cryogenic systems), where the aim is often to reduce self-heating of samples during measurement. These meters can also be useful in the context of nanoscale devices, where taking measurements often requires a low-energy stimulus. Quantum-based devices, such as Josephson junctions [1] [2] and



NanoRanger. *Credit: AltoNovus*

superconductor / insulator / superconductor (SIS) mixers [7] [8], are very sensitive to overvoltage. Nanoscale devices, such as single electron transistors (SET) [6], single molecule switches [3], or nanowires [4] [5], are very sensitive to stimulus energy.

Once integrated into a full system, these delicate devices are usually hidden behind a protective buffer. However, developing the integrated system often requires the test and measurement of individual elements. A standard handheld multimeter has the potential to damage all of these types of devices, or to create false readings. AltoNovus handheld meters feature low stimulus for measuring resistance and current:

- ΩhmRanger-LCV applies approximately 380 or 206 millivolts (selectable) during a resistance measurement.
- NanoRanger has a burden voltage of under 50 millivolts during a current measurement.

While there is expensive lab equipment available that can perform the same measurements, it is usually bench or rack mounted and requires a powered connection. At times, that may be convenient; however, AltoNovus meters are compact, highly portable, and battery-operated, so they can be used anywhere in the lab. They are especially handy for in-situ measurements or when needing to measure in unavoidably awkward spots like at the top of a dilution refrigerator system. At less than GBP200, AltoNovus meters are also significantly cheaper than most bench meters, allowing a cost-effective solution if additional meters are needed.

AltoNovus meters have been designed to simplify complexity growth. Should a user identify the perfect application for these meters and then decide to automate the measurement process, AltoNovus meters have the functionality to support automation with low user implementation overheads. There is a USB port for computer connection and a scripting language to control and export measurements. Finally, AltoNovus meters have low energy consumption, so batteries last a long time (up to 300 hours of continuous operation on 2 x AA lithium batteries), a solution when users want an automated measurement in a flexible, mobile, and scalable format. **www.altonovus.com**

References:

[1] Room Temperature Characterization of Josephson Junctions, 2014 Thesis, Nicholas Ross Baxter, Syracuse University

[2] Physics and Technology of Small Josephson Junctions, 2013 Thesis, Simon Schmidlin, University of London, pg. 74

[3] Measuring single-molecule switches – see Fig. 11 of **https://pubs.rsc.org/en/content/articlepdf/2015/cs/c4cs00377b**

[4] Resistance of nanowires – Fig. 3 of **https://link.springer.com/content/pdf/10.1007/s12274-009-9039-2.pdf**

[5] Resistance of nanowires – Fig. 4A of **www.cchem.berkeley.edu/pdygrp/pub_files/pubpdf/143.pdf**

[6] page 68 of **https://qspace.library.queensu.ca/bitstream/handle/1974/493/Dubejsky_Gregory_Stefan_200707_MSc.pdf**

[7] page 63 of **http://www.sophphx.caltech.edu/Thesis/Thesis%20Rice.final.pdf**

[8] page 99 of **https://www.nrao.edu/meetings/isstt/proceed/2008-Proceedings.pdf**

ACME CRYOGENICS®

TURN TO ACME CRYOGENICS FOR ENGINEERING, DESIGN, FABRICATION, INSTALLATION, AND REPAIR SERVICES.

- FOOD PACKAGING
- PHARMACEUTICAL
- SEMI-CONDUCTOR
- MEDICAL GAS PIPE
- INDUSTRIAL GAS INDUSTRIES

Venturing into the Hydrogen Economy, Bio-Cryo, Space Launch Services, Satellite Constellation Expansion, Niche Food Beverage, Specialty Manufacturing, and Electronics, Acme Cryogenics has you covered, yesterday, today, and tomorrow.

800.422.2790

WWW.ACMECRYO.COM

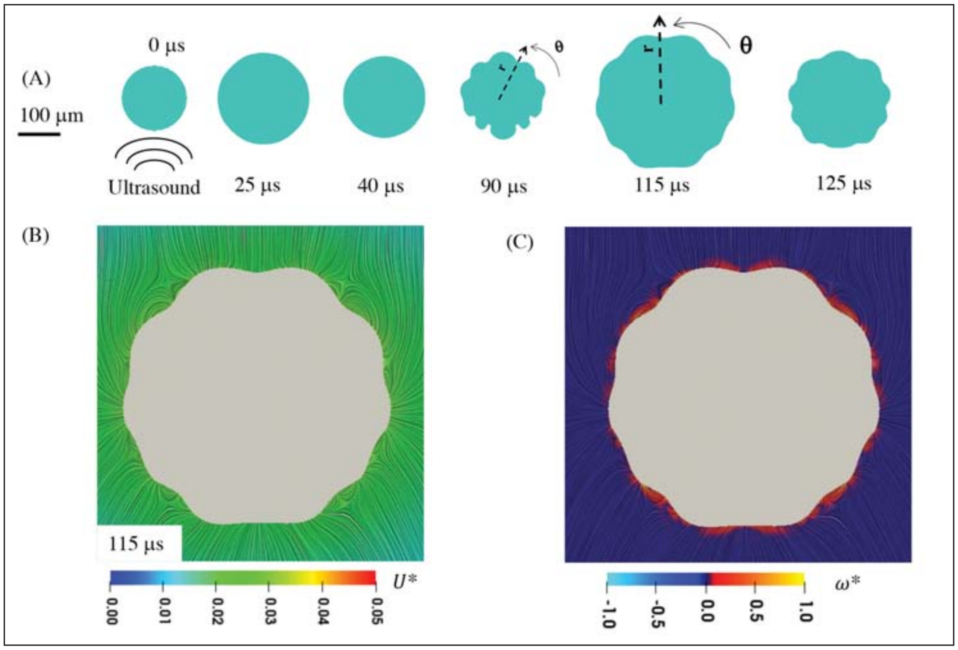
by: Joydip Mondal, and Prof. Parthasarathi Ghosh, Process Equipment and Design Laboratory, Indian Institute of Technology Kharagpur, India

Our Cool Cryo Guest feature highlights articles submitted by industry experts. We encourage you to send in your work for possible inclusion in a future issue. For consideration, please contact Anne DiPaola at editor@cryogenicsociety.org.

Cryogenic Bubble Interaction: Challenges, Motivation and Potential Benefits in Cryosurgery

Cryogenic fluid management systems use pumps, turbines, pipes (chilldown lines), valves/orifice, etc., operating at very low temperatures (below 120 K) that are at considerable risk of heat-inleak from ambient surroundings (300 K). This leads to the development of a multiphase environment, consisting of both liquid and vapor, and manifests as several bubbles that undergo intense growth and collapse (commonly known as cavitation). Cavitation damage is a well-known risk to equipment, often causing the failure of the entire cryogenic system. However, bubbles in cryogenic systems need not always be a threat. Our investigation reveals the useful nature of bubble oscillation and its potential for specific applications at liquid nitrogen (LN_2) temperature.

This is possible when we look more closely at the different forms of bubble interaction that ultimately lead to cavitation damage. These include liquid jets, shockwaves, streaming motion, etc. Among these, streaming motion in liquid dominates when the bubble keeps oscillating in the presence of an acoustic perturbation (or soundwave), something quite like that taking place in a turbopump. It has been pointed out by previous authors that bubble interaction depends on certain physical properties of the fluid: compressibility, surface tension and viscosity for example. When compared to fluids at room temperature, these values vary by a significant margin for cryogens, LN_2 for example. Hence, the flow features in multiphase LN_2 would likely vary from that in water.



(A) Subfigures show sequential evolution of bubble shape with time under the effect of ultrasound. Here, bubble and surrounding liquid are assigned properties of N2 vapor and LN₂ respectively, at 20 kHz acoustic field. (B) The flow pattern developed corresponding to an evolving shape is shown amidst velocity colormap, with streamlines indicating the flow path. (C) The vorticity field developed by the bubble at the same time instance. *Credit: Indian Institute of Technology Kharagpur, India*

Challenges

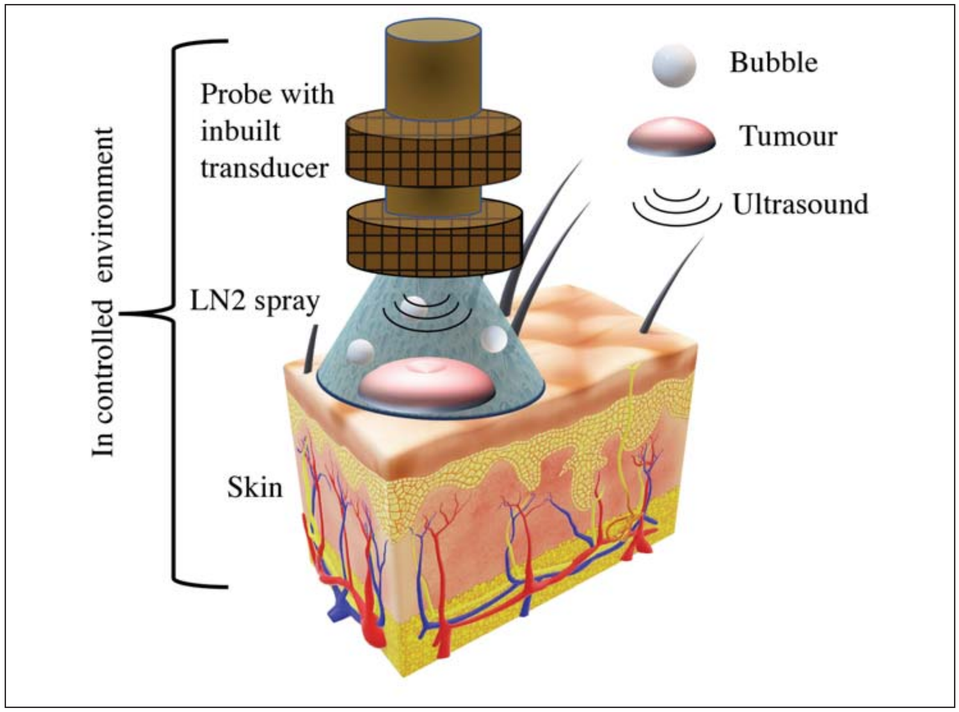
But there are *many challenges* with investigating bubbles in LN_2. First and foremost, bubble oscillation generally takes place over a short time (~ microsecond) and spatial scales (~ micrometers). It is very difficult even with modern equipment to isolate and examine nitrogen bubbles at that resolution in LN_2. In addition, there are other challenges to running repeatable experiments on such a small entity as a bubble in a controlled environment. The accessory costs (high-speed camera, specially fabricated leakproof vessels with optical windows, etc.) further add to the challenges of operating with LN_2.

Motivation

But these difficulties are much less when weighing the motivation behind applying nitrogen bubbles in creative applications, and one of these is the role of LN_2 in cryosurgical operations. Cryosurgery provides a unique method of cancer treatment, wherein the premalignant and malignant tissues are frozen by open spraying of LN_2. This is followed by several alternate cycles of freezing and thawing until the frozen part peels off/detaches from the body. This is relatively painless because liquid nitrogen can desensitize nerves around a frozen tissue. Also, LN_2 – being non-toxic, inert and non-irritating – can sanitize the skin around a cancerous tissue. However, the multiple freezing and thawing cycles (until the portion peels off) invite problems like osmotic stress, denaturation of macromolecules, the release of lysosomal proteases, membrane disruption and intracellular ice formation. Hence, a less risk-prone cryosurgical process can help improve its effectiveness.

