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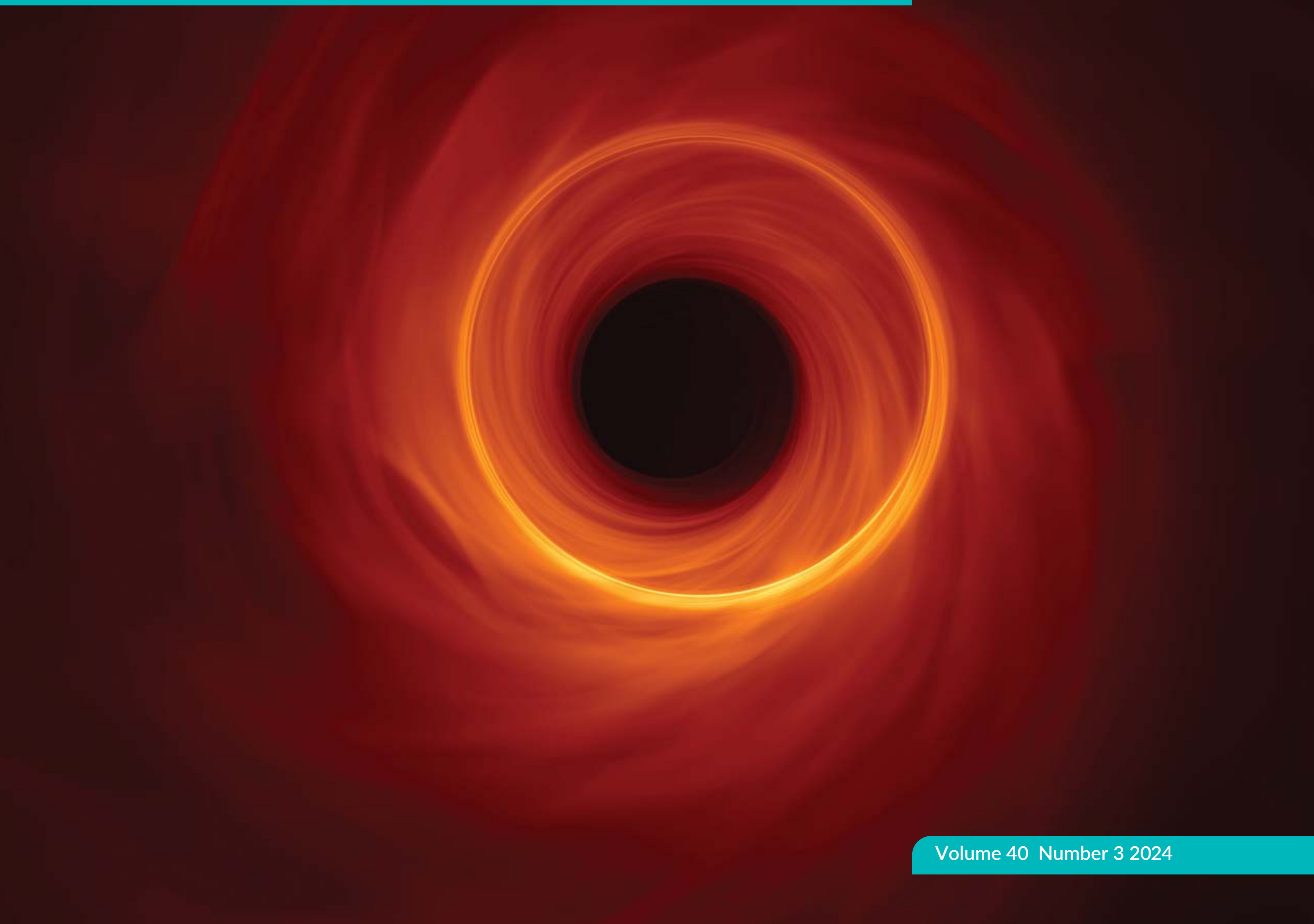
The Magazine of the Cryogenic Society of America, Inc.



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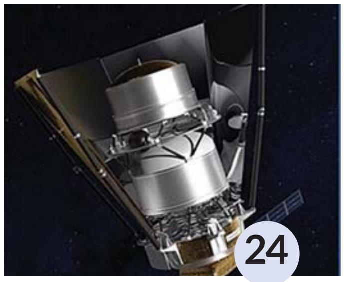

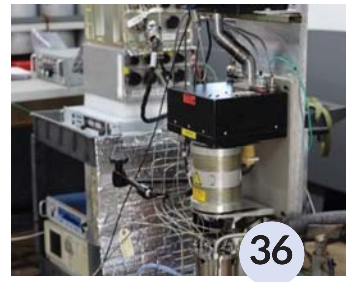

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ON OUR COVER

The Black Hole Explorer (BHEX) mission will discover and measure black hole photon rings by capturing orbiting light. BHEX will extend the Event Horizon Telescope (EHT) into space, creating the sharpest images in astronomy history by operating a space-Earth hybrid VLBI observatory, linking the BHEX radio telescope in space with the EHT on Earth. *Credit: George Wong (IAS).*

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From the Executive Director

Happy summer to all our readers in the northern hemisphere! Here in Chicagoland, the warmer weather brought some not-so-welcome visitors this year: cicadas. For those who might be unaware, cicadas are a very noisy insect, about one inch in size, that appear each summer in the Midwest. However, this year, a massive emergence of cicadas, called Brood XIII, is occurring in our area. It only happens every 17 years! Luckily, cicadas are completely harmless, and they'll be gone in a matter of weeks.

Along with the cicadas, I have "emerged" after taking a few months off for maternity leave. I'm happy to be back at work with my CSA colleagues. I want to give a big THANK YOU to the CSA team for keeping everything moving forward in my absence. They did a fantastic job and have made my return to work seamless.

Upon my return, we jumped right back into the swing of things with our Foundations of Cryocoolers short course which was held in conjunction with the International Cryocooler Conference, June 3, in Madison, Wis. The course was once again instructed by Ray Radebaugh, NIST Fellow Emeritus, and co-instructed by Fons De Waele, Professor Emeritus at Eindhoven University of Technology. We are happy to report that the course sold out with more than 30 attendees!

After the short course, some of the CSA team attended ICC and had the opportunity to meet and mingle with many of you. It was a great conference. Our thanks go to this year's host: the University of Wisconsin Madison. The Memorial Union served as a fantastic venue with lots to do nearby.

September 1-6, CSA will also be attending the Applied Superconductivity Conference in Salt Lake City, Utah. During the conference, we will be presenting the Roger W. Boom Award, which is 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." For the most up-to-date information in about ASC'24, please visit **www.appliedsuperconductivity.org/asc2024**.

Lastly, do you know someone whose dedication to cryogenics in theory or practice would make them a progressive leader of CSA? Is that person you? We're looking for candidates for president-elect and four director positions on the CSA Board of Directors. This is your chance to not only engage with, but also help direct the future of CSA and the field of cryogenics. If you'd like to nominate someone, please email me at megan@cryogenicsociety.org. If you'd like to nominate yourself, please complete the candidate information form at **www.surveymonkey.com/r/2SWVT5G**. The deadline for nominations is August 23, 2024.

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


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Frozen Imaging: How Cryogenic Cameras Power Unprecedented Discovery

The Legacy Survey of Space and Time (LSST) Camera in Chile and NASA's Compact Thermal Imager (CTI) represent cutting-edge advancements in astronomical and Earth science technology. The LSST Camera, soon to be operational at the Vera C. Rubin Observatory, will survey the entire southern sky every three nights for a decade, producing detailed data to study dark matter, dark energy and transient astronomical events. In contrast, NASA's multiple high-resolution infrared cameras and their sensors, already in operation, are designed for specific scientific and practical applications, from monitoring wildfires to studying planetary compositions. These cameras provide high-resolution imaging for wildfire detection and atmospheric studies from the International Space Station.

The LSST Camera employs sophisticated cryogenic systems to cool its CCD sensors to very low temperatures, significantly reducing thermal noise and enhancing image quality. Similarly, NASA's compact cameras use cryogenic technology to maintain their strained-layer superlattice sensors at optimal low temperatures, ensuring high-resolution and high-spectral range infrared imaging. Both categories of instruments exemplify the integration of advanced sensor technology and innovative design to enhance our understanding of the universe and our planet. Join us as we explore how these state-of-the-art cameras are pushing the boundaries of what we can observe and understand.

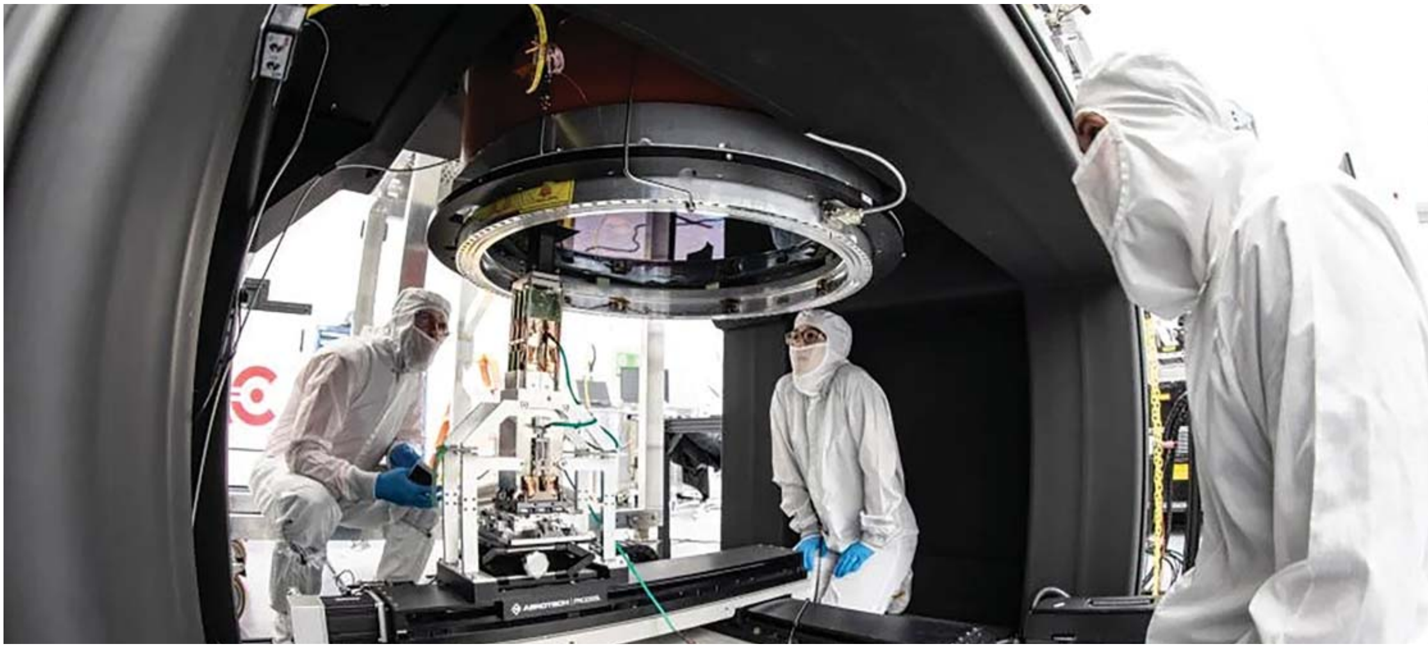
Yousuke Utsumi and Aaron Roodman remove the pinhole projector from the cryostat assembly after projecting the first 3,200-megapixel images onto the focal plane of the LSST Camera. *Credit: Jacqueline Orrell/SLAC National Accelerator Laboratory*

Part I: LSST Camera Peers Deep into the Cosmos

The Vera C. Rubin Observatory, perched on a mountaintop in Chile, is set to revolutionize our understanding of the universe with its ambitious Legacy Survey of Space and Time (LSST). Over the course of a decade, this international scientific endeavor will map the southern hemisphere sky in unparalleled detail, aiming to answer some of the most pressing questions in cosmology. Central to this project is the LSST Camera, the largest digital camera ever built for astronomy, created at SLAC National Accelerator Laboratory.