Potential Benefits

Oscillating bubbles in the presence of ultrasound can help improve the efficiency of these cryosurgical processes. This is because bubbles are known to generate several chemical and physical effects during their sustained oscillation or microstreaming. These oscillating bubbles, when introduced into a liquid, are known to inactivate microbes and generate shear forces in the adjacent liquid. However, the mechanism of these sub-processes is not clearly understood. Also, the typical governing parameters for micro streaming are not clearly documented.



Schematic demonstrating the idea of an ultrasound-aided cryosurgical process comprising oscillating bubbles in liquid nitrogen for operating on a tumor. This idea was also discussed in Mondal et al., "Acoustic Cavitation-induced Shear: A Mini-Review," Biophysical Reviews (2021) and Mondal et al., "Numerical Investigation of the Flow-field Due to Oscillating GN2-LN2 Interface in Presence of Ultrasound," Space Cryogenics Workshop (2021). *Credit: Indian Institute of Technology Kharagpur, India*

Our Findings

We try to navigate through this complex problem by first understanding the chemical effects of bubbles in controlled environment, with low dissolved gas concentration. Our studies (albeit in water) suggest that under such conditions, bubble collapse, as well as the rate of chemical reaction, is sharply reduced. This indicates that there is a much lesser chance of any untoward chemical reaction under evacuated conditions, irrespective of the solvent liquid.

To understand the physical effects of bubbles, two-dimensional and three-dimensional simulations were then performed to capture the dynamics of a single bubble (assigned properties of nitrogen vapor), located in the middle of a 20 kHz (and low power) acoustic field. Subcooled LN_2 is selected as the surrounding liquid to assume minimal effects of heat and mass transfer. A fully developed ultrasound standing wave field is simulated around a bubble at resonant conditions. The liquid was free of any dissolved gases, in conjunction with our earlier experiment. We observed the shape evolution of the bubble with time (for both 2D and 3D simulation), showing a dominant and periodic shape (called shape mode oscillation). Additionally, 3D simulations helped capture the simultaneous formation of flow vortices in the adjacent liquid boundary layer. These vortices help generate shear stresses. The number of these vortices depends indirectly on the dominant shape mode.

It was observed that the dominant shape could be controlled by indirectly controlling the operating pressure amplitude of the perturbation and the bubble radius. This finding offers confidence in the fact that shear stresses required for cryosurgery can be induced by bubbles and tuned by changing the power amplitude and frequency (to control the bubble size distribution) of the perturbation. Also, a controlled low-pressure environment (using a vacuum pump) would prevent external gas contamination. This may help check any chemical effects.

By combining conventional cryosurgery with simple ultrasonic equipment, one can facilitate an ultrasound-aided cryosurgical process, for efficient removal of cancerous tissue. This can be accomplished by operating a piezoelectric transducer in tandem with the nozzle spraying LN_2 under evacuated conditions. The power amplitude and frequency of the transducer would be the operating parameters alongside that of the LN_2 spray.

Overall, cryogenics can help provide a solution to this increasingly widespread problem by updating conventional techniques with inexpensive ultrasound-based techniques, reducing the diagnosis time as well as the associated risks with post-surgery complications, and above all, offering relief to patients using modern treatment. Our preliminary results suggest that cryogenic flow-field can be abrasive and prospective for additional futuristic applications.

Cool Fuel

by Dr. Jacob Leachman, Associate Professor, Washington State University, jacob.leachman@wsu.edu

Hydrogen's Massive Sensing Challenges

I had a realization the other day: most of us may be incorrectly measuring cryogenic hydrogen mass flows. Nearly all types of flow meters are affected—pressure-differential, sonic, thermal, etc. The differences arise from changing thermophysical properties of hydrogen at cryogenic temperatures, and are more complicated for flow metering than just adjusting for temperature and pressure. Hydrogen at room temperature sourced from a cryogenic dewar can also be affected, which covers most hydrogen use. In response, this column covers the basics of mass flow metering and how to correctly measure a cryogenic hydrogen mass flow.

Mass flow metering is the foundation of custody exchange. I once ran the numbers for delivering a single load of the LNG Rivers tanker vessel and was shocked to see that an engineer's annual salary was in the margin of error for just the density of the LNG! There are two basic choices for mass flow meters: an absolute-type flow meter, such as a Coriolis, or relative meters based on thermophysical properties. Coriolis meters utilize rotating or vibrating tubes and measure impedance due to the mass flow. As a result, Coriolis meters are typically better for larger scale applications with significant mass flows. The low mass of hydrogen causes reduction in sensitivities and difficulty in controls at these temperature extremes. For most of us dealing with smaller cryogenic hydrogen mass flows, Coriolis meters are not yet practical.

Relative mass flow meters measure changes in thermophysical property indications due to flow velocity. A simple type of flow meter is a thermal anemometer. Thermal anemometers utilize a hot-wire in a constant resistance Wheatstone bridge configuration where the power output required to keep the hot-wire at a constant resistance correlates to the flow velocity, assuming the thermal conductivity is known at the measured temperature and pressure. However, thermal conductivity was one of the first and most highly variable properties of the ortho-parahydrogen spin isomers of hydrogen. Any thermal-based flow meter must also measure the ortho-parahydrogen composition of the flow to accurately determine the thermal conductivity for meter calibration. The easiest way to measure the thermal conductivity of a flow is a hot-wire anemometer and, unless you know the ortho-parahydrogen composition, we're back where we started.

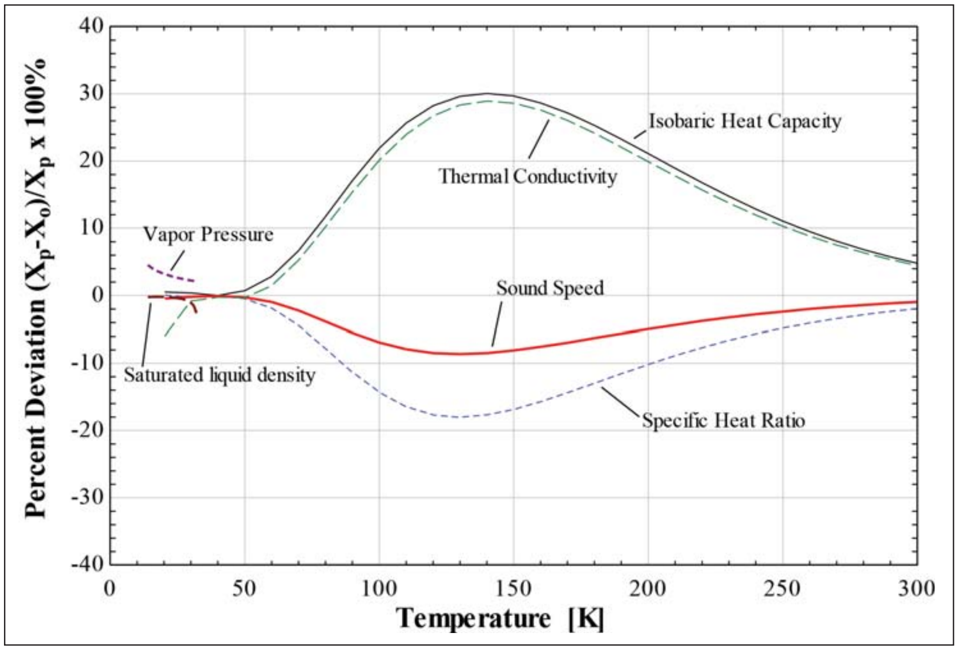
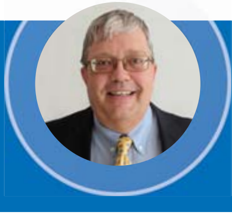


Figure 1: Percent deviation between parahydrogen and orthohydrogen thermophysical properties below room temperature. *Credit: Jacob Leachman*

What if we used a non-thermal mass flow meter? Pressure differential-based orifice plates, targets and venturi meters should consider the compressibility of hydrogen (the highest of any substance). The standard equation for mass flow from a flow orifice meter with compressible flow relies on the ratio of specific heats. Traditionally assumed as constants for a fluid, the surprising result is that this ratio varies based on ortho-parahydrogen composition as well. Sonic and ultrasound gauges? Yep, sound varies with ortho-parahydrogen composition too. The figure above shows the percentage variation in these properties between ortho- and parahydrogen versus temperature over the cryogenic regime. And we shouldn't use a hot-wire anemometer to measure the composition before going to a different relative flow meter, as they both suffer from not knowing the ortho-parahydrogen composition.

What if we just warmed the hydrogen to room temperature? Although better than at some temperatures, there are still differences between para- and orthohydrogen larger than the typical accuracies of these instruments. If we were relying on our flow meter to account for hydrogen utilization, we'd be wondering how we ended up with more than we started with; or even more troubling, where the hydrogen was escaping to.

▶ *continues on page 29*



Cryo Bios

by Dr. John Weisend II, European Spallation Source ERIC, CSA Chairman, john.weisend@esss.se

Heinz London

Heinz London, the younger brother of Fritz London (***Cold Facts*** Vol. 38 No. 3) made important theoretical and experimental contributions to a wide range of topics: superconductivity, superfluid helium, production of cold neutrons, isotope separation and dilution refrigerators.

Heinz London studied physics in Bonn, Berlin, and Munich. In 1931, he started as a graduate student at the Technische Hochschule in Breslau, Germany, where he studied under Franz (Sir Francis) Simon (***Cold Facts*** Vol. 37 No. 2), working on the topic of superconductivity. Heinz was particularly interested in superconductors carrying radiofrequency alternating currents. It was well known that direct currents in superconductors experienced no resistive losses, but Heinz postulated in his 1934 thesis that alternating currents would cause resistive losses in superconductors. He attempted to measure these losses, but the equipment he used wasn't sensitive enough at the frequency (40 MHz) at which he was experimenting.

In 1934, having received his doctorate, Heinz, along with Simon, Kurt Mendelssohn (***Cold Facts*** Vol. 37 No. 1) and Nicholas Kurti (***Cold Facts*** Vol. 38 No. 1), moved from Breslau to Oxford. Fritz London also came to Oxford from the University of Berlin. This transfer of talented scientists, a direct result of Hitler's rise to power, established Oxford University as a leading center for research in cryogenics and superconductivity. In Oxford, Heinz, working together with his brother, Fritz, developed the London equations which model the electromagnetic behavior of superconductors. Heinz London also continued his experiments with radiofrequency superconductivity, this time up to 150 MHz, but he was still unable to measure any resistive losses.

Funding was limited at Oxford, and in 1936, Heinz moved to the University of Bristol; Fritz went to the University of Paris at about the same time. While in Bristol, Heinz London had a number of breakthroughs. He was finally able to measure resistive losses in superconductors carrying radiofrequency currents. We now know that such losses increase as a function of frequency, and London was able to successfully measure them at 1,500 MHz. This result provided fundamental information about the phenomena of superconductivity. The explanation given by London was that within a superconductor, some electrons participate in the superconductivity, whereas some do not; today we know this to be true. It was also a very early step to developing practical radiofrequency superconductors.

Another important result of London's time in Bristol was his explanation, based on thermodynamics, of the observed fountain effect in He II (superfluid helium). This paper not only explained the effect, but also predicted the complementary mechanocaloric effect. This effect was actually discovered by J. Daunt and K. Mendelssohn after London's paper was written, only before its publication.

London was briefly interred as an enemy alien on the Isle of Man at the start of the second World War. However, he was fairly quickly released so that he could work on the problem of uranium enrichment with Simon and Kurti. London made a number of contributions to this effort for the remainder of the war. In part, due to his wartime work, Heinz London became one of the early employees of the Atomic Energy Research Establishment in Harwell, UK. He remained there the rest of his professional life. Initially, he worked on isotope separation, in particular the production of isotopes such as ^{13}C used in biology and medical studies. He moved back into cryogenics by developing a system to produce cold, i.e. low energy neutrons, by scattering reactor neutrons through a liquid hydrogen moderator. He then used cold neutrons to probe the structure of liquid helium.

Heinz London was the first to propose the idea of dilution refrigeration. In 1951, he suggested that diluting ^{3}He with ^{4}He would produce cooling. London and colleagues at Harwell worked to develop such a refrigerator, but significant work, and even some new discoveries, were required. The first operating dilution refrigerators were built at Leiden University and Manchester University in 1965. These refrigerators were commercialized and remain a primary method for reaching temperatures below 1 K.

Heinz London

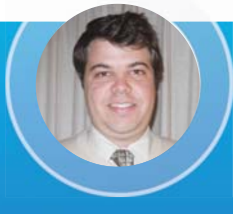
Born November 7, 1907

Died August 3, 1970

Oxford, England

Throughout his life, Heinz London made significant contributions to fields that remain important to this day. For example, radiofrequency superconductivity, He II, cold neutrons and dilution refrigeration are all key technologies for my home institution, the European Spallation Source. London's contributions were recognized by a number of awards. He was made a Fellow of the Royal Society in 1961 and awarded the Simon Memorial Prize in 1959.

A broader biography of Heinz London may be found in D. Schoenberg's profile of London in *Biographical Memoirs of Fellows of the Royal Society*. Examples of London's work can be found in "Thermodynamics of the Thermomechanical Effect of Liquid He II" and P. A. Egelstaff and H. London's "The Scattering of Cold Neutrons by Liquid Helium," both appearing in *Proceedings of the Royal Society of London, Series A, Mathematical and Physical Sciences*. Information on commercially available dilution refrigerators may be found in the CSA Buyers Guide: **www.csabg.org.**



Space Cryogenics

by Wesley Johnson, NASA Glenn Research Center, wesley.l.johnson@nasa.gov

High-Capacity 20 K Cryocooler Developments for In-Space Applications

Active cooling via cryocoolers is required for maintaining cryogenic propellants for extended periods of time to enable NASA's planned long duration missions. Cryocoolers enable propellant conditioning, tank pressure control, and the liquefaction of In-Situ Resource Utilization (ISRU)-generated propellants. Utilizing state-of-the-art passive cryogenic fluid management technologies and excluding active cooling, cryogenic storage on-orbit is limited to approximately 30 to 100 days, though this is highly dependent on the architecture, propellant type and tank size. NASA's planned long duration missions, particularly to Mars, will require long-term storage (up to five years) of cryogens. To enable such storage times, zero boiloff conditions (net heat load of zero) must be achieved, meaning all heat loads must be intercepted and/or removed from the propellant via active cooling. Otherwise, heat entering the propellant will result in boiloff, which leads to tank pressurization, which would then require ullage venting, hence propellant loss. [1-2]

For in-space propulsion applications using cryogenic propellants, there are generally two main temperature ranges: approximately 20 K for nominal operating pressures of hydrogen and 90 to 120 K for oxygen and methane. For those two temperature classes, Stirling and pulse tube type cryocoolers have been developed and flown with heat removal capacity on the order of 1 W of heat removal for 20 K and 20 to 30 W of heat removal for the higher temperature range. [3] Conceptual vehicle studies performed by both GRC and MSFC have shown that there is a need for much larger cryocoolers at both ranges. [4,5] In addition to increasing the cryocoolers lift capacity, they also need to be more energy efficient. state-of-the-art 20 K flight pulse tube or Stirling cryocoolers consume approximate 370 watts of input power (W_{elec}) per watt of

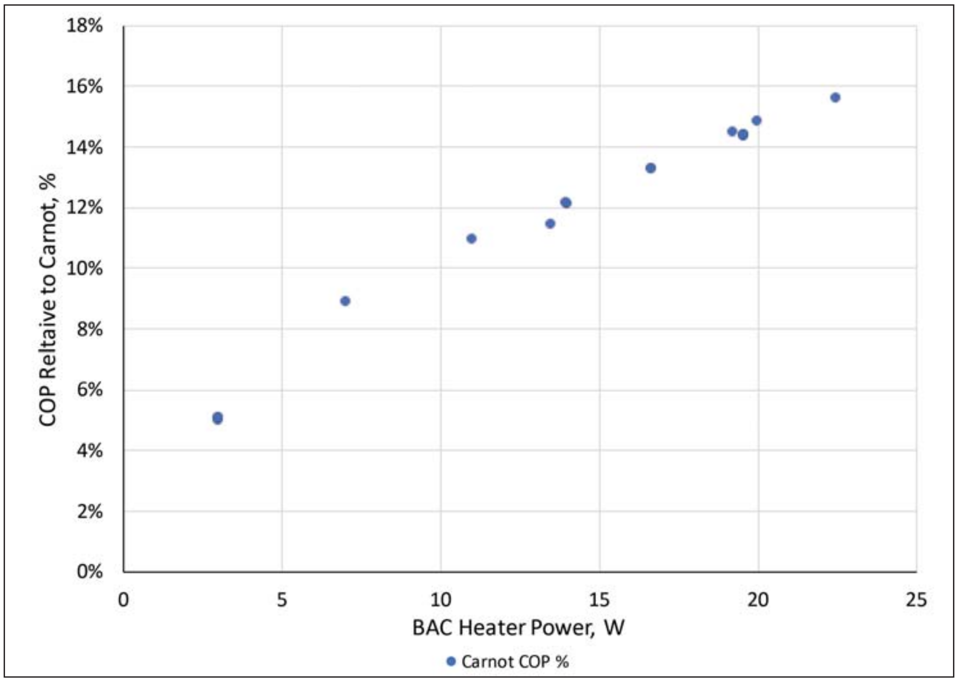


Figure 1: 20 K cryocooler performance as a function of heat removal power. Note: this data does not account for power savings from turbine recovery or harness losses. *Credit: Wesley Johnson*

Figure 2: 20 W / 20 K cryocooler in Creare's clean room. *Credit: Creare, Inc.*

heat removal ($W_{thermal}$) and weigh 18.7 kg per watt of heat removal.

To improve the performance of the 20 K class cryocoolers, both in heat removal and efficiency, a small business innovative research (SBIR) call was used to develop concepts as well as explore different refrigeration cycles' performance and efficiency. Of the cycles studied, the Reverse Turbo-Brayton (RTB) cycle provided the most promising solution moving forward. The RTB-cycle refrigerators provide specific power and specific mass improvements and can be more easily scaled up further if necessary. Creare, based on its previous SBIR performance, was chosen to further develop a high-capacity, 20 K "flight-like" RTB cryocooler. During development, multiple challenges were encountered throughout the program with the bearings of the turbomachinery due to the very tight tolerances (within 1/50 the width of a human hair), and with operations of the compressors at speeds in excess of their legacy design speed. Additionally, the recuperative heat exchangers are a novel and compact design. Originally developed for race car radiators, they were modified for flight cryocooler applications and included welding over 6,000 tubes into each of five recuperator modules (over 60,000 total welds). [7] After successful maturation of the component technologies, these components were integrated into a flight-like cryocooler configuration.

Testing of the cryocooler occurred at Creare in May 2022, covering two different phases: manual chilldown and cryocooler performance mapping. Multiple different chilldown tests occurred as the test team learned how the cryocooler and support hardware responded to new control algorithms. A total of ten discrete data points were taken at temperatures of 22.8 K (corresponding to the saturation temperature of liquid hydrogen at 25 psia) and 20 K, along a range of load input power from 3 W to 22.4 W. The overall performance of the cryocooler met threshold requirements with maximum cooling of 19.2 W at 20 K with a heat rejection temperature of 285 K and a specific power of 91.6 $W_{elec\text{-}input}/W_{heat\_removal}$. The coefficient of performance related to Carnot was approaching 16%. Further results of the testing are provided by Nugent et al. [6] and Cragin and Zagarola [7] at the International Cryocooler Conference.

$$COP_{Carnot} = \frac{\left(W_{heat\ removal}/W_{input}\right)}{\left(T_{cold}/(T_{warm} - T_{cold})\right)}$$

The test data gathered demonstrates the viability of the 20 W at 20 K RTB cryocooler and that its performance relative to the Carnot efficiency of a refrigerator was similar to high performance industrial type systems. The data provided also allows for increased confidence to mission planners for future exploration architectures such as the Nuclear Thermal Propulsion or other oxygen/hydrogen propulsion systems. The test hardware will now proceed into a multi-month characterization test sequence at Creare to better characterize the performance and put more operating time on the system. Following the characterization testing, the hardware will be delivered to Glenn Research Center for planned vibration testing to verify the cryocooler system can survive launch environments and further post-vibration life testing.

References

[1] Plachta, D.W., Feller, J.R., and Guzik, M.C. (2016). "In-Space Cryogenic Propellant Storage Applications for a 20 W at 20 K Cryocooler," *Cryocoolers* 19, ed. Miller, S.D. and Ross Jr, R.G., Boulder, CO.

[2] Dankovich, J. (March 2022). "GO: Cryogenic Fluid Management, NASA Space Technology Mission Directorate," NSPIRES.

[3] Cha, J.S., Yuan, S.W, Space Cryocooler Vendor Survey update: 2013, Aerospace Report number TOR-2013(3905)-4, 2013.

[4] Meyer, M.L., Hartwig, J.W., Sutherlin, S.G., and Colozza, A.J. (2021). "Recent Concept Study for Cryogenic Fluid Management to Support Opposition Class Crewed Missions to Mars," Space Cryogenics Workshop.

[5] Plachta, D., Hartwig, J., Stephens, J., Carlberg, E. (2018). "Zero-Boil-O ff System Trades Applied to Nuclear Thermal Propulsion," *Cryocoolers* 20, ICC Press, Boulder, CO. pp 439 -446.

[6] Nugent, B.T., Grotenrath, R.J., and Johnson, W.L., "20 Watt 20 Kelvin Reverse Turbo-Brayton Cycle Cryocooler Testing and Applications," presented at the 22nd International Cryocooler Conference (ICC22), Bethlehem, PA.

[7] Cragin, K.J., and Zagarola, M.V, "Development and Testing of a High-Capacity 20 K Cryocooler," presented at the 22nd International Cryocooler Conference (ICC22), Bethlehem, PA.

Cool Fuel... Continued from page 26

How do we measure a cryogenic hydrogen mass flow correctly? You only have a few options:

1) Know the ortho-parahydrogen fraction by either measuring it using a rotational Raman probe or other flow-insensitive technique, or assume that you know the composition due to equilibration at room temperature or 20 K. Then use a program like REFPROP to determine the correct thermophysical properties to input into the meter correlations.

2) Use an absolute flow meter at room temperature or a combination of relative and absolute mass flow meters, for instance a hot-wire to determine the ortho-parahydrogen composition and a room temperature Coriolis gauge.

I have yet to see a mass flow meter manufactured to account for, let alone acknowledge, these challenges. But with more of us looking to utilize liquid hydrogen, I'd enjoy the opportunity to help someone figure it out. And with any luck, there will eventually be a day when most are familiar enough with ortho-parahydrogen property variation that mass flow meters will be designed to auto-compensate.