This 3,200-megapixel marvel will capture the entire southern sky every three nights, providing invaluable data to explore the elusive nature of dark matter and dark energy, study galaxy formation and evolution, catalog asteroids and observe the dynamic night sky. The camera's sophisticated components include the world's largest lens for astronomy, an array of specialized filters and a state-of-the-art cryostat to maintain optimal operating temperatures for the charge-coupled device (CCD) sensor, a type of image sensor used in cameras, including astronomical cameras like the LSST Camera. It converts light into electrical signals, which can then be processed to create digital images. Once operational, the LSST Camera will gather images at a rate of three per minute, contributing to a vast repository of data that will significantly enhance our understanding of the cosmos.

Cryogenics plays a crucial role in the LSST Camera's design and functionality.



A crew installs a raft of sensors and supporting electronics into the LSST Camera focal plane. These so-called "science rafts" were assembled at Brookhaven National Laboratory and shipped to SLAC. *Credit: Jacqueline Orrell/SLAC National Accelerator Laboratory*

Justin Wolfe, from Lawrence Livermore National Laboratory (standing left), and Travis Lange inspect the L3 lens for imperfections after delivery to the lab. *Credit: Jacqueline Orrell/SLAC National Accelerator Laboratory*

According to Martin Nordby, the LSST Camera project manager, "The LSST Camera includes two separate cooling systems to cool the CCD sensors and electronics inside our cryostat." He elaborates that the front-end analog-to-digital electronics and circuit boards are cooled to -40° C by a two-stage cascade refrigeration system developed by inTest Thermonics, a division of inTest Corporation. Brian Qiu, LSST camera process engineer, adds, "The second system cools the CCD sensors and their support structure to -130 ° C using an auto-cascade refrigeration system with a custom mix of refrigerant." This ensures there are no cold spots or condensation that could affect telescope operations or image quality.

Implementing the cryogenic system for the LSST Camera posed several challenges. Qiu notes, "Challenges included understanding issues around oil propagation and freezing in the system, water ingress and hose material choice, and impacts of contaminants on such a distributed system." To address these, the team developed a full-scale prototype system and two complete test units to prove the design and operations, better characterizing system behavior in real-world conditions.

The cryogenic system is essential for maintaining the optimal operating temperature for the CCD sensors within the LSST Camera. Nordby emphasizes, "The cryogenic

▶ *continues on page 10*

Frozen Imaging:... Continued from page 9

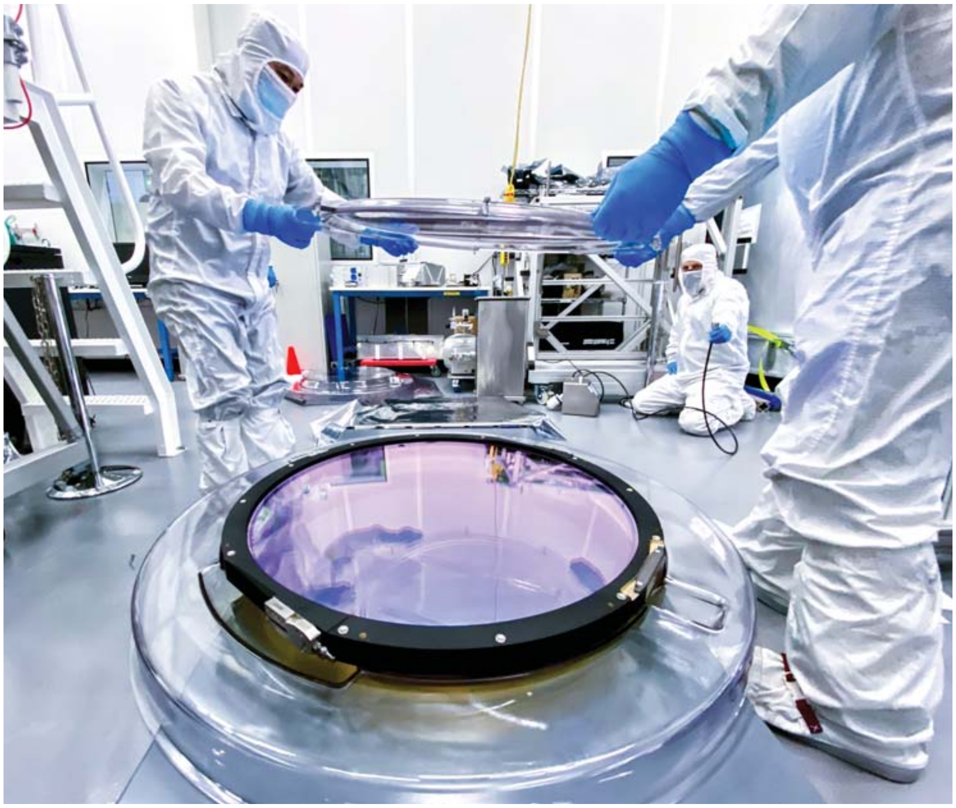
LSST back flange installation. *Credit: Jacqueline Orrell/SLAC National Accelerator Laboratory*

Researchers at SLAC National Accelerator Laboratory are nearly done with the LSST Camera, the world's largest digital camera ever built for astronomy. Roughly the size of a small car and weighing in at three tons, the camera features a five-foot-wide front lens and a 3,200 megapixel sensor that will be cooled to -100°C to reduce noise. Once installed atop the Vera C. Rubin Observatory's Simonyi Survey Telescope in Chile, the camera will survey the southern night sky for a decade, generating a wealth of data for scientists to analyze. This data will help unravel some of the universe's biggest mysteries, including the nature of dark energy and dark matter. *Credit: Jacqueline Ramseyer Orrell/SLAC National Accelerator Laboratory*

system is critical in cooling the CCD sensors and removing both process and radiative heat loads." This cooling is necessary to reduce noise and dark current, which could otherwise impact the ability to record faint light from distant sources. The system operates stably, ensuring consistent sensor performance.

Several innovative features and technologies were incorporated into the LSST Camera's cryogenic system to enhance its performance and efficiency. "The -130° C system uses a ten-component nontoxic and nonflammable refrigeration mix, developed for our system by MMR Technologies, achieving a coefficient of performance (COP) of 11%, which is outstanding for a cryogenic refrigeration system," Qiu highlights.

Ensuring the reliability and longevity of the cryogenic system, especially for the LSST Camera's extended operational period, was a key focus. "We used high-quality components with proven operational



The R filter of the camera is unpacked and inspected in the clean room at SLAC. *Credit: Travis Lange/SLAC National Accelerator Laboratory*

pedigree, added considerable instrumentation to track trends in performance over time and developed empirical testing procedures," Nordby explains. These procedures include flushing and moisture dry-out processes on the refrigeration transfer lines and a periodic replacement program for the filter dryers to improve long-term reliability.

Unexpected hurdles and breakthroughs were part of the development process for the cryogenic system. Qiu recounts that a significant hurdle was the bankruptcy of the refrigerant supplier. "We developed the methods for mixing and testing the ten-component refrigerant mix at SLAC to ensure a sufficient supply over the course of the LSST operation."

The cryogenic system significantly impacts the overall data quality and accuracy of the LSST Camera's observations. According to Mr. Nordby, "The cooling systems are essential for stable operations, which are critical for avoiding systematic errors in the resulting images. Stable thermal environments ensure high-quality image data, vital for our ten-year survey."

Collaboration and coordination among different teams and institutions were crucial in designing and implementing the cryogenic system. "The cryogenic systems were developed by a team at SLAC and commercial suppliers. The sensors, electronics, and support components inside the cryostat were designed and tested at Brookhaven National Laboratory," Qiu shares. Close communication and face-to-face interactions were vital for successful integration.

Regarding future upgrades or improvements, Nordby mentions that the team doesn't anticipate any upgrades from advances in cryogenic technology. "However, we have options for future system upgrades to support streamlined maintenance, although the current systems are operating well," he adds.

"Cryogenic cooling systems are vital for the scientific potential of Rubin Observatory and the LSST Camera," Nordby and Qiu conclude. "They enable the cooling and thermal stabilization of our custom CCD sensors and control electronics, maximizing the camera's potential and supporting significant scientific advances in understanding our solar system, galaxy and universe." **www.lsst.org**

As NASA's CTI pushes the boundaries of infrared imaging on Earth and beyond, the LSST Camera at the Vera C. Rubin Observatory is set to transform our view of the universe.

Key Highlights of the LSST Camera:

Vast Sky Survey – The camera will map the entire southern sky every three nights for a decade, aiding in the study of dark matter, dark energy and galaxy formation. This extensive coverage will enable scientists to track transient astronomical events, such as supernovae and near-Earth objects, in unprecedented detail.

Advanced Technology – The LSST Camera features a 3,200-megapixel resolution, advanced CCD sensors, sophisticated cryogenic systems and the largest lens ever built for astronomy. It will capture unprecedented detailed images of the night sky, spotting objects 100 million times dimmer than those visible to the naked eye. The camera's specialized filter array and stable CCD temperatures ensure high image quality and reduced noise.

Successful Deployments – Installation will take place at the Vera C. Rubin Observatory, and the camera will gather high quality data at a rate of three images per minute. The data collected will encompass approximately 20 billion galaxies.