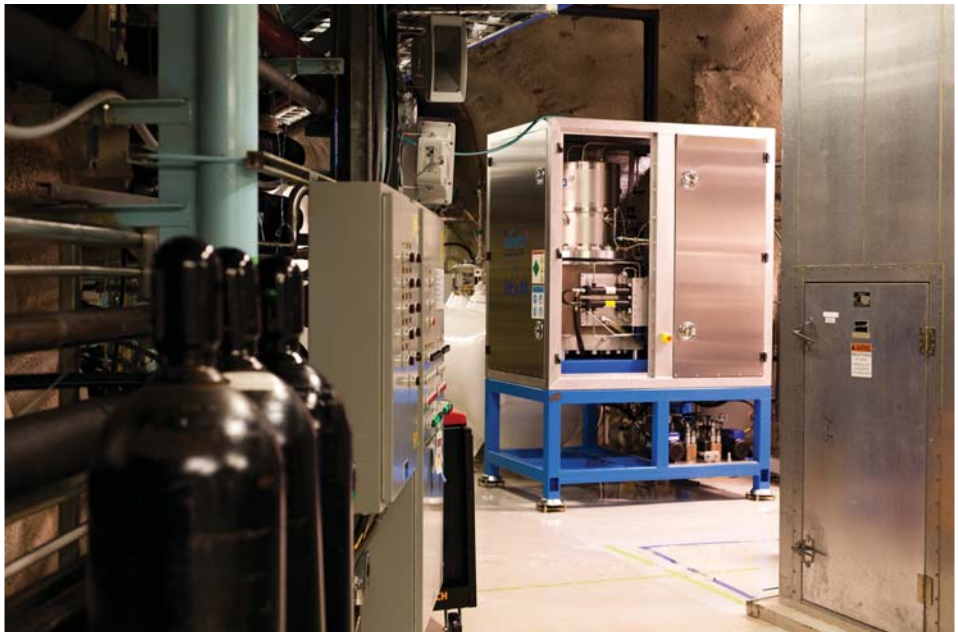
Extreme Cool – Making Liquid Nitrogen in a Deep Underground Clean Lab

by Blaire Flynn, Senior Education and Outreach Officer, SNOLAB, and Jenna Saffin, Education and Outreach Coordinator, SNOLAB

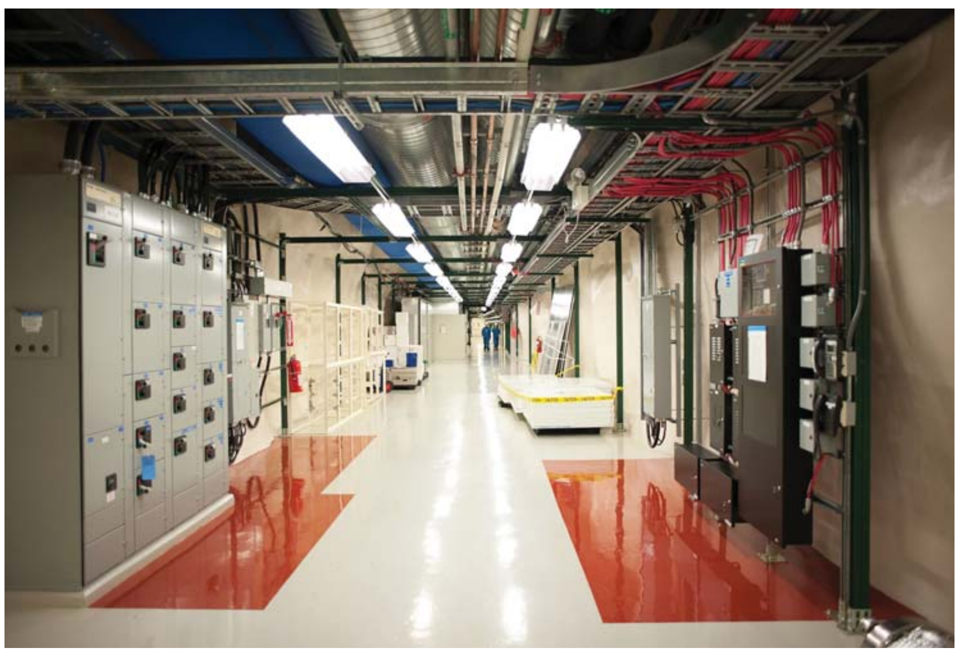
SNOLAB is Canada's deep underground research laboratory, located two kilometers underground in Vale's Creighton mine near Sudbury, Ontario, Canada. SNOLAB is a unique facility, providing a low background environment designed for scientific research and operates a 5,000m² underground campus as a class-2000 clean lab. While the science program is focused on astroparticle physics, the location is also well suited to biology, geology and low radiological studies.

SNOLAB is an expansion of the underground facilities created to host the Sudbury Neutrino Observatory (SNO) experiment. The success of SNO, both scientifically and as a model for an underground facility, helped to secure the funding necessary to construct SNOLAB and the expanded facility that opened in 2012. Since then, the lab has hosted a suite of world-leading experiments focused primarily on dark matter and neutrino studies. These experiments are run by large international collaborations, many designing multi-tonne detectors that require cutting-edge technology and take decades to plan, build and operate.

One of the challenges of hosting sensitive detectors operating at cryogenic temperatures is providing the necessary support services in an underground environment with limited space and unique shipping challenges. (Every item and person entering the lab travels underground on the mine cage and can be thoroughly cleaned before entering the clean lab.) To support the experiments effectively and efficiently, SNOLAB has built several facilities in the underground lab: an ultrapure water plant, a scintillator plant (effectively an oil refinery), low-background counting facilities, a chemistry lab, a machine shop and more. Recently, three diesel generators on the surface were tied into the lab's power circuit to reduce the impact on experiments during power outages and planned maintenance.



LN2 plant installation. *Credit: Fabrum-SNOLAB*



Main hallway at SNOLAB. *Credit: Gerry Kingsley*

As SNOLAB prepares to host next-generation detectors that have increasing demands in terms of cooling and cryogenic operations, continuous power becomes more essential.

Next-generation experiments that operate at cryogenic temperatures will also have higher liquid nitrogen demands. SNOLAB experiments already have high LN_2 demands: some experiments use it for cooling and others use it as a high-purity inert cover gas. (Cover gas maintains constant pressure in large detector vessels and provides a barrier between the detector medium and lab environment.) Several of SNOLAB's underground support facilities, such as the ultrapure water plant and

View past the CUTE experiment at SNOLAB. *Credit: Gerry Kingsley*

low-background counting facility, also use LN_2 in their processes.

Until recently, all LN_2 used in the underground lab – about 2,000L per week – had to be shipped underground in 230L dewars. In addition to the resources and logistics necessary for shipping and cleaning these dewars, the process took time, resulting in nitrogen boiloff during the journey. To meet this challenge, the SNOLAB team recently completed installation of an LN_2 plant that can produce 18L/hour in the underground lab. This achievement is the result of years of planning and hard work by nearly every team involved in the underground and surface operations of SNOLAB.

"It is an impressive accomplishment that means SNOLAB now has on-demand LN_2 underground, ensuring continuous access to its current and future science program," said Steven Back, Operations Engineer for the project. SNOLAB contracted Fabrum to create a custom plant that would meet the lab's LN_2 needs and work within the constraints of the lab's location and cleanliness requirements. The plant is made up of four components: a 3,000L dewar, a nitrogen generator, an air compressor and a cryocooler.

The dewar was manufactured by Wessington in the UK and was purpose-built to ensure it could be smoothly shipped underground. It travelled by sea, stopping in France and Germany before heading up the St. Lawrence River to Montréal, and then to Sudbury by truck. Holtec (USA) produced the nitrogen generator which scrubs everything except nitrogen and argon from the compressed air with a resulting purity of 99.998% and less than 10 ppm oxygen. The highly specialized pulse tube cryocooler was machined and manufactured by Fabrum in New Zealand, alongside the control panels and acoustic enclosure for the plant. The cryocooler was also shipped by sea, via the Panama Canal, before arriving by train from Philadelphia.

"The completion of the plant itself is a big milestone," said SNOLAB Director of Operations Allan Barr. "Not only does this remove the logistical demands of shipping liquid nitrogen underground, but it also helps to expand our technical expertise to support future experiments." Experiments no longer wait for shipments of liquid nitrogen to arrive underground. In addition to reducing labor demands, having an operational plant underground frees up valuable space on railcars for experiment components and other supplies.

Said SNOLAB Director of Research Jeter Hall, "Many of the future experiments planned for SNOLAB have substantial cryogenics requirements. This plant enables research and the development of robust operations that will bolster the scientific impact of these projects." The installation of this plant and the additional capacity it brings positions the facility well to host next-generation experiments – a significant milestone in the year that SNOLAB is celebrating its tenth anniversary.

Look who's NEW in the Cold Facts Buyer's Guide

Cold Facts Buyer's Guide is the place to find suppliers in every area of cryogenics and superconductivity. These are the new suppliers added to the Buyer's Guide since the last issue of ***Cold Facts***. Find it online at **csabg.org**.

CryoTechnics LLC*

Providing cryogenic process sensors, controls, and design and testing services with a focus on thermometry, advanced development tools, and collaboration to support and advance low-temperature application or research.

Deep Cryogenics International

Deep Cryogenics International is a deep cryogenic treatment facility providing an on-site research lab. It manufactures and leases industrial-size equipment and demonstrates the technology to large industrial customers.

iLenSys Technologies India Pvt Ltd*

iLenSys is a one-stop engineering service provider in the field of Life Sciences and Process Industries. The company's expertise lies in new product development and product life cycle management, among other areas.

JEVI Vacuum Instruments

JEVI Vacuum Instruments is dedicated to scientific and industrial instrumentation, with its main activity based on vacuum systems, gas analysis, cryogenic systems, and helium leak detection. The company also offers technical service and support.

Label Solutions Inc.

Supplier of custom (branded imprint) pressure sensitive regulatory compliant labels and large signage for the compressed gas industry. Specializes in testing and engineering label-to-surface solutions.

m-tech gmbh

m-tech's ball valves are specially designed and manufactured to meet relevant cryogenic standards (DIN EN 1626, BS 6364). The valves are suitable for handling cryogenic liquefied gases such as LIN, LAR, LOX and LNG.

Stäubli Corporation

Stäubli's KBH breakaway coupling provides a safe solution for temperatures ranging from -196 °C to +65 °C. The KBH disconnects the line at a defined tensile load, and non-return valves immediately seal it tightly and reliably during disconnection.

***CSA CSM**

A Quarter-Century Industry Experience Brings About New Company

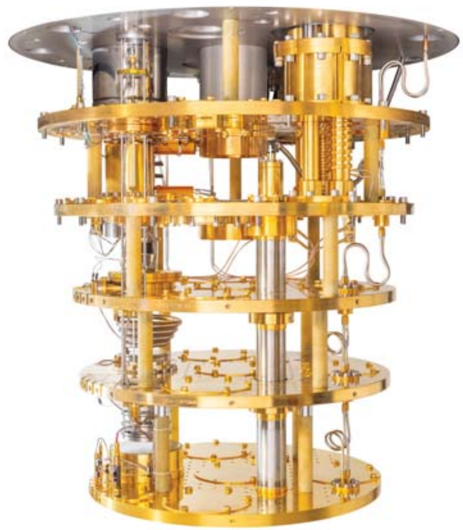
After 25 years in the high-tech cryogenics field, while employed at Cryogenic Technical Services (CTS) and High Precision Devices (HPD) and working with some of the best scientific minds in the world, Charlie Danaher started Danaher Cryogenics in early 2022 to respond to the ever-increasing demand for elegant, collaborative solutions to address the new cryogenic challenges. To paint a picture of Danaher Cryogenics' offerings, a brief review of Charlie's experience is in order. The following handful of high-profile projects represent the foundation for Danaher Cryogenics:

Propellant Densification Without Use of Rotating Machinery—Worked on by CTS with Boeing, the outcome of this project was a novel system that provided LN_2 subcooled to 65.5 K (118 Rankine) at a rate of 32 lbm/sec and a heat rejection rate of 600 BTU/sec. [1]

Main Cryostat for Deuterium Test System for the National Ignition Facility (NIF) Cryogenic Target System (NCTS)—CTS worked with General Atomics on their Inertial Fusion project, located at the National Ignition facility at Lawrence Livermore National Laboratory. The product delivered was used to cool deuterium targets to ~7 K and held to a temperature stability of ~1 mK. [2]

ATRAP II Trap—CTS worked with Harvard University on ATRAP II Trap for trapping and studying antihydrogen atoms. The CTS-delivered system was a 19" warm bore cryostat that housed a superconducting 1T solenoid magnet. The full system went on to be installed at CERN. [3]

While at HPD, Charlie was instrumental in developing the Adiabatic Demagnetization Refrigerator (ADR) family of cryostats, as well as a dilution refrigerator cryostat. The ADR family of cryostats became the most successful commercialization of lab-based ADR technology in the world. The ADR cryostats are used worldwide in astronomy, quantum computing, and nuclear non-proliferation efforts. It's from this basis that Danaher Cryogenics entered the market. Establishing business in Boulder, Col., allows Danaher to capitalize on the rich cryogenic roots in the area, including the notable National Institute of Standards and Technology (NIST) Laboratory, with which Charlie has collaborated in developing several cryostat models.



Leiden Cryogenics Cryostat Model CF-CS110, available with 500, 1,000 and 1,500 microW @ 100mK*. Credit: Leiden Cryogenics*

Continuing with the cryostat product focus, Danaher Cryogenics is excited to offer a range of 1 K and millikelvin cryostats. To offer the broadest range of systems possible, Danaher is partnering with other reputable cryogenic companies, and the team can now offer 100 mK cooling with powers ranging from just a few microWatts to 1,500 microWatts. For instance, to address the ever-increasing need for high-power, millikelvin systems, Danaher is partnering with Leiden Cryogenics to offer dilution refrigerator sales and service in North America. Leiden cryostats enjoy an excellent reputation and have been used in many reputable institutions on exciting projects. Leiden's most popular cryostat is the Model CF-CS110, which offers impressive 100 mK cooling powers ranging from 500 microW to 1,500 microW.

Chase Research Cryogenics (CRC) is legendary for making sorption-pumped refrigerators used in many cryostats throughout the world. Danaher is proud to be partnering with CRC to provide full cryostat systems. These systems will include single-shot and continuous 1 K, .5 K and continuous 100 mK mini-DR systems. Particularly exciting is CRC's Continuous Miniature Dilutor (CMD) which offers unique, compact, continuous 100 mK cooling. The special beauty of the CRC CMD is that one can obtain continuous 100 mK cooling without the hassles typically associated with dilution refrigerators. For instance, the CMD is a small self-contained unit, only requiring a few liters of expensive He-3 gas. And because the CMD is sealed, there is no need for the usual external gas-handling system, thereby eliminating the service required for pumps and greatly reducing the chances of gas loss. In the past, CRC customers were typically forced to exert the effort to incorporate the Chase refrigerator into a cryostat themselves, usually with the customer needing to design and fabricate their own cryostat. With the Danaher partnership, customers can order a complete cryostat, with the CRC cooler already integrated.

The need for new cryogenic systems does not appear to be waning. Every day, new uses are discovered, requiring new products. Danaher Cryogenics is up for the challenge. By exercising the relationships formed over the last quarter-century, and employing the experience gained from many past successes, Danaher Cryogenics embraces the future with optimism and enthusiasm. **https://danahercryo.com**

References:

[1] **https://arc.aiaa.org/doi/abs/10.2514/6.2002-3599**

[2] **https://fusion.gat.com/pubs-ext/AnnSemiannETC/A23852_sec3_2.pdf**

[3] **https://dash.harvard.edu/handle/1/14226066?show=full**

Are We Alone in the Cosmos? Space Dynamics Lab to Help Answer the Question

Utah State University's Space Dynamics Laboratory (USU SDL) announced in May 2022 that it has delivered a critical subsystem to NASA's Jet Propulsion Laboratory (JPL) for integration onto the Nancy Grace Roman Space Telescope. The Cryogenic Thermal Subsystem for the Roman Coronagraph Instrument was delivered to JPL at SDL's facilities on USU's Innovation Campus.

SDL Mechanical Engineering Associate Paul Fluckiger (left), Mechanical Engineer Trever Mitton (center), and JPL Cryogenic Thermal Subsystem Project Lead Weibo Chen prepare the CTS for delivery to JPL in this April 25, 2022 photo at SDL facilities in North Logan, Utah. *Credit: SDL/Kelden Peterson*

SDL designed, built, tested, and delivered the cryogenic thermal subsystem, which includes two space-qualified radiators, two thermal straps, and support structures that will reject heat generated by the detectors of Roman's sensitive coronagraph instrument. One of two instruments on the Roman Space Telescope, the Roman coronagraph instrument will demonstrate technology to enable future missions to discover and characterize planets that could sustain life within their star's habitable zones. Planets within a habitable zone are those within the range of a star where water could exist on the planet's surface.

Since the 1970s, SDL has been at the forefront of developing thermal technologies for space applications. Early in its history, SDL understood the need for cryogenically-cooled instruments to obtain accurate space-based measurements in the infrared and other wavelengths. Now a signature SDL capability, the thermal subsystems SDL designs and manufactures enable exceptionally sensitive instruments, which, in turn, provide scientists with information to better understand the universe and our place in it.

The cryogenic thermal subsystem's most critical function is to provide cooling to maintain the detectors in two of the Roman Coronagraph Instrument's cameras at sufficiently low temperatures, approximately -161 °F, to allow them to function with the required sensitivity. The first-stage radiator shields the second-stage radiator from the heat radiated by the Roman Coronagraph Instrument and other parts of the spacecraft.

Matt Felt, head of SDL's thermal technologies, further explained, "Two thermal straps conduct heat from the cameras to the second-stage radiator, radiating that heat into deep space. Size and weight are premium commodities on any spacecraft, and SDL's new Pyrolytic Graphite Sheet thermal strap technology allows the cryogenic thermal subsystem's mass to be significantly lower than previously possible with metallic straps."

"The talented staff of NASA's Jet Propulsion Laboratory have long been world leaders in developing technologies that enable space exploration. SDL is honored to support JPL and be a part of the historic Nancy Grace Roman Space Telescope program," said Gabe Loftus, SDL's program manager for the project. "The delivery of the cryogenic thermal subsystem for the Roman Coronagraph Instrument shows our commitment to providing quality space flight hardware with the rigorous program execution that has become synonymous with SDL."

The Roman Space Telescope is slated to launch no later than May 2027. With an estimated mass of 4,059 kilograms, the spacecraft will operate at the second Earth-Sun Lagrange point, where the gravities of the earth and sun balance each other, to answer fundamental questions about dark energy, exoplanets, and infrared astrophysics. It will measure the history of cosmic acceleration in addition to searching for worlds beyond our solar system.

Since 1959, SDL has been solving the technical challenges faced by the military, science community and industry, and it supports NASA's mission to drive advances in science, technology, aeronautics and space exploration to enhance knowledge, education, innovation, economic vitality and stewardship of Earth. SDL is a research laboratory headquartered in North Logan, Utah, and has offices in Albuquerque, N.M.; Colorado Springs, Colo.; Dayton, Ohio; Houston, Texas; Huntsville, Ala.; Los Angeles, Calif.; Stafford, Va.; and Washington, D.C. For more information, visit **www.sdl.usu.edu**.

iLenSys Technologies Shares Engineering Design and Digital Services with the Cryo Industry

by Mr. Karthikeyan Devan, iLenSys Technologies, India, Karthikeyan.devan@ilensys.com

iLenSys Technologies, India, is an engineering, digital services and software provider for leading industry players from life sciences to lab equipment, and analytical instruments to industrial products. The company is also ISO 9001:2015 and ISO 13485:2016 certified.

Cryogenic Design Services

iLenSys engineers have worked on static and transportable cryogenic vessels which are vacuum insulated and non-vacuum insulated with applications from medical to industrial use. Our expertise lies in the areas of new product development, product design, industrial design, design for excellence (DfX), finite element analysis, sustenance engineering, electronic product obsolescence management, prototype testing and environmental compliance solutions.

The company has executed design projects per ASME Section VIII - Div I, II, EN – 13458, EN – 13648, EN – 13530, DOT MC 338 (MC-338 Cryogenic Cargo Tank), DOT MC 331 (gases that are liquefied by pressure application only), and API 620 (Design and Construction of Large, Welded, Low-Pressure Storage Tanks).

At iLenSys, we specialize in designs of freezer products, enclosures, containers, vaporizers, end plates, dewar chambers and piping. Instrumentation, including a selection of accessories like valves, seals, O-rings, flex lines and connectors for air separation units, compressor selections, liquid distribution storage tanks, bulk storage tanks and ISO containers, and storage tank capacities ranging from 17L to 48L (for the life sciences sector in adherence to client specifications focusing on low-power consumption and zero greenhouse gas concerns) are key areas of expertise.

3D digital interactives and 3D animations. *Credit: iLenSys Technologies, India*

iLenSys project execution methodology helps product-based companies with cost and time management. We execute projects under non-disclosure agreements by setting up restricted work zones for each client in line with ISO 27001 practices that have enabled product- and project-based OEMs to focus on R&D initiatives by its core team. Best practices also offload day-to-day engineering designs, detailing, shop floor engineering change requests (ECR), assembly issues, FMEA performance, market study, competitor analysis and market intelligence. We also support microprocessor control unit and interface design in relation to product obsolescence issues.

The following is a list of our applications for the cryogenics industry:

- 3D interactive tool for marketing, training and development process
- 3D digital user and service manuals for customers and technicians
- 3D product tour and configurator
- Educational / training videos
- Architectural walkthroughs
- 3D scanning and reverse engineering
- Game object development for XR / mobile

https://ilensys.com

CONFERENCE CONNECT

Keeping Cool at ICC22–International Cryocooler Convention Recap

by Sarah Mitchell, Sumitomo (SHI) Cryogenics of America, Inc. (SCAI), ICC22 Conference Chair

Over 170 attendees from industry, government and academia gathered between June 27-30, 2022, to attend the 22nd International Cryocooler Conference (ICC22). The ICC convenes every two years, allowing attendees to present and explore cutting-edge technical issues and solutions related to cryocooler development and cryogenic applications. This year's event was held at the Wind Creek Bethlehem in Bethlehem, Penn., with virtual elements to accommodate those still travel-restricted due to COVID. Sumitomo (SHI) Cryogenics of America, Inc. (SCAI), from neighboring Allentown, Penn., hosted the event, with Sarah Mitchell and Donniel Hartzell serving as conference chair and conference co-chair.