Real-World Impact – The camera will enhance our understanding of the universe's structure and evolution and will detect and catalog asteroids and other celestial objects. The LSST Camera's ability to capture detailed images at high resolution will contribute significantly to ongoing dynamic universe research.

Future Prospects – The project will be marked by continuous data collection contributing to a vast astronomical database and by supporting future research and discoveries in cosmology and astrophysics.

Part II: NASA's Compact Infrared Cameras Enable New Science

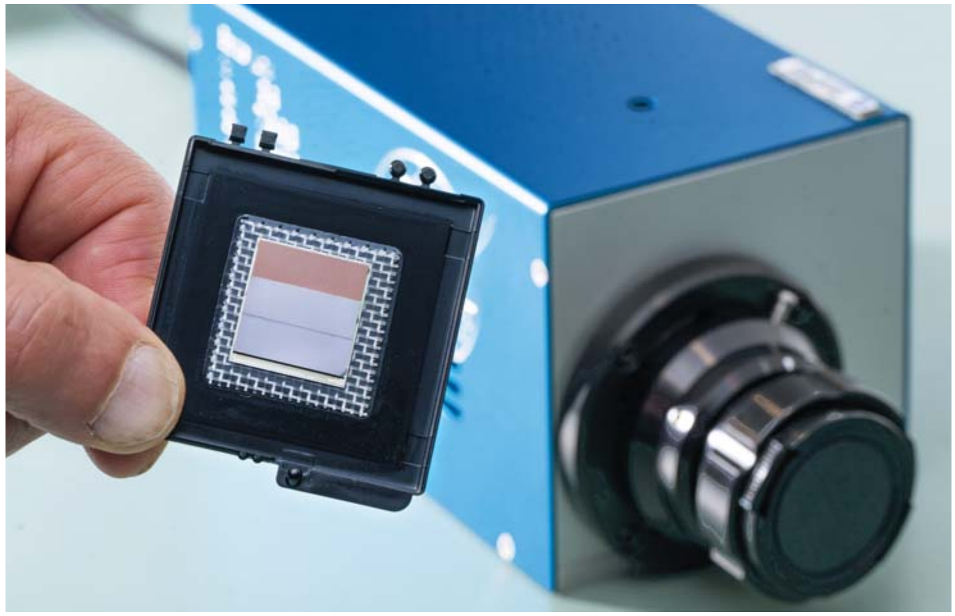
by Karl B. Hille, NASA's Goddard Space Flight Center, Greenbelt, MD.

A new, higher-resolution infrared camera outfitted with a variety of lightweight filters could probe sunlight reflected off Earth's upper atmosphere and surface, improve forest fire warnings and reveal the molecular composition of other planets. The cameras use sensitive, high-resolution strained-layer superlattice sensors, initially developed at NASA's Goddard Space Flight Center in Greenbelt, Maryland, using Internal Research and Development funding.

Their compact construction, low mass and adaptability enable engineers like Tilak Hewagama to adapt them to the needs of a variety of sciences. "Attaching filters directly to the detector eliminates the substantial mass of traditional lens and filter systems," Hewagama says. "This allows a low-mass instrument with a compact focal plane which can now be chilled for infrared detection using smaller, more efficient coolers. Smaller satellites and missions can benefit from their resolution and accuracy."

Goddard engineer Murzy Jhabvala holds the heart of his Compact Thermal Imager (CTI) camera technology – a high-resolution, high-spectral-range infrared sensor suitable for small satellites and missions to other solar system objects. Jhabvala led the initial sensor development at Goddard Space Flight Center, as well as leading today's filter integration efforts. Jhabvala also led the CTI experiment on the International Space Station (ISS) that demonstrated how the new sensor technology could survive in space while proving a major success for Earth science. More than 15 million images captured in two infrared bands earned inventors, Jhabvala, and NASA Goddard colleagues Don Jennings and Compton Tucker an agency Invention of the Year award for 2021.

The CTI captured unusually severe fires in Australia from its perch on the ISS in 2019 and 2020. With its high resolution, it detected the shape and location of fire fronts and how far they were from settled areas – information critically important to first responders. Data from the test not only provided detailed information about wildfires, but also better understanding of the vertical structure of Earth's clouds and atmosphere, and captured an updraft called a gravity wave caused by wind lifting off Earth's land features.



Goddard engineer Murzy Jhabvala holds the heart of his Compact Thermal Imager camera technology – a high-resolution, high-spectral-range infrared sensor suitable for small satellites and missions to other solar system objects.
Credit: NASA Goddard

The groundbreaking infrared sensors use layers of repeating molecular structures to interact with individual photons, or units of light. The sensors resolve more wavelengths of infrared at a higher resolution: 260 feet (80 meters) per pixel from orbit compared to 1,000 to 3,000 feet (375 to 1,000 meters) possible with current thermal cameras.

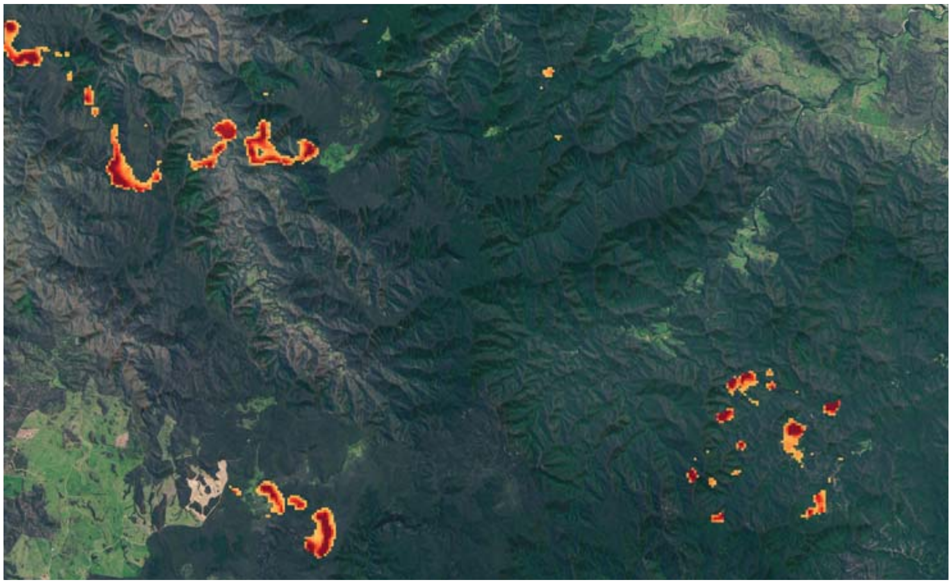
The success of these heat-measuring cameras has drawn investments from NASA's Earth Science Technology Office (ESTO), Small Business Innovation and Research and other programs to further customize their reach and applications. For example, Jhabvala and NASA's Advanced Land Imaging Thermal IR Sensor team are developing a six-band version for this year's LiDAR, Hyperspectral, and Thermal Imager airborne project. "This first-of-its-kind camera will measure surface heat and enable pollution monitoring and fire observations at high frame rates," Jhabvala explains.

Similarly, NASA Goddard Earth scientist Doug Morton leads an ESTO project developing a Compact Fire Imager (CFI) for wildfire detection and prediction. "We're not going to see fewer fires, so we're trying to understand how fires release energy over their life cycle," Morton says. "This will help us better understand the new nature of fires in an increasingly flammable world."

CFI will monitor both the hottest fires, which release more greenhouse gases, and cooler, smoldering coals and ashes that produce more carbon monoxide and airborne particles like smoke and ash. "Those are key ingredients when it comes to safety and understanding the greenhouse gases released by burning," Morton explains.

After they test the fire imager on airborne campaigns, Morton's team envisions outfitting a fleet of 10 small satellites to provide global information about fires with more images per day. Combined with next generation computer models, he adds that this information can help the forest service and other firefighting agencies prevent fires, improve safety for firefighters on the front lines and protect the life and property of those living in the path of fires.

"Outfitted with polarization filters, the sensor could measure how ice particles in Earth's upper atmosphere clouds scatter and polarize light," NASA Goddard Earth scientist



The Compact Thermal Imager captured unusually severe fires in Australia from its perch on the International Space Station in 2019 and 2020. With its high resolution, it detected the shape and location of fire fronts and how far they were from settled areas – information critically important to first responders. *Credit: NASA*

Goddard is NASA's premiere space flight complex and home to the nation's largest organization of scientists, engineers, and technologists who build spacecraft, instruments, and new technology to study Earth, the sun, our solar system and the universe. *Credit: NASA*

Dong Wu adds. This application would complement NASA's PACE – Plankton, Aerosol, Cloud, ocean Ecosystem — mission, which revealed its first light images earlier this month. Both measure the polarization of light wave's orientation in relation to the direction of travel from different parts of the infrared spectrum.

"The PACE polarimeters monitor visible and shortwave-infrared light," he explains. "The mission will focus on aerosol and ocean color sciences from daytime observations. At mid- and long-infrared wavelengths, the new infrared polarimeter would capture cloud and surface properties from both day and night observations."

In another effort, Hewagama is working with Jhabvala and Jennings to incorporate linear variable filters which provide even greater detail within the infrared spectrum. The filters reveal atmospheric molecules' rotation and vibration as well as Earth's surface composition." That technology could also benefit missions to rocky planets, comets and asteroids," planetary scientist Carrie Anderson says, also adding that they could identify ice and volatile compounds emitted in enormous plumes from Saturn's moon Enceladus.

"They are essentially geysers of ice," she explains, "which of course are cold, but emit light within the new infrared sensor's detection limits. Looking at the plumes against the backdrop of the Sun would allow us to identify their composition and vertical distribution very clearly." **www.nasa.gov**

While the LSST Camera is revolutionizing our understanding of the cosmos, NASA's Compact Thermal Imager (CTI) is making waves closer to home.

Key Highlights of NASA's CTI:

Versatile Applications – The compact infrared cameras are designed for a wide range of applications including wildfire detection and monitoring, atmospheric studies (such as analyzing cloud and surface properties), Earth science (pollution monitoring and vegetation analysis), and planetary exploration (identifying surface composition and atmospheric phenomena on other planets).

Advanced Technology – These cameras feature advanced strained-layer superlattice sensors for high-resolution and high-spectral range infrared imaging. Their compact and lightweight design incorporates integrated filters, eliminating the need for traditional lens systems. This technology allows for higher resolution imaging, achieving up to 260 feet per pixel from orbit.

Successful Deployments – These cameras have demonstrated their resilience and performance through various space missions, including successful experiments on the International Space Station where they captured over 15 million images in two infrared bands, providing valuable data for Earth Science.

Real-World Impact – The data from these cameras improve wildfire response by detecting fire fronts and their proximity to settled areas. They also provide detailed information on the vertical structure of Earth's clouds and atmosphere, and they enhance the understanding of greenhouse gases released by fires and other sources.

Future Prospects – Future developments include creating six-band versions for more detailed observations and deploying a fleet of small satellites for global fire monitoring with high-frequency imaging. There are also plans for new applications in planetary science, such as studying ice plumes on Saturn's moon Enceladus, and other missions to explore the composition of rocky planets, comets, and asteroids.

Concept art for BHEX. *Credit: Joseph Farah (UCSB/CfA)*

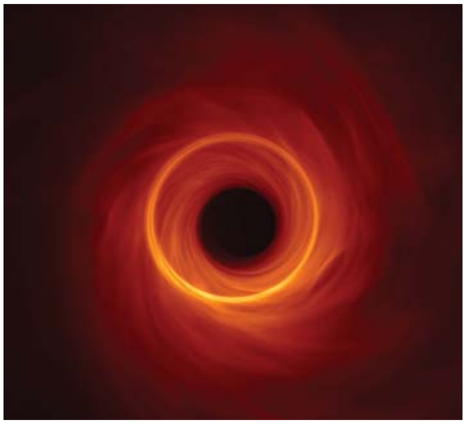
BHEX Leverages Cryogenics to Capture Black Holes

by Hannah Rana, BHEX Cryogenics Co-Lead

Introduction to BHEX

The Black Hole Explorer (BHEX) is a mission that will discover and measure a black hole's photon ring, capturing light that has orbited a black hole. BHEX will extend the Event Horizon Telescope (EHT) into space, producing the sharpest images in the history of astronomy, whilst operating a space-Earth hybrid VLBI observatory by sending the BHEX radio telescope into space to link down with the existing EHT telescope on Earth.

The mission aims to deepen our understanding of black holes by capturing and analyzing detailed images and data. Black holes, regions of spacetime with gravitational pulls so intense that nothing, not even light, can escape, are fundamental to the structure and evolution of the universe. Studying them can reveal insights into general relativity, mechanisms that form powerful relativistic jets in active galactic nuclei, and galaxy formation.



High-resolution image of a black hole, showing the photon ring. *Credit: George Wong (IAS)*

The BHEX mission seeks to overcome significant challenges, such as the need for extreme precision and sensitivity in observations due to the vast distances and faint signals involved. Advanced technologies like the Event Horizon Telescope (EHT) are employed, which combine data from multiple observatories worldwide to create a virtual telescope of Earth-sized proportions. This approach enabled the groundbreaking capture of the first image of a black hole's event horizon.

Understanding black holes also involves studying phenomena like photon rings—bright rings of light that encircle black holes, predicted by Einstein's theory of general relativity. These rings can provide further insights into the black hole's properties and the behavior of light in extreme gravitational fields. Despite the complexities, the mission's potential to uncover the secrets of black holes makes it a significant and exciting scientific endeavor.

▶ *continues on page 16*

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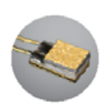

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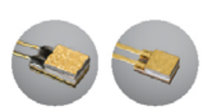

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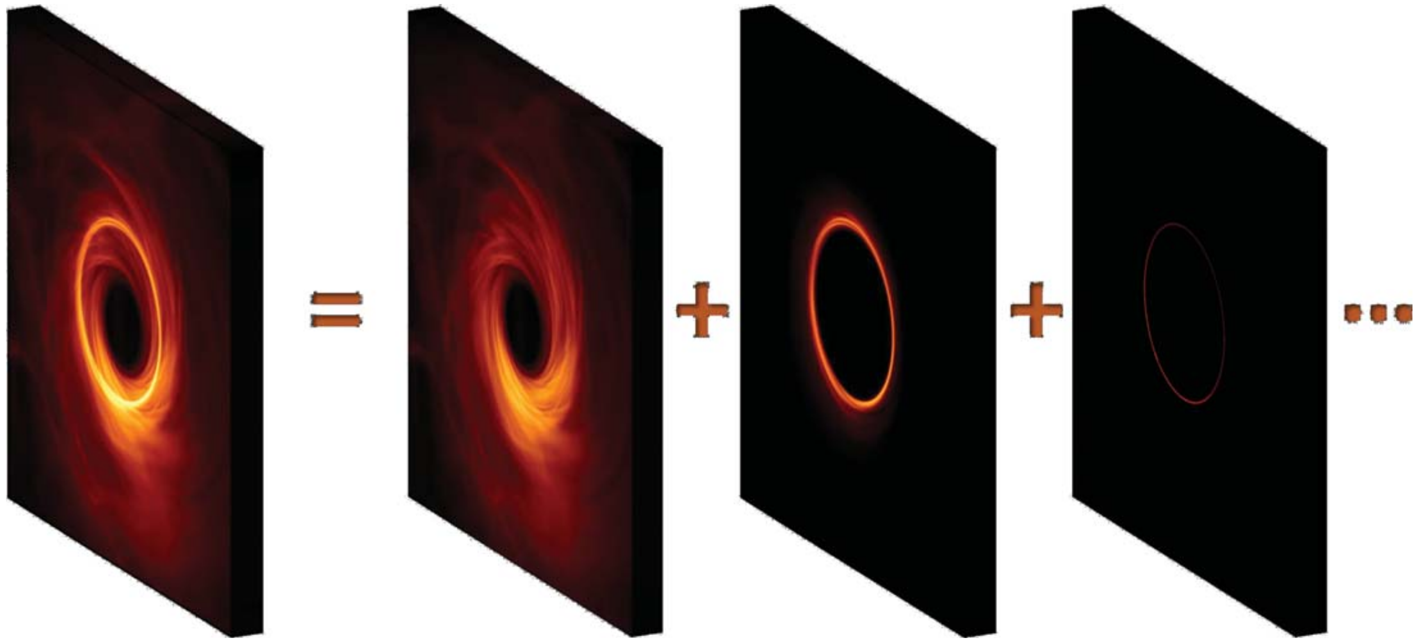


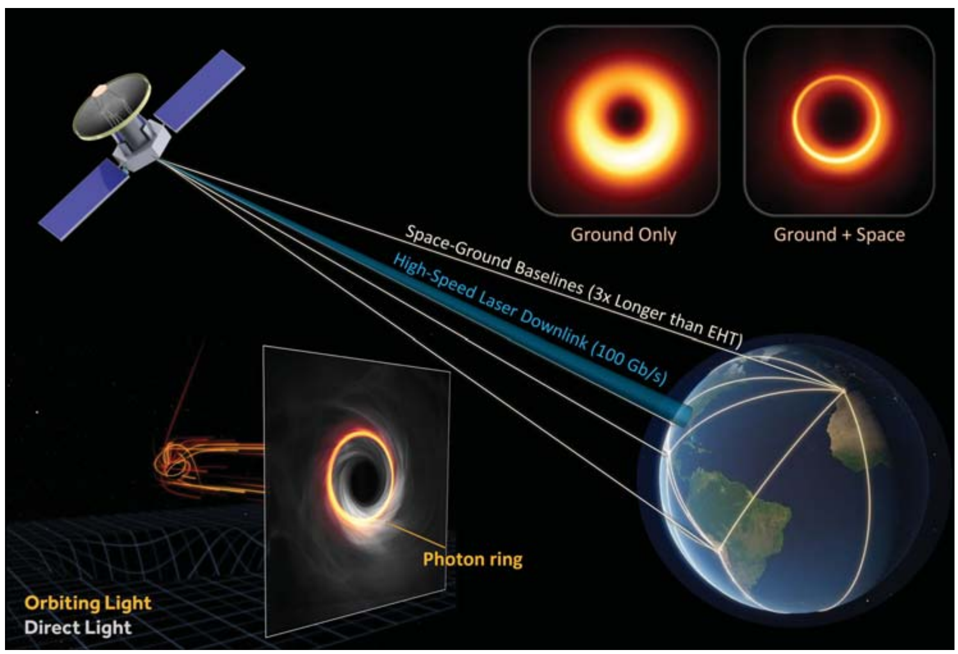
The black hole images decompose into a series of increasingly sharp photon rings. *Credit: George Wong (IAS) and Michael Johnson (CfA)*

The Science of Cryogenics in BHEX

Cryogenic systems are crucial for the BHEX mission, enabling the observation of black holes with unparalleled precision. The mission employs advanced 4 K spaceflight cryocoolers to maintain the required low temperatures for its sensitive detectors. These cryocoolers operate at multiple temperature stages, specifically cooling to 4.5 K and 20 K, which is essential for the optimal performance of the BHEX receiver systems.

The significance of cryogenics in space missions lies in its ability to reduce thermal noise, thereby enhancing the sensitivity of detectors used for astronomical observations. "BHEX will use superconducting detectors, so-called superconductor-insulator-superconductor mixers. They have to be operated at very low temperature, but in return they provide sensitivity that approaches the limits set by quantum mechanics", according to Dan Marrone, BHEX Instrument Scientist and Professor of Astronomy at the University of Arizona.

BHEX utilizes a combination of cryogenic technologies, including Stirling and Joule-Thomson coolers, designed to meet stringent mass and power constraints. These technologies ensure effective heat load management and vibration control, crucial for maintaining the stability and functionality of the receiver system in the harsh space environment. These cryogenic systems are integral to achieving BHEX's objectives of capturing high-resolution images of black holes and their photon rings, thus advancing our understanding of these enigmatic cosmic entities.



BHEX Mission Concept [from The Black Hole Explorer: Motivation and Vision, SPIE, 2023]. *Credit: Michael Johnson (CfA)*

The Photon Ring

The photon ring around a black hole is a bright, thin ring created by photons that closely orbit the black hole before escaping. This ring is a unique feature resulting from extreme gravitational lensing near the event horizon, making it a key observational target for understanding black hole properties. Capturing the photon ring provides direct

BHEX team during a workshop at NASA Goddard Space Flight Center in November 2023. *Credit: BHEX*

insights into the black hole's mass, spin, and inclination by measuring its shape and size. Black hole images are composed of a series of ever sharper photon rings, produced from light that has orbited the black hole increasingly more times before escaping. The properties of the black hole are imprinted on the size and shape of the photon ring, allowing us to directly study whether supermassive black holes are spinning.

Building the Mission

Led by Dr. Michael Johnson, BHEX PI, the BHEX team is a large collaboration consisting of scientists, researchers, engineers and other professionals from across multiple international organizations. From the cryogenic point of view, a Request for Information (RFI) is currently live and receiving responses for information on 4 K spaceflight cryocooling systems that could be used for the BHEX mission. Through the BHEX mission, the first demonstration of a closed-cycle 4 K spaceflight cryocooler on a US-led space mission will be performed. This is an incredibly exciting mission for the astrophysics community, and cryogenics plays a pivotal role in making it a reality. **www.blackholeexplorer.org**.