ICC22 featured more than 60 papers presented across 14 oral sessions, which could be attended both in-person and virtually. *Credit: CSA*

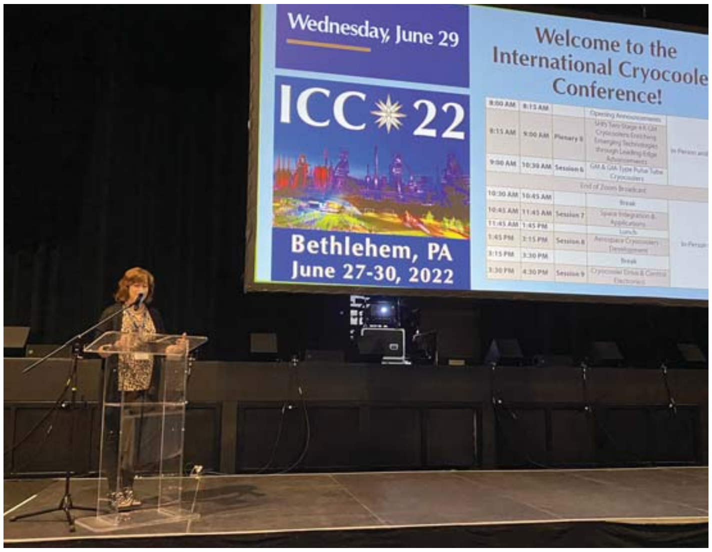
The conference was preceded by the Cryogenic Society of America's Foundations of Cryocoolers Short Course, taught by Ray Radebaugh, NIST-retired, and Ralph Longsworth, SCAI-retired. Attendees not participating in the short course had the option of joining a private tour of the nearby National Museum of Industrial History, a Smithsonian-affiliated museum that interprets industry past, present and future through dynamic exhibits, hands-on interactives and engaging programs.

ICC22 was preceded by the Cryogenic Society of America's Foundations of Cryocoolers Short Course, taught by Ralph Longsworth, SCAI-retired and Ray Radebaugh, NIST-retired. *Credit: CSA*

Conference events at the Wind Creek Bethlehem kicked off on Monday evening, June 27, with a welcome reception in the Vision Bar. Attendees shared light refreshments, relaxed after travel, and took the opportunity to catch up with colleagues. For many, it was the first time networking face-to-face at an international conference in over two years.

The following three days featured more than 60 papers presented across 14 oral sessions. Program Co-Chairs Peter Bradley, NIST, and Tamirisa Apparao, SCAI, along with the program committee, organized sessions into topics including aerospace cryocoolers, Stirling and pulse tube cryocoolers, and GM and GM-type pulse tube cryocoolers. Nearly two-thirds of the authors presented live, while the remainder submitted pre-recorded videos of their presentations.

In addition to oral sessions, the program featured two plenary sessions. The first, "Conceptual Design and Development History of the 6 K MIRI Cryocooler on JWST," was presented by Ronald Ross, JPL-retired. Given the recent release of the James Webb Space Telescope (JWST)'s first images, the presentation provided a timely overview of the Mid-Infrared Instrument (MIRI) cooler concept and development history as it evolved to meet the demanding



Morning announcements at ICC22 – Sarah Mitchell, ICC22 Chair. *Credit: Tamirisa Apparao*

Conference Dinner at the ArtsQuest Center. *Credit: Sarah Mitchell*

requirements of the JWST over its nearly 20-year development.

The second plenary, "SHI's Two-Stage 4 K GM Cryocoolers: Enriching Emerging Technologies through Leading-Edge Advancements," was presented by Mark Derakhshan and Tian Lei, SCAI. Derakhshan discussed the history of the SHI Cryogenics Group and its products, focusing on Sumitomo's 4 K Gifford-McMahon technology. Lei delved into further detail on this particular technology, explaining its critical role in the development of low-cryogen MRIs and quantum applications such as desktop quantum computing and superconducting single-photon detectors.

The plenaries and early morning oral sessions were livestreamed to a virtual audience, comprising approximately 35% of total attendees. After the morning break, in-person attendees continued with live sessions for the remainder of the day. Recordings of the plenary sessions, all presentation slides and author-submitted videos are available to both in-person and virtual attendees through the end of August 2022 on the ICC website (**www.cryocooler.org**).

On the last evening of the conference, in-person attendees were treated to dinner at the nearby ArtsQuest Center. The event featured local Pennsylvania specialties, a liquid nitrogen ice cream sundae bar and a spectacular view of the SteelStacks. The former Bethlehem Steel blast furnaces anchor ArtsQuest's ten-acre campus and serve as both a reminder of Bethlehem's industrial past and a focal point of its recent revitalization.

Technical session at ICC22 – Virtual presentation by Yoshikatsu Hiratsuka, Sumitomo Heavy Industries, Ltd. *Credit: Sarah Mitchell*

The dinner also offered the opportunity to present two awards that are recent additions to the conference. The ICC Exceptional Service Award was presented to Jeff Raab, Northrop Grumman-retired, for his contributions to the cryocooler community, particularly his ongoing support of conference activities. In addition to being a regular attendee and author, Raab is also a past program chair and program committee member. He is a current board member and proceedings co-editor, and he chairs the ICC Best Student Paper Award committee. The Exceptional Service Award is sponsored by Sumitomo (SHI) Cryogenics of America, Inc.

Following this presentation, the Conference presented its inaugural Best Student Paper Awards to students it deemed to have presented the best papers at ICC21 in 2020. Chloe Gunderson, University of Wisconsin-Madison, was awarded first place for her paper "The Development of an Active Magnetic Regenerative Refrigerator (AMRR) for Sub-Kelvin Cooling of Space Science Instrumentation." Ali Ghavami, Georgia Institute of Technology, was awarded the runner-up prize for his paper "Boundary Layer Losses in a Miniaturized Tapered Pulse Tube." The awards were sponsored by Cryomech.

After a third full day of sessions exploring the latest advancements in cryocooler technology, it was announced that the next conference, ICC23, will be hosted by the University of Wisconsin-Madison in June 2024.

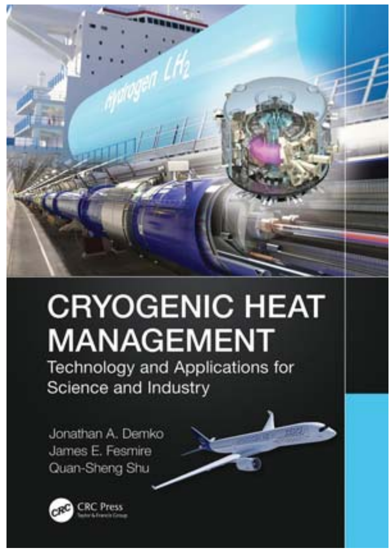
Book Annoncement: Cryogenic Heat Management–Technology and Applications for Science and Industry

Announcement by James E. Fesmire, President, Energy Evolution LLC, james@321energy.us

As hydrogen is clearly identified as a core requirement for achieving the goal of clean energy aviation, ground transportation, marine shipping, energy storage, and many other sectors, the practical necessity then becomes putting liquid hydrogen to work. The technology pieces are perhaps mostly available, but putting them together in an integral whole becomes the challenge. These pieces include hydrogen liquefaction, storage, transfer and distribution. The scale and quantities are a crucial tenant, as well as is understanding the management of heat in the different end-use applications.

The liquid hydrogen servicing systems, from end to end, are synergistic with the aircraft, trucks, ships or other uses in the coming new mainstream of life. Providing practical engineered systems that are safe and robust in the actual-use environment is paramount. Long-range objectives of bringing about a renewable energy economy based on hydrogen are being addressed by the Department of Energy program H2@ Scale. In a 2018 summary, Pivovar asserts that improving the economies of scale depend on how we make, move and use hydrogen, which, in turn, depends on improved bulk-storage technologies like thermal integration approaches. [1]

One benefit of liquid hydrogen systems is that the minimum viable standard for functionality is high and, thus, the issues of materials, fabrication and leakage are at the core of the equipment designs. *Cryogenic Heat Management* provides resources for the development of technical capabilities related to cryogenic applications, or "putting cold to work." The book addresses the different means of providing liquid hydrogen on-site, as well as cryo-refrigeration plants for providing controlled storage and transfer capability. Dealing with boiloff must be addressed from both safety and economic standpoints. As new markets come about for the hydrogen, clean energy transition, and more cryogenic applications proliferate, practical information is needed to meet these demands and ensure both technical and business success.



Hot or cold, it is the temperature difference that makes the heat flow, and cryogenic heat management takes care of it.
Credit: NASA and ITER

About the Authors

Jonathan A. Demko began his career in industry on the thermal management of the X-30 National Aerospace Plane (NASP). He transitioned to the Super Collider Laboratory Cryogenics Department. At Oak Ridge National Laboratory, he worked on cryogenics for high temperature superconducting (HTS) power equipment. He is currently a Professor of Mechanical Engineering at LeTourneau University in Longiew, Texas.

James E. Fesmire, a renowned expert in cryogenic systems design and thermal insulation, is president of Energy Evolution LLC, chief architect and CTO of GenH2 Corp., and founder of the Cryogenics Test Laboratory at Kennedy Space Center (NASA-retired). Distinctions include the NASA Distinguished Service Medal, an R&D 100 Award, 20 US Patents, and inductee of the NASA Inventors Hall of Fame. '

Quan-Sheng Shu is a leading expert in cryogenics and has authored four monographs on cryogenics and superconductivity. He has led scientific teams at Fermilab, SSC Lab, Cornell University, DESY, and Zhejiang University. His achievements include the world's first prototype of HTS Cryo-Maglev; SRF cavities reaching the highest accelerating fields; creation of the Enhanced Black Cavity Theory for MLI with crack/slot; and cryogenic devices for SC magnets.

Official review to follow in upcoming ***Cold Facts***. For more information, visit: **www.routledge.com/9780367542351**.

References:

[1] Bryan Pivovar, Neha Rustagi, Sunita Satyapal, Hydrogen at Scale (H2@Scale): Key to a Clean, Economic, and Sustainable Energy System, Electrochemical. Soc. Interface, Spring 2018 27(1).

Hardback
$144.00 suggested retail price in USD
ISBN 9780367542351
www.routledgecom/
9780367542351

Fabrum Solutions and AFCryo Merge to Create Fabrum

Leading engineering innovator Fabrum Solutions announced its merge with AFCryo, a world leader in cryocoolers and liquefiers, to create a new organization, Fabrum. Additionally, the company appointed Dr. Ojas Mahapatra as chief executive officer. The new corporate identity and appointment follow a period of accelerated growth for Fabrum, fuelled by its demand for mission-critical technology solutions across a broad range of global industries like green hydrogen systems.

Fabrum Solutions, established in 2004, earned a global reputation as a leading innovator in the design, development and manufacture of composite cryostats, superconducting motors and cryogenic systems. Its world-leading cryocooler and liquefier systems, produced by Fabrum joint-venture company AFCryo since 2017, will now be designed and manufactured by Fabrum and marketed under the AFCryocooler brand.

Christopher Boyle, managing director and co-founder of Fabrum, says the company's changes and new identity reflect its future vision and purpose. "We're excited to launch our new identity, Fabrum. For almost two decades, our business has transformed as we have responded to customers' future needs in diverse industries that are more challenging and complex than ever. For example, our green hydrogen technologies, which combine our cryocooler technology and innovative engineering, will power the future and provide decarbonization solutions for industries including heavy transport, aviation and marine."

Boyle says with the significant growth in the business, he and co-founder Hugh Reynolds identified the need to build out the leadership team's capability. "We're proud to welcome Ojas as chief executive to lead our high caliber Fabrum team. He will be critical in spearheading the company's technology delivery. His entrepreneurial, forward-thinking mindset and business management experience, combined with an in-depth understanding of disruptive market strategies, complex business issues and financing, will be a real asset for the company," Boyle says.

Company photo taken after Fabrum Solutions merged with AFCryo to create Fabrum. *Credit: Fabrum*

Boyle, a power systems engineer and world-leading hydrogen expert, will remain as Fabrum's managing director and focus on new business applications for Fabrum's technology. Hugh Reynolds will remain as Fabrum's technical director.

Dr. Mahapatra has a Bachelor of Technology in biotechnology from SRM University in Tamil Nadu, India, and a Ph.D. in nanotechnology from the University of Canterbury. "I'm thrilled to join such an innovative and ambitious company," he says. "Fabrum has gained global attention for its world-first technology solutions and counts some of the most innovative blue-chip companies as customers. Fabrum is on a rapid growth trajectory and has enormous potential in many high-value markets; additionally, Fabrum is well-positioned to have a significant decarbonization impact with its green hydrogen technologies."

Fabrum's mission-critical solutions include water jet profiling, CNC machining, composite solutions, cryogenics (gas separation and liquefaction), green hydrogen technologies and magnetic systems. Globally, customers use Fabrum's cryogenic technologies to liquefy and recondense nitrogen, oxygen, methane, argon, neon, biogas and hydrogen for animal science, food and beverage, research, medicine and energy applications.

2021 was a pivotal year for Fabrum as it applied its world-leading cryogenic technology for gas separation and liquefaction to hydrogen. In conjunction with UK company CPH_2, the company unveiled a green hydrogen production system to enable hydrogen production on-site in a decentralized, containerized system for point-of-use refueling. The revolutionary system splits water into pure hydrogen and medical grade oxygen without the polymer membrane used in common electrolyzers by combining Fabrum's AFCryocooler with unique and patented Membrane-Free Electrolyser™ technology from CPH_2. For more information, visit **www.fabrum.nz**.

Book Review: *Helium: Its Creation, Discovery, History, Production, Properties and Uses by John A Taylor*

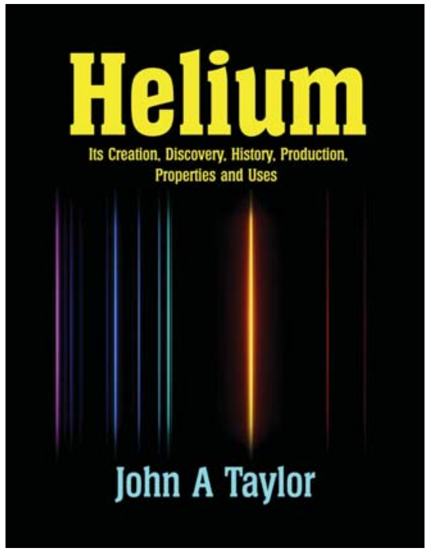
Reviewed by Richard Chadburn, Former Chair, The Airship Association

Taylor's book is an exceedingly comprehensive study of the element helium. Having worked with helium during a career in airships and now having spent six years researching all aspects of the element, Taylor divides his book into six parts.

Part 1 – *Creation and Distribution* – begins with the creation of helium in the Big Bang and in stars, and its distribution in the cosmos. It continues with helium's creation here on Earth by radioactive decay deep underground, and its migration and distribution within the earth and in the atmosphere.

Part 2 – *Discovery and History* – begins with a detailed account of the discovery of helium, first in the sun and then on Earth. It continues with a history of the helium industry, which in its early years served to supply helium for the huge airships of the 1930s and the US Navy's submarine-hunting blimps of World War II. The Cold War and the space race brought increased demand and the creation of the US national helium reserve. The text details the reasons for the privatization and recent closure of the reserve and today's cycles of surplus and shortage. The section closes with a review of historic helium production plants that are preserved today and a record of US helium legislation.

Part 3 – *Production* – covers the processes through which helium is extracted from natural gas and non-fuel gas streams and how it is refined. Future extraction from the atmosphere is addressed. Worldwide helium production is detailed, along with helium reserves and their locations.



Part 4 – *Properties* – deals mainly with the physical properties of gaseous, liquid, superfluid, solid and plasma helium. Radioactive decay and the alpha particle are then addressed, followed by chemical properties and compounds.

Part 5 – *Uses and Conservation* – describes many uses of helium. Superconductors, superconducting magnets and nuclear magnetic resonance are explained, followed by the use of liquid helium in MRIs and spectroscopes, particle accelerators, magnetically levitating trains and other devices. Uses for gaseous helium include controlled atmospheres, lighter-than-air flight, diving, health care, scientific research and the next generation of nuclear reactors. Uses for the alpha particle range from the mundane smoke detector to Mars rovers. Refrigeration and cryopumping are included in a separate chapter, with the helium refrigerator, cryocooler, sorption cooler and dilution refrigerator. The section ends with global consumption by region and by application, and helium conservation and substitutes.

Part 6 – *Helium-3* – begins with the creation of helium-3, its presence in the cosmos and on Earth, and its discovery in the 1930s. Produced until now as a byproduct of nuclear weapons maintenance, increasing demand requires other sources, including the moon. The text then compares properties of helium-3 with common helium-4, and describes current and future uses, including fusion power and spacecraft propulsion.

In summary, this book is immense in scope and highly educational. It is no exaggeration to describe it as the definitive work on the element helium. ■

Paperback
$26.90 suggested retail price in USD
ISBN 979-8832762135
http://2csa.us/l7

Dr. Jack DaGrave
FormFactor
Dr. Philip Krantz
Keysight

Product Showcase

This Product Showcase is open to all companies and related manufacturers offering new or improved products for cryogenic applications. We invite companies to send us short releases (150 words or fewer) with high-resolution JPEGs of their products to editor@cryogenicsociety.org.

FormFactor

He-3 Cryostat

FormFactor model HE-3-SUHV-PT high power, continuous flow-type cryogen-free He-3 cryostat includes vacuum shroud, 40 K cold plate and radiation shield, 10 K intermediate cold plate, 3 K cold plate and radiation shield, Joule-Thomson He-3 condensing unit, and the He-3 pot. A model PT420 two-stage pulse tube refrigerator (PTR) with remote motor valve is used to cool the 40 K cold plate/radiation shield, the 10 K cold plate, and the 3 K cold plate/radiation shield. The Joule-Thomson He-3 condensing unit contains a recuperate heat exchanger and a JT condensing impedance. Pfeiffer model HiPace 400 turbo pump, backed by an A100L pump with Roots technology, are used to circulate the He-3. This configuration generates approximately 10-milliwatt cooling power at 620 mK. This system reaches a base temperature of 435 mK with the continuous flow operation model and 346 mK with single shot mode. **www.formfactor.com**

Instrucan Scientific

Compact Automated Liquid Nitrogen Generators

From Instrucan Scientific comes this reliable, fully integrated system that produces liquid nitrogen by using room air in an unattended mode with just an annual preventive maintenance of a few hours. Cabinet units with lockable castors can produce up to 80 liters per day, including a 210-liter storage tank. These replace deliveries of 10-12 dewars per month and are extensively used in dermatology, IVF labs, research centers, cryotherapy and any other process that requires liquid nitrogen. Larger skid-based systems can produce up to 1,150 liters per day, useful for industry needs like dosing, material treatments, cooling large magnets, etc., and as a replacement of bulk supply. **www.instrucanscientific.com**

m-tech gmbh

LCV – Cryogenic Ball Valve

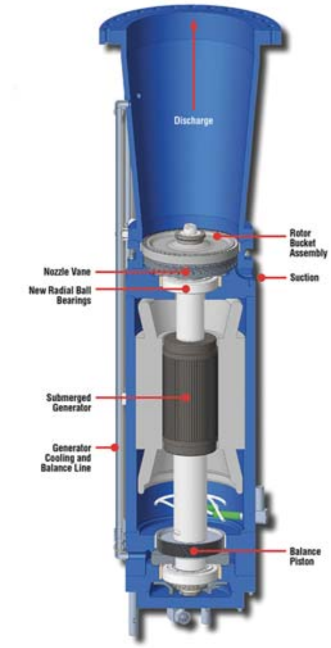
The complete valve assembly series, LCV, is designed for cold service applications. The standard bonnet length complies with relevant cryogenic standards (DIN EN 1626 & BS 6364), which allows safe and efficient use of this valve at low temperatures. The valves are suitable for handling cryogenic liquefied gases such as LIN, LAR, LOX and LNG. The LCV product range covers DN15 to DN50 (1/2" to 2") and is optimized for both on/off and control applications. The finned bonnet design ensures efficient heat transfer, allowing reliable sealing of the stem packing.

The m-tech standard connection (three pieces of metal connection) enables easy installation and maintenance. No valve disassembly is required by welding/brazing to the pipeline, which minimizes the labor of installation. The connections are available in both brass for copper and stainless steel for stainless steel pipework. **www.m-tech-gmbh.com**

Elliott Group

Impulse-Type, Two-Phase Cryogenic Expander

Based on proven impulse turbine blade technology, Elliott Group's impulse-type, two-phase cryogenic expander allows for the expansion of liquefied gases into two-phase mixtures. Harnessing the energy of two-phase expansion increases the expander's generator output, reduces boiloff losses and improves the overall liquefaction and cooling processes. This cryogenic expander has optimized staging to minimize axial load at the radial ball bearings and tolerates a high content of vapor mass. Custom designed, it is offered for liquefaction and refrigeration processes with relatively high vaporization capability in cryogenic hydrocarbon applications. The isentropic efficiency of these units is estimated at around 60% to 70%, depending on the mass flow rate and unit pressure drop. These expanders do not require a Joule-Thomson valve at the downstream. If the process requires high-flow output, these units can be installed and operated in parallel configuration. In addition, they can be retrofitted to existing LNG liquefaction and cooling applications. **www.elliott-turbo.com**



Infrared Laboratories

Cryogenic Filter/Aperture Wheels

Infrared Laboratories has several tried and true designs that can be used to fit a large range of applications from 4 K to room temperature. These filter wheels use standard threading for COT filter sizes and hold-down rings. They can also be designed to a user's specific needs for unique filter sizes or number of positions. Wheel control is achieved with either a manual control shaft through a vacuum gland for simple external control, or incorporated with a stepper motor and controller for automated movement. Motor-controlled wheels can be configured with externally mounted motors using a thermally isolating control shaft or with a cryo-rated motor that is installed within the cryostat. In short, IRLabs' filter/aperture wheels are designed to accommodate an application's requirements for filter/aperture size, number of positions and actuation method. **www.irlabs.com**

Cryo Industries of America, Inc.

SUBcooled-LHe

The SUBcooled-LHe takes advantage of Cryo Industries' helium liquefier technology and improves upon it to offer a truly innovative and convenient design. The design provides experimental access ports into a SUBCOOLED liquid helium bath for insertion of up to 14 tesla superconducting magnet inserts and variable temperature and helium-3 inserts. Inserts are interchangeable and set up for all cooling flows to recirculate back into the dewar. The subcooled liquid helium bath provides many benefits over a traditional 4.2 K liquid helium bath, including lower sample base temperature and increased cooling power—all with ZERO liquid helium loss. **www.cryoindustries.com**

≈In Memoriam≈

A Lifetime Legacy in Space Cryogenics

by Jeffrey R. Olson, Ph.D., Principal Research Scientist, Lockheed Martin Space, Advanced Technology Center

Ted Nast

1934-2022

Ted Nast, an expert in space cryogenics and a longtime employee of Lockheed Martin, passed away June 4, 2022, at the age of 88 after a long fight with cancer. Ted lived a long, full and extraordinary life.