NIST Scientists Modify Common Lab Refrigerator to Cool Faster with Less Energy

In a groundbreaking development, scientists at the National Institute of Standards and Technology (NIST) have engineered a significant enhancement to the efficiency of cooling materials to temperatures near absolute zero. Through modifications to a commonly used laboratory refrigerator, they have achieved remarkable reductions in both cooldown time and energy consumption. This innovation holds profound implications for various fields reliant on ultracold temperatures, from quantum computing to astronomy and superconductors.

The prototype device, now in the process of commercialization in collaboration with an industrial partner, promises substantial savings in power consumption, estimated at 27 million watts annually. Additionally, it is projected to save $30 million in global electricity costs and conserve enough cooling water to fill 5,000 Olympic swimming pools. (These numbers are on an annual basis, and the dollar savings come from the electricity savings.)

For decades, the pulse tube refrigerator (PTR) has been instrumental in achieving the ultracold temperatures necessary for numerous applications. These refrigerators operate by cyclically compressing and expanding high-pressure helium gas, akin to the principles underlying household refrigeration but on a far more extreme scale. However, despite their reliability, PTRs have been notorious for their voracious appetite for power, consuming more electricity than any other component in ultralow temperature experiments.

Upon closer examination, NIST researchers identified a critical inefficiency in PTRs: their design prioritized cooling performance at their final operating temperature of 4 K, at the cost of energy efficiency during cooldown. At higher temperatures, particularly during the initial cooling phase from room temperature, these refrigerators exhibited significant energy wastage.

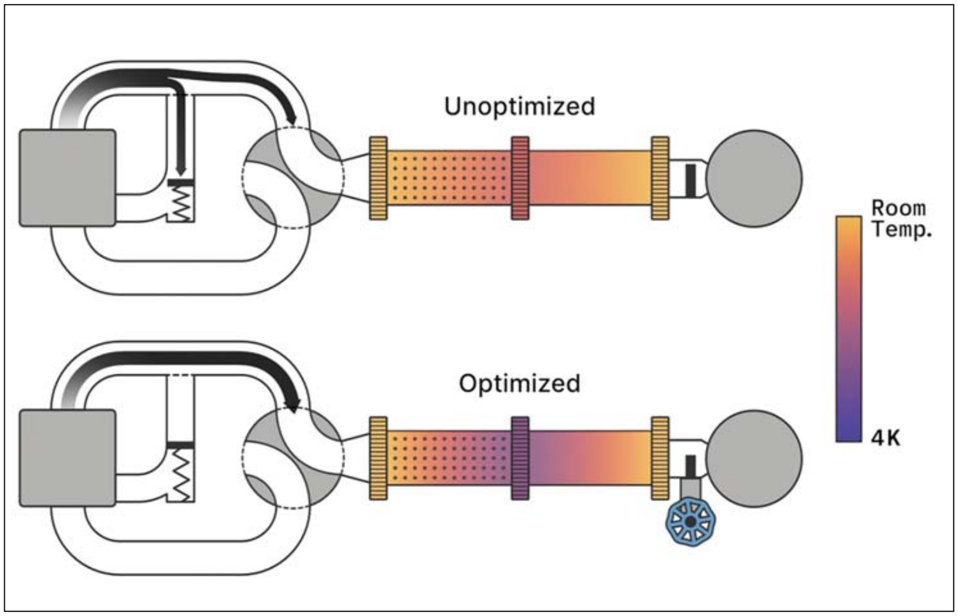
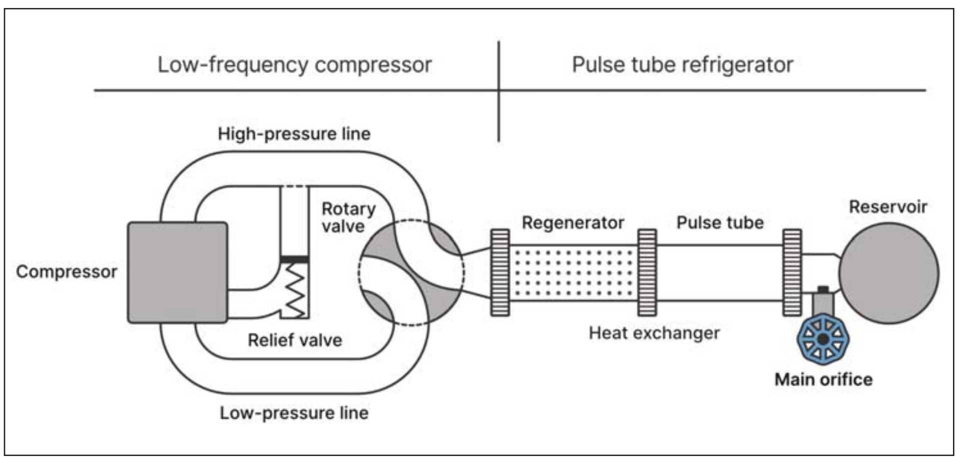


Illustration of a pulse tube refrigerator. Notice that in the unoptimized case there is an additional arrow on the left side of the figure (showing that part of the gas from the compressor is wasted because it is sent back to the compressor, instead of to the refrigerator). Also note the optimized refrigerator shows colder temperatures during the cooldown, since it cools more quickly. The image is taken during the same time in the cooldown process for the two refrigerators. Credit: NIST



A simplified version of a pulse tube refrigerator (PTR), commonly used to cool materials to a few degrees above absolute zero by compressing and expanding helium gas held under high pressure. NIST researchers optimized the efficiency of the PTR, dramatically reducing the amount of time and energy required to reach ultracold temperatures, by continuously adjusting the valve connecting the pulse tube to a reservoir of helium gas. Credit: NIST

Through a series of innovative adjustments to the refrigerator's mechanical connections, led by researcher Ryan Snodgrass and his colleagues Joel Ullom, Vincent Kotsubo and Scott Backhaus, NIST addressed this inefficiency. By optimizing the flow of helium gas from the compressor to the refrigerator through a series of dynamically controlled valves, they ensured that none of the gas was wasted, thereby drastically improving efficiency.

Their approach involved continuously adjusting these valves, allowing for a larger opening at room temperature and gradually closing them as cooling progressed. This simple yet ingenious method resulted in a reduction of cooldown time to between 60 and 30 percent of the previous duration. Previously, scientists had to wait a day or more for new quantum circuits to reach the required temperatures for

▶ *continues on page 20*

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NIST Scientists Modify Common Lab... Continued from page 18

testing. With this enhancement, the time barrier to reaching cryogenic temperatures is significantly diminished, potentially accelerating progress across various fields, particularly quantum computing.

Furthermore, this innovation opens avenues for downsizing refrigeration equipment, as smaller PTRs could replace larger, less efficient models, requiring less supporting infrastructure. As the demand for ultracold temperatures, driven by advancements in quantum computing and related technologies, continues to surge, the implications of this development become increasingly significant.

Ryan Snodgrass explains the modification's efficiency enhancement: "For status quo pulse tube refrigerators, a significant portion of the helium flow generated by the compressor is not used by the refrigerator during the cooldown process. This is inefficient because the compressor consumes an enormous amount of electricity to produce that flow. In the new, optimized configuration, all of the flow generated by the compressor is utilized by the refrigerator."

Regarding potential implications for various industries and scientific research fields, Snodgrass adds, "The implications of faster and more efficient cooldowns is increased accessibility of 4 K and below temperatures. This is achieved in two ways. First, experimentalists can significantly increase their work throughput. For example, an experiment that previously took a full day to cool down may now be cooled in less than 8 hours, so experimentalists may be able to start low temperature characterization before leaving work for the day. The second impact to accessibility is through miniaturization of cryostats. Cryocoolers that were previously oversized to achieve acceptable cooldown times can be replaced with much smaller ones that consume less electricity and cooling water and occupy less space. It is important for the cryocooler industry to increase the efficiency of these systems since they are continuously becoming more ubiquitous."

Published in *Nature Communications*, the research outlines a dynamic acoustic optimization method for PTRs, providing a blueprint for rapid cooldown capabilities. The collaboration between NIST and the University of Colorado Boulder underscores the interdisciplinary nature of this pioneering work.[1]

Beyond its immediate applications, this breakthrough represents a significant step towards sustainability in scientific research, offering substantial reductions in energy consumption and associated costs. By expediting the cooling process, it accelerates scientific discovery and innovation, paving the way for transformative advancements in fields reliant on ultracold temperatures. **www.nist.gov**

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Ebara Elliott Energy Takes Flight with Sustainable Aviation Fuel Project

by Sheila Holt

Ebara Elliott Energy, formerly known as Elliott Group, has secured a contract to supply a motor-driven recycle compressor with a variable frequency drive (VFD) for the Sustainable Fuel Development Project (SFP) by TTCL Public Company Limited. This project is set to advance Thailand's sustainable aviation fuel (SAF) industry.

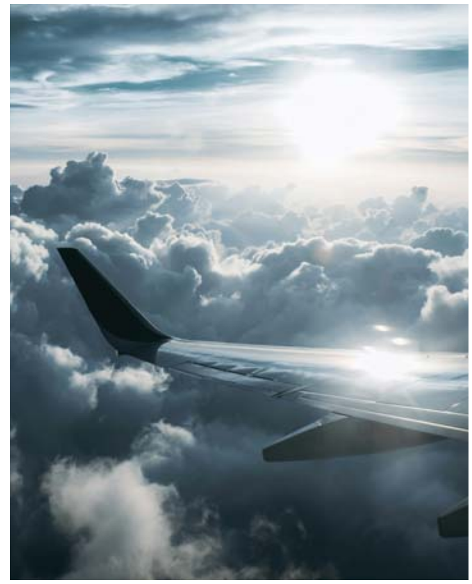
Based in Bangkok, Thailand, the SFP Project is the nation's inaugural commercial production unit for SAF, exclusively utilizing 100% recycled cooking oil. Operated by BSGF Company Limited, a joint venture between Bangchak Corporation Public Company Limited, BBGI Public Company Limited and Thanachok Oil Light Company Limited, this initiative is strategically positioned to serve both domestic and international aviation sectors.

With an initial daily production capacity of 1,000,000 liters, Thailand’s first SAF production plant offers immediate integration into the aviation industry without compromising engine performance. Moreover, the production of SAF is expected to significantly reduce the industry’s greenhouse gas emissions by an estimated 80,000 tons of carbon dioxide equivalent annually compared to current levels.

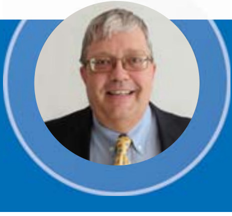
“Ebara Elliott Energy continues to lead compressor supply in the Thailand market. We’re pleased to offer our equipment and services for this SAF project in Thailand, committed to delivering solutions to our customers,” said Fucai Lin, an area sales manager for Ebara Elliott Energy New Apparatus Asia/Pacific Sales.