Ted worked in space cryogenics from its very inception. His professional career began as the lead engineer in airframe heating for the Polaris missile in the 1950s, but soon thereafter, he began working on the Reactor In-Flight Test (RIFT) nuclear rocket, a program which required handling and storage of liquid hydrogen. This was Ted's introduction to cryogenics, his primary field of endeavor for the remainder of his professional career. Ted pioneered the development of solid cryogen coolers for space instruments, flying the first such cooler ever flown in space in 1970, and the first Stirling cryocooler ever flown, in 1972. His seminal work on multilayer insulation is still used routinely by NASA and other space agencies around the world. Ted also pioneered many other areas of cryogenic technology, including the first two-stage solid cryogen cooler for the NIMBUS-F weather satellite, and solid hydrogen coolers for very long-wave infrared sensors, most recently flown on the Wide-field Infrared Survey Explorer (WISE) space telescope.

Ted Nast with two-stage solid methane/ammonia dewar built for Nimbus-F. *Credit: Lockheed Martin Corporation*

In the late 1990s, as the field of space cryocoolers began to transition from solid cryogen coolers to long-life mechanical coolers, Ted led the Lockheed Martin team that developed two-stage pulse tube cryocoolers for cooling below 35 K, three-stage pulse tubes for cooling below 10 K and four-stage pulse tubes for cooling below 4 K. He also led the development of high capacity cryocoolers and microcryocoolers. The success of his teams was due, in large part, to Ted's constant enthusiasm and spirit of teamwork that positively affected and motivated the many people who had the good fortune to work with him. Universally, the people who worked with Ted remember his friendly nature, his welcoming attitude, and his almost heroic capability to remain calm and level-headed even under adversity.

Ted was very active in the cryogenics community, attending nearly all the Cryogenic Engineering Conferences and International Cryocooler Conferences while he was still working. Dean Johnson from the Jet Propulsion Laboratory mentioned that he thinks he first met Ted at a conference in Helsinki in 1984, and Ron Ross said that he first met Ted at an ICC in 1988. Ted organized the ICC 10 in Monterey, Calif. in 1998.

Ted will be sorely missed. He is survived by his sons Tom Nast (Terry) and Rob Nast (Liz); daughter Jennifer Lawrence (Glenn); grandchildren Katie Nast Hart, Sean Nast, Lucy Nast, and Ryan Nast; great-grandchildren Hattie Hart and Jack Hart; and predeceased by his wife Carole Nast of 64 years, parents Ruth Nast and Edward Nast, and brother Charles Nast.

People, Companies in Cryogenics

The US Particle Accelerator School (USPAS) Prizes honor individuals for their outstanding achievements over the full range of accelerator physics and technology. The 2022 USPAS Prize recipients include **Rama Calaga (CERN)**, who received the Early-Career Award "for outstanding leadership, bringing the crab cavities in hadron colliders

Rama Calaga

Geoffrey Krafft

Gennady Stupakov

from concept to reality, and for the first demonstration of crabbing on a hadron beam"; **Geoffrey Krafft (Jefferson Lab)**, who received a General Award "for pioneering contributions to superconducting linear accelerators and radiation sources driven by them, and for his dedication in educating and mentoring the next generation of accelerator scientists"; and **Gennady Stupakov (SLAC, CSA CSM)**, who also received a General Award "for his comprehensive contributions to collective effects including coherent synchrotron radiation, his invention of the echo-enabled harmonic generation scheme for external seeding of FELs, and his role as a teacher and a mentor in many schools and workshops."

....

Meyer Tool (CSA CSM) announced its newest addition to its team: Business Development Manager **Christian Cunningham**

Credit: Meyer Tool

(at right in photo). Before receiving his BA in Professional Sales and Marketing from Illinois State University, Christian served the Meyer Tool family in a variety of roles. Starting as a teenager sweeping floors and performing industrial maintenance, he gained exposure to a variety of manufacturing roles, stretching his shop skills, and eventually working his way up to becoming a well versed, ASME code certified welder and team leader.

....

Austrian company **RUAG Space GmbH** (CSA CSM) announced in early August its operation under a new name, **Beyond Gravity Austria GmbH**. Combining a start-up culture with decades of experience and proven quality, Beyond Gravity will continue its innovations in satellite platform, payload, and launch rocket technology.

....

Premier Cryogenic Services is getting back into the new cryogenic transport and storage tank manufacturing business, having broken ground on a brand new manufacturing facility. Located in the company's headquar-

Credit: Premier Cryogenic Services

ters in La Porte, Texas, the facility will be used to fabricate new stainless steel and aluminum cryogenic, plus steel carbon dioxide, transport trailers and storage tanks.

....

Reflect Scientific, Inc., a provider of diverse products and services for the biotechnology, pharmaceutical and transportation industries, announced a new product showroom installation at its Orem, Utah facility. To address increasing customer interest in its Cryometrix product lines, Reflect Scientific has set up a demonstration facility for all of its commercially proven liquid nitrogen temperature-controlled product offerings. The facility is set up to showcase applicable products for three strategic initiatives: processing (including R&D applications), storage, and transportation.

Meetings & Events

CryoCourse 2022 – European intensive course on Advanced Cryophysics and Cryogenics
September 9-21, 2022
Heidelberg, Germany
http://2csa.us/l5

National Symposium on Cryogenics and Superconductivity 28
October 18-21, 2022
Kharagpur, India
http://2csa.us/kw

ASC 2022
Oct 23-28, 2022
Honolulu, HI
http://2csa.us/ko

....

CryoWorks, Inc. (CSA CSM) has announced the launch of its e-commerce website, **www.Shop.CryoWorks.Net**. The inaugural e-commerce store from CryoWorks offers a variety of products for the storage, distribution and transfer of cryogenic fluids. The launch of the website provides several features to allow new and existing customers to "make it happen," including:

- Account registration – Users can create an account to access history of previous orders, billing terms, as well as exclusive OEM pricing (when applicable).
- Explore products – Users can browse an extensive selection of cryogenic piping and accessories that are readily available.
- Purchase and ship orders – Customers can place an order, checkout and have their order processed within 48 business hours (subject to stock availability).

....

Cryogenic Industrial Solutions (CIS) has confirmed its acquisition of Colorado-based NITROcrete. Sharing news of the transaction this week, CIS said NITROcrete will now join Alloy Custom Products, WesMor Cryogenics, CIS Leasing and Integrity Gas Services under the CIS umbrella of brands.

Index of Advertisers

Acme Cryogenics, Inc. 23

American Magnetics 7

Cryo Technologies . . . . Inside Front Cover

CryoCoax (Intelliconnect) 32

Cryocomp 7

Cryofab, Inc. . . . . Inside Back Cover

Cryomech, Inc. 13

CryoWorks, Inc. 19

HPD, a FormFactor Company. 41

gasworld 25

Lake Shore Cryotronics 20

Linde Cryogenics . . . . Inside Back Cover

Magnatrol Valve 7

Omega Flex, Inc . . . . Back Cover

PHPK Technologies . . . . Inside Front Cover

Sumitomo SHI Cryo America 3

Raterman Manufacturing 17

Join CSA and start receiving Cold Facts!

Rates: circle $ amount

In US: Individual $80 • Student or retiree: $35

Outside US: Individual $120 • Student or retiree $75

Corporate, in US, number of employees:
1-10, $470 • 11-25, $660 • 16-50, $870 • 51-100, $1,290
101-500, $2,340 • 501-1,000, $5,250 • 1,000+, $7,350

Corporate, outside of US, number of employees:
1-10, $525 • 11-25, $725 • 16-50, $940 • 51-100, $1,330
101-500, $2,455 • 501-1,000, $5,450 • 1,000+, $7,615

Government/Non-profit: $450

Outside the US, please remit in US $ on US bank. No bank transfers.

Charge your membership

__Discovery __Visa __MasterCard __AmEx

Account number ______ Expiration ______ Security code ______

Signature ______

Please print

Name ______ Title ______

Company ______

Address ______

City ______ State/Country ______ Zip + 4 ______

Email ______ Website ______

Phone ______ Fax ______

Send to:

New Memberships • Cryogenic Society of America
800 Roosevelt Rd. Suite 312-C • Glen Ellyn, IL 60137
Fax: 630-790-3095

Join CSA online!
http://2csa.us/l2

***Cold Facts* is the official technical magazine of The Cryogenic Society of America, Inc.** 800 Roosevelt Rd. Suite 312-C • Glen Ellyn, IL 60137
Phone: 630-858-7337 Ext. 8765 • Fax: 630-790-3095
Email: membership@cryogenicsociety.org • Web: cryogenicsociety.org
A non-profit technical society serving all those interested in any phase of cryogenics
SSN 1085-5262 • August 2022
Printed in USA


TELL US WHAT YOU'RE THINKING...
We begin each specially-designed, custom-built cryogenic solution by identifying your requirements, leveraging our comprehensive range of products and adding our vast experience and expertise.
•DEWARS
•CONTAINERS
•TANKS
•CRYOSTATS
•TRANSFER SYSTEMS
•VACUUM COMPONENTS
•VACUUM JACKETED VALVES
Contact us today
WE'RE LISTENING!
CRYOFAB
www.cryofab.com
sales@cryofab.com
1.800.426.2186


Making our world more productive
Partner you can count on
Linde
For over eight decades, we have been enabling ground-breaking discoveries that challenge the boundaries of physics. As the world's leading cryogenic engineering company, we have the technologies, experience and skills to keep cool – while you unravel the secrets of science.
Linde – your trusted partner.
Linde Cryogenics
A Division of Linde Engineering North America Inc.
6100 South Yale Avenue, Suite 1200, Tulsa, Oklahoma 74136, USA
Phone +1 918 477-1200, Fax +1 918 477-1100, www.leamericas.com
Linde Kryotechnik AG
Daettlikonerstrasse 5, 8422 Pfungen, Switzerland
Phone +41 52 304-0555, www.linde-kryotechnik.ch, info@linde-kryotechnik.ch

OmegaFlex®

Cryogenic / Vacuum Jacketed Hose Assemblies

Keep Cryogenic Liquids Cold • Safety Containment

Omegaflex Cryogenic / Vacuum Jacketed Hose Assemblies
- Superior insulation properties
- Multi-layer insulation creates a low heat transfer rate
- Minimizes cryogenic liquid boil-off
- Containment of the media in case of inner hose rupture

Metal Hose
- Allows for the transfer of liquids or gases, usually at high pressure and high or cryogenic temperature

Cryogenics Applications
- Nitrogen
- Hydrogen
- Oxygen
- Carbon Dioxide
- Helium
- Argon
- Other Natural Gases

Omegaflex welders and Omegaflex welding procedures are qualified to Section IX of the ASME Boiler and Pressure Vessel Code. Omegaflex hose assemblies are qualified to ISO-10380:2012.

Cryogenic and Vacuum Jacketed Assemblies are oven dried and purged with Argon to a moisture content of 2 PPM and verified with a moisture analyzer. Hose assemblies can be charged with Helium to maintain dryness during shipping and storage.

Cryogenics and Vacuum Jacketed Assemblies are Helium Leak checked to 1 x 10-9 std. cc/sec.

Contact OmegaFlex with your specification and we will engineer a custom jacketed hose assembly for you.

omegaflex.com

OmegaFlex®

OmegaFlex, Inc.

451 Creamery Way • Exton, PA 19341

ISO 9001 Registered Company

IND-156 09/21