According to Director of Sustainability Business Development HongPing Zhang, SAF production from recycled cooking oil follows existing refinery practices such as hydro-treatment. “Ebara Elliott Energy has extensive experience and expertise in hydrogen-rich gas centrifugal compressors,” Zhang stated. “We recognize SAF’s role in decarbonizing the aviation sector and are excited to be part of this project aimed at reducing greenhouse gas emissions in Thailand.”

As an energy industry solution provider, Ebara Elliott Energy designs, manufactures and services advanced centrifugal and axial compressors, steam turbines, power recovery expanders, custom pumps and cryogenic products. These are widely used in petrochemical, refining, oil and gas, and liquefied gas industries, as well as power applications. With 2,300 employees across 29 locations worldwide, Ebara Elliott Energy operates as a wholly owned subsidiary of Ebara Corporation, headquartered in Tokyo, Japan. Aligned with its parent company’s vision, Ebara Elliott Energy aims to advance the sustainable development goals by addressing key priorities and enhancing corporate value through medium-term management plans. **www.elliott-turbo.com**



Ebara Elliott Energy will supply a motor-driven recycle compressor for Thailand's first sustainable aviation fuel project, using recycled cooking oil to reduce emissions by 80,000 tons annually. *Credit: Ebara Elliott Energy*



Cryo Bios

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

Looking Backward and Forward

Since 2018 I have been writing this column on pioneers in cryogenics. So far, a total of 30 people have been profiled. With this column taking a slightly different direction in the future (more below), it's worth asking if these pioneers had anything in common. Here are a few common themes seen in many of the people examined so far:

The individuals had interests in and made significant contributions to other fields.

Breadth of interest is probably the most commonly seen trait of these pioneers. Lord Kelvin (William Thomson) made important contributions to electrical engineering, including assisting in the laying of the first transatlantic telegraph cable. Georges Claudet started companies and made fortunes in three separate areas: acetlyene production and storage, air separation, and neon signage. He also was an early advocate of ocean thermal energy conversion. Francis Simon and Nicholas Kurti both made major contributions to uranium enrichment by gaseous diffusion during World War II. Kurt Mendelssohn helped develop an improved ether vaporizer for use in field hospitals during World War II and later wrote well-regarded books on science history and Egyptology. Jack Allen was an early innovator in the use of photography and motion pictures in science education. Russell Donnelly supported and was heavily involved with classical music festivals in Oregon. Olli Lounasmaa was a pioneer in the field of magnetoencephalography. Fredrick Lindemann was Winston Churchill's informal science advisor and served in both of his cabinets. The image of a scientist as a specialist in a narrow field is just not reflected in these people.

The individuals stressed scientific communication and collaboration.

Many of these people not only made important scientific discoveries but also developed the mechanisms by which the discoveries were carried out and disseminated. H. Kamerlingh Onnes created a school for instrument makers and published a scientific journal at Leiden University. He also coined the term cryogenics. Keiichi Oshima and Kurt Mendelssohn helped establish the International Cryogenic Engineering Conference and Kurt Mendelssohn was the driving force behind the journal *Cryogenics*. The majority of the people profiled so far served on the editorial board of scientific journals, helped organize conferences and workshops and participated in professional societies. Some of them, like Kurt Mendelssohn, also helped to make science accessible to the general public. Many of them hosted visiting scholars and students in their home institutions and themselves worked as visiting researchers in other institutions. Taken together, all these activities greatly expanded both the number of places and number of people conducting research in cryogenics and established much of the infrastructure of our field.

The individuals overcame adversity frequently driven by war and politics.

The events of the 20th century were challenging to many of the scientists profiled. Kurt Mendelssohn, Francis Simon, Nicholas Kurti, Fritz London and Heinz London all had to flee Germany at the start of the Second World War. Laszlo Tisza, having previously left Hungary and the USSR for France, was forced to leave again when Germany invaded in 1940. Chaosheng Hong's entire undergraduate university had to relocate to southwestern China when Japan invaded China. Tisza was imprisoned in Hungary for being a communist while Lev Landau was briefly imprisoned in the USSR during Stalin's purges.

Despite these upheavals, the scientists portrayed in this column continued their work and even prospered, creating new centers of excellence on cryogenic research.

Up until now, all the people I have portrayed in this column have been deceased. This approach has some fundamental issues. Not only is the number of people described limited, but the time period covered in this way ends in the late 1970s to the mid-1980s. To address these limitations, the Cryo Bios column will transition from biographies of deceased pioneers to interviews with living ones. The complete interviews will be recorded and will be available on the CSA website while extracts of the interviews will make up this column. I'm very happy to announce that I will be joined in this effort by ***Cold Facts*** Editor Anne DiPaola who will assist with the interviews and writing of the column. The first of these columns, a fascinating interview already recorded with Ray Radebaugh, will appear in the next issue. The old format won't completely go away; look for a column on Russell Scott in 2025. Please join me as we continue to explore the people and history of cryogenics.

Dr. Mohammad Kassemi, Case Western Reserve University & NASA Glenn Research Center, Mohammad.Kassemi@nasa.gov

Validation and Verification of CFD Models for Cryogenic Fluid Management of Propellant Tanks in Space

Significant advancement beyond the current state of the art in fluid management of propellants is needed to use cryogens as viable fuels for the high-performing nuclear thermal propulsion or chemical propulsion systems in future long-duration exploration missions. To realize this advancement, the aerospace community has converged on the zero-boiloff (ZBO) or reduced boiloff (RBO) strategies that use active operations to achieve reliable, cost-effective and efficient propellant storage and transfer operations with minimum fuel loss.[1]

Unlike the current short-duration gravity-insensitive passive pressure control systems, the future ZBO and RBO pressure control strategies will rely on a complex combination of dynamic forced mixing and energy removal from the two-phase, multi-component propellant system to control the tank temperature and pressure during various storage and transfer operations. These operations that will hopefully be tested in a future large-scale cryogenic fluid management (CFM) demonstration for in-space refueling (Figure 1) involve either segregated or interpenetrated fluid phases that may be single component or consist of different condensable and noncondensable species. They will be governed by complex dynamic interactions between forced mixing and the various gravity-dependent transport mechanisms in the vapor and liquid phases, and by the condensation-evaporation phase change processes that occur at the moving and deforming vapor-liquid interfaces. They may also be complicated due to the injection of gas or liquid into the bulk phases and because of boiling, condensation and cavitation that may occur at the solid boundaries, creating complex interpenetrating phase distributions that have to be properly captured. The complexity of the underlying physics has created an increased reliance on first-principal computational models to guide and optimize the future propellant tank designs by crossing different spatial scales, fluid types and gravitational levels.[2]

Figure 1: NASA STMD Large-Scale CFM Demonstration for In-Space Refueling. *Credit: (https://spacenews.com/lockheed-martin-removes-momentus-from-nasa-technology-demonstration-mission)*

In order to address this need, the tendency within the aerospace community and NASA has been to use the industry standard multipurpose computational fluid dynamics (CFD) codes such as Ansys/Fluent, Star-CCM+, and Flow3D to guide the design process. Unfortunately, straight-off-the-shelf application of these CFD codes to the complicated propellant tank pressurization, pressure control and transfer processes, especially, under microgravity conditions, has been difficult and often not entirely fruitful. The difficulties are due to the following factors:

1. Multipurpose codes are designed to address a vast and diverse set of engineering and scientific problems.

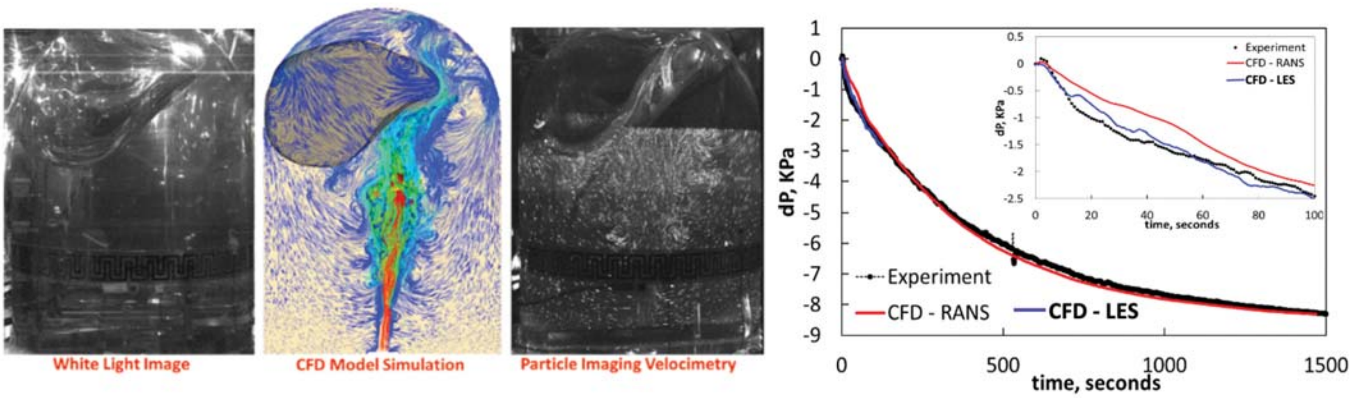


Figure 2: Validation of two-phase VOF Fluent CFD models against microgravity ZBOT pressure control experiments: (a) Fluid flow and ullage deformation during the liquid jet mixing (b) Depressurization rates during subcooled jet mixing.[3]

Thus, individual capabilities that are needed for CFM applications may not be as refined as they would be in a customized in-house code and might not have passed a stringent and targeted quality control process for CFM type problems.

2. Multipurpose codes may not possess or only partially possess the underlying physics that is required for the complicated space CFM simulations.

3. Sometimes the mathematical formulation exists, but it has not been validated for the nonintuitive manifestations of the associated physics in microgravity.

4. The codes may not have the required numerical discretization schemes, especially, at the diffusely captured dynamically changing two-phase interfaces that are prevalent under weightlessness conditions.

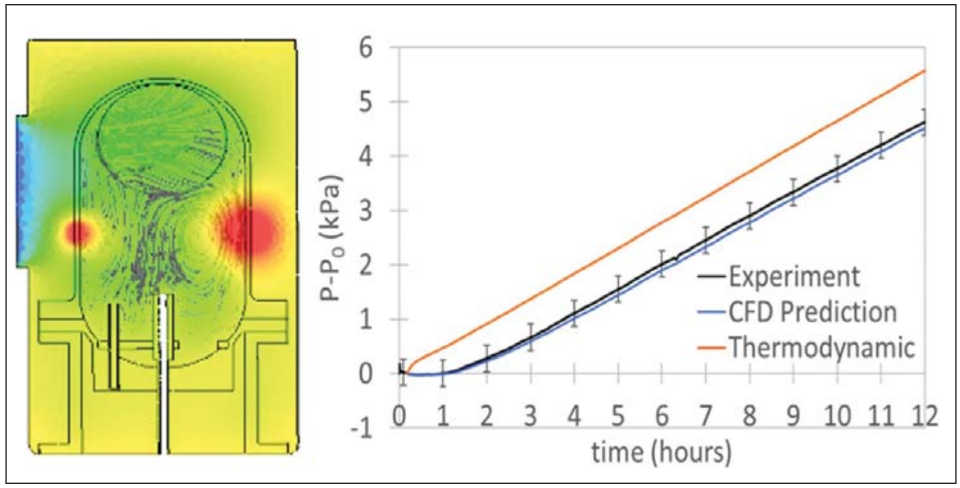


Figure 3: Validation of the sharp interface fluent CFD model against ZBOT microgravity self-pressurization data.[4]

To overcome these shortcomings, the strategy adopted at NASA GRC and within the computational research group at Case Western Reserve University has been to first attempt to validate the capabilities of the multipurpose CFD codes against relevant 1g and microgravity experiments for the specific CFM problem at hand. This step identifies where the existing formulations may be incorrect, or the required physics is missing.

Next, either the improper formulations are corrected by working with the software company or the required theory and mathematical formulations are developed in-house to address the missing physics. The new formulations are then encoded and implemented into a customized version of the multipurpose code through its specific user-defined functions (UDFs) or subroutines. Finally, the customized code goes through a comprehensive verification and validation study to confirm the physical fidelity and accuracy of the enhanced capability for the specific CFM application in 1g, microgravity, or partial gravity. In this manner, through targeted enhancements and without reinventing the proverbial wheel, a powerful customized CFD code is created with the required capabilities that ensures high-fidelity computational performance for the specific CFM applications.

A question that is often asked is what is the accuracy of the CFD models that are developed for CFM applications? This is not an easy question to answer. In reality, the degree of fidelity of the CFD models is not only dependent on the correctness of their mathematical and numerical formulation but also on the nature, quality, detail, precision and relevance of the experimental data that is used for their validation. For scientific accuracy, where CFD predictions are within 5% of the measurements, the validation experiment must be performed in smaller scaled geometries that can be tightly meshed for CFD simulations and where all the flow, temperature and heat flux boundary conditions are controlled tightly and measured with high precision. These measurements provide the required input data to the model. But for scientific validation, detailed whole field temperature and velocity field data are also needed in addition to the local pressure, temperature and flow sensor measurements to confirm the correct predictive capability of the models.

The zero-boiloff tank (ZBOT) experiments that investigate various aspects of tank pressure and temperature control in 1g and microgravity are a good example of this small-scale class of scientific experiments. ZBOT experiments are performed using a transparent low temperature phase change simulant fluid (PnP, C5F12) in a small well-instrumented transparent tank. This enables the use of nonintrusive

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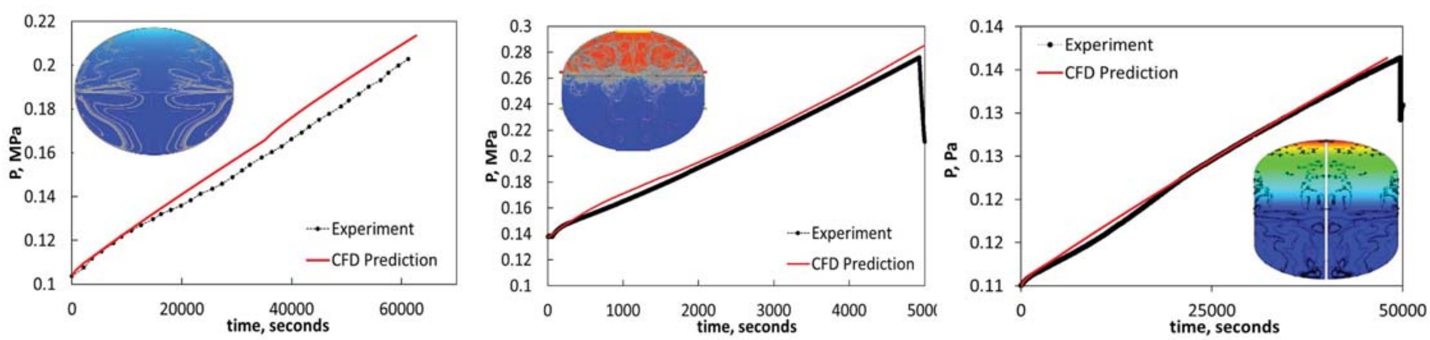

Figure 4: Validation of Fluent-based two-phase CFD models against 1g self-pressurization experiments: (a) K-site (50% Fill)[5]; (b) SHIVER (70% Fill)[6]; (c) MHTB (80% Fill).[5]

particle image velocimetry (PIV) and quantum dot thermometry (QDT) diagnostics to provide whole field flow and temperature data for model validation. Examples of the ZBOT-1 self-pressurization and jet mixing microgravity data and model validations are shown in Figures 2 and 3. However, the ZBOT-scale experiments do not have the right fluid type and the relevant spatial dimension to guarantee the models' ability to predict the exact performance of the large cryogenic propellant storage and transfer processes in space. To ensure the model validation process covers the relevant fluid types and tank dimensions, the CFM CFD models must also get validated against the data provided by large cryogenic experiments which use the same propellent fluids considered for future missions, such as liquid hydrogen (LH_2), liquid oxygen (LOX), and liquid methane (LCH4). The large LH_2 ground experiments performed in the K-site, MHTB, and SHIIVER facilities at NASA GRC and MSFC are great examples of these engineering class experiments.

These experiments are mostly focused on assessing the engineering performance of the propellant tanks during storage and transfer operations and are not necessarily geared towards providing insight into the underlying physics, especially in microgravity. Furthermore, due to their geometrical size and the complexity of their support structure, the thermal and flow boundary conditions in these experiments are not precisely controlled, and the validation data is limited to the ullage pressure and temperature measurements at selected internal and wall locations. Several examples of the CFD model validations against this class of engineering data for tank pressurization and pressure control are included in Figures 4 and 5.

In order to assess the current status of models that are developed for CFM applications, it is conducive to classify them into two model categories. The first category consists of CFD models that are required for capturing the behavior of *segregated* liquid and vapor phases and the condensation and evaporation phase change that occurs at the bulk interface separating them. These models rely on the VOF or other interface capturing numerical schemes to simulate important CFM processes such as: (a) tank self-pressurization; (b) unsubmerged autogenous and noncondensable gas pressurization; (c) jet mixing thermal destratification and pressure control; and (d) pressure collapse during liquid drainage with and without liquid slosh.

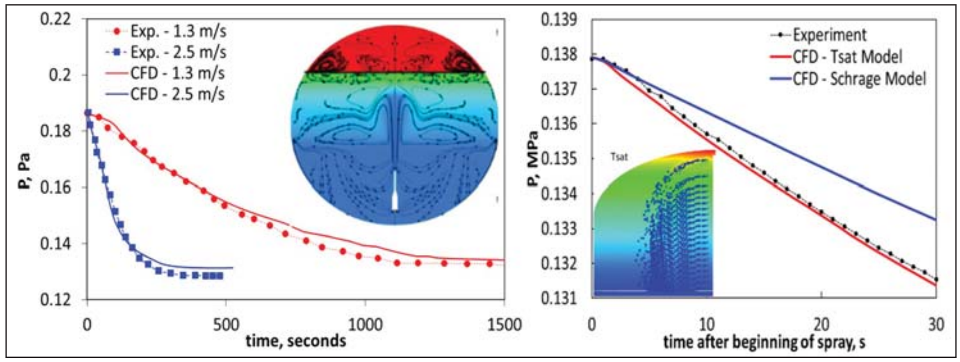

***Figure 5:** Validation of two-phase CFD models against 1g pressure control experiments: (a) K-site jet mixing at two jet velocities[7] and (b) MHTB ALE-Droplet Injection CFD Model.[8]*

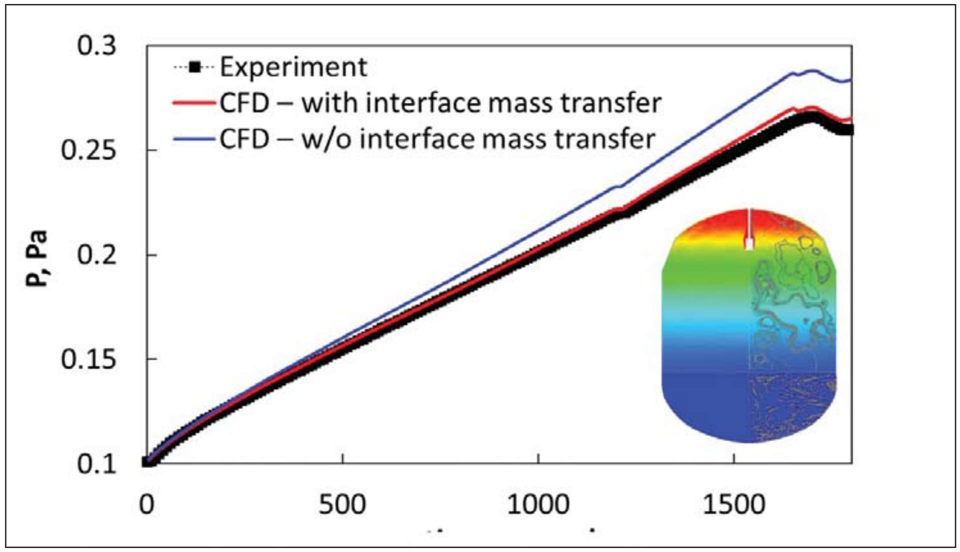

***Figure 6:** Validation of two-phase CFD pressurization models against the results of 1g EDU LN_2 autogeneous pressurization experiment.[9]*

Significant accomplishment has been made in the development and validation of this class of models, especially for tank pressurization and jet mixing pressure control as shown in Figures 2-6. For example, the customized Ansys-Fluent CFD tank pressurization model developed as part of the ZBOT project has been successfully validated against 1g and microgravity small-scale simulant fluid experiments (ZBOT-1 and TPCE), against large LH_2 experiments in 1g (SHIIVER, K-Site, and MHTB), and finally against medium-sized LCH4 pressurization experiment in microgravity (RRM3). Similarly, the Fluent CFD tank jet-mixing pressure control models have also been validated by ZBOT and TCPE simulant fluid experiment in microgravity and large LH_2 K-Site experiment in 1g.

The second category consists of CFD models that capture the behavior of *interpenetrating* liquid and vapor phases created by such phenomena as gas and liquid injection, wall boiling, wall condensation and cavitation. These phenomena are present in CFM processes such as: (a) droplet injection pressure control; (b) submerged autogenous and noncondensable gas pressurization; (c) tank chilldown and filling; (d) transfer line chilldown; and (e) liquefaction. In this category, Eulerian two-fluid, Eulerian Mixture, and Discrete Particle CFD models are typically required to capture the complex phase distributions that occur. The Eulerian two-fluid models need interphase exchange closure submodels that currently rely on empirical correlations that may not be valid in microgravity or exist for cryogens. They also may need to be coupled to customized subgrid models that have to be developed in-house to capture detailed phenomena that occur at the boundaries on a scale that cannot be practically captured on a CFD mesh. As an example, a Eulerian Mixture CFD model coupled to a subgrid nucleate boiling model has been recently developed at NASA GRC for transfer line chilldown and is currently being validated against existing 1g experimental data. However, in general, the development and validation of the models in this category, to the extent that has been accomplished for the CFD models in the first category, is going to be more cumbersome and will take considerably more time. Unfortunately, microgravity data for their validation is also almost nonexistent. Developing modelling capabilities for solving this second category of CFM problems and acquiring the relevant 1g and microgravity data with cryogens for their proper validation is an important priority and challenge that needs to be addressed by the space CFM engineering and research community in the near future.

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Zero Resistance Zone

by Quan-Sheng Shu, Retired Senior Scientist and Jonathan Demko, LeTourneau University

Superconducting Superfluids Meet Machinery

The superconductor (SC) and liquid helium (superfluid He II & He I) are two vital materials in cryogenic engineering, playing crucial roles in various applications. They both exhibit miraculous zero resistance and other fascinating quantum behaviors at the large macroscopic level. **Superconducting electrons show fermionic performance due to their half-integer spin**, governed by the Pauli exclusion principle. In a SC below its critical temperature (T_c), electrons form Cooper pairs, which move without scattering or dissipating energy as heat and electrical resistance is completely absent. **He II consists of bosons with integer spin values**. Superfluidity in He II occurs when it is cooled to ~ 2 K, and a significant fraction of **helium atoms undergo a phase transition to Bose-Einstein condensate (BEC) state**. Due to excellent thermal conductivity and cooling capability, liquid He is the only practical cryogen for large SC machines (exclusion of HTS), while LN_2 is often used for precooling and thermal shields.[1-4] The Large Hadron Collider (LHC), NbTi magnets cooled by subcooled-superfluid He II at 1.8K (Figure 1), and the ITER Tokamak Nb_3Sn magnets cooled by supercritical He I at ~ 3.7 K to 4.5 K (Figure 2), are two exceptional scientific projects respectively demonstrating these technical achievements. Consequently, a range of helium liquefaction/refrigeration systems with varying capacities and multiple temperatures have been developed for various superconducting applications.

Advancements of LHe and SC Machinery

The applications of superconductors not only depend on LHe cooling, but also significantly contribute to the advancement of LHe technologies. Thanks to the unique and irreplaceable advantages of both SC magnets made of NbTi and Nb_3Sn, as well as superconducting radio-frequency (SRF) cavities, more large-scale SC machinery has been successfully developed and operated.[1, 3-4] For example, the LHC operates at 1.8 K, requiring a 20-kW cooling power and holding a 130-ton inventory of LHe across its 27 km SC accelerator.[5]

Furthermore, SC applications that involve high magnetic fields (H) and high accelerating fields (Eacc) have consistently required lower operating T. As illustrated in Figure 3, the widely adopted NbTi cable demonstrates the capability to operate from 7 Tesla at 4.5 K to 10 Tesla at 1.8 K, maintaining the same current density (Jc).[5] The dynamic cryogenic loss of SRF cavities primarily arises from the BCS RF surface resistance R_{BCS}. This resistance exhibits both as a function of RF frequency and an exponential dependence on the ratio of the operating temperature to the critical temperature, as shown in Figure 4.[6]

Best SC Operational Points vs. He Liquefier Cost Realities

Researchers and engineers have constantly explored the optimized LHe operation points for best cooling of SC machines. Figure 5 delicately illustrates the He phase diagram (T-P): LHe is divided by the green λ-line into normal He I and superfluid He II. The λ transition is 2.17 K at one atm. Between LHe and He vapor is the blue saturation line, where liquid and vapor coexist with the critical point at 5.2 K & 2.25 atm. LHe above the saturation line is referred to as subcooled He, also called as pressurized LHe or supercritical He. While SC magnets and SRF cavities excel in lowering operating T, it's crucial to note that refrigeration efficiency increases from approximately 280

Figure 1. LHC SC magnets cooled by subcooled, superfluid He II at ~2 K in the accelerator tunnel. *Credit: CERN*

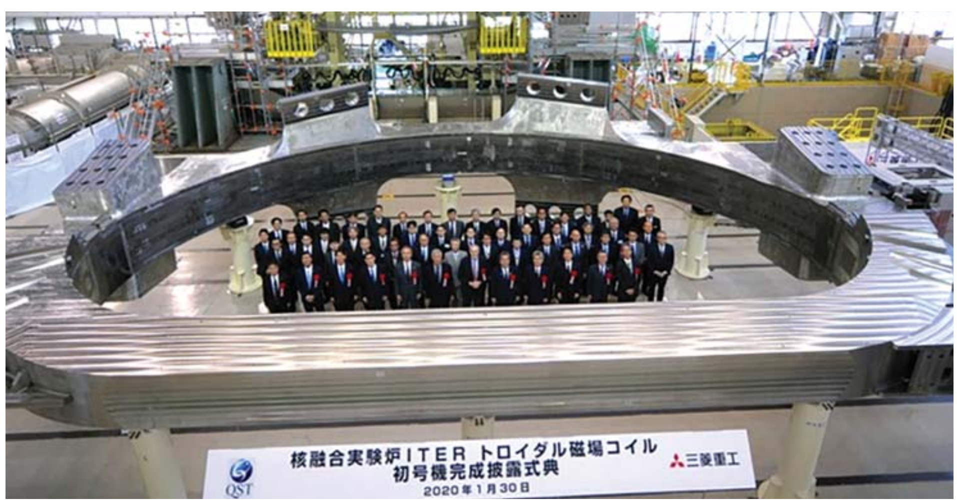

Figure 2. A 360-ton SC magnet with the D-shaped toroidal field coil cooled by supercritical He I at ~3.7 to 4.5 K (constructed by Japan for the ITER Tokamak). *Credit: ITER*

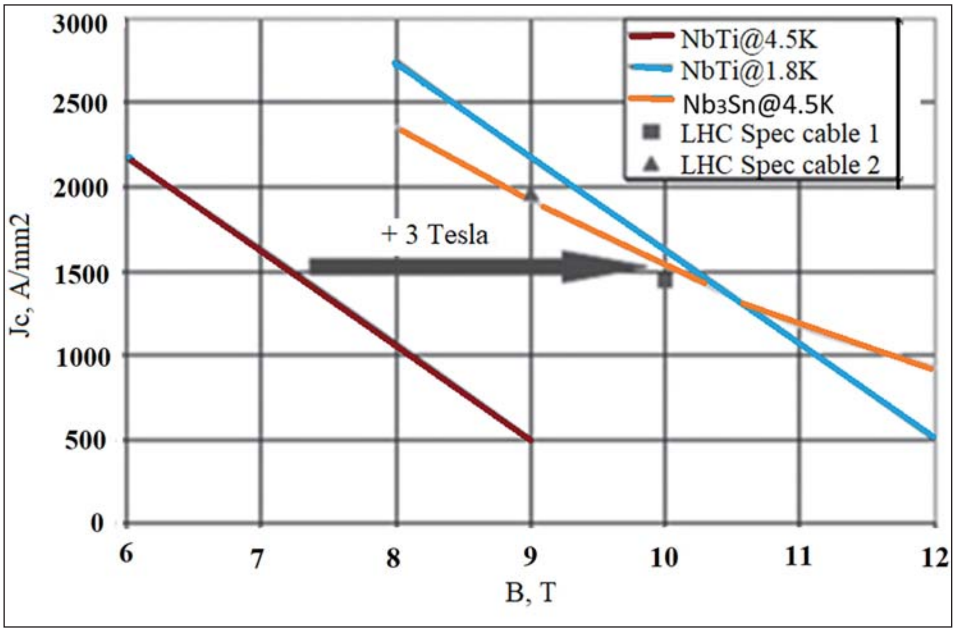

Figure 3. LHC cable specs and Critical B vs Jc of NbTi & Nb3Sn at 4.5 and 1.8 K.[5] *Credit: Ph. Lebrun*

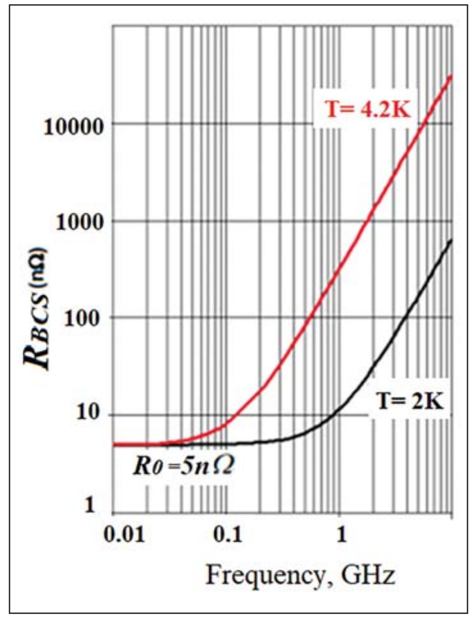

Figure 4. RF surface resistance (BCS) of Nb as function of RF frequency and operation T.[6] *Credit: P. Duthil*

W/W at 4.5 K to about 900–1,100 W/W at 1.8 K.

Accordingly, designing helium liquefier/refrigeration systems involves balancing technical benefits and cost considerations by selecting optimal temperature (T) and pressure (P) points for liquid and gaseous helium. Efficient use of all helium's cooling capacity during circulation to cool thermal shields, anchors etc. is crucial, with designs evaluated on a case-by-case basis.[1-4] Key thermodynamic parameters of He I and He II at critical operating conditions are outlined in Table 1, commonly used for initial estimations when designing cryogenic systems for SC machinery.

Status	T K	P Pa	Lv J/kg	ρ kg/m^3	Cp J/kg·K	S J/kg·K	H J/kg	K W/m·K
Saturated, L	4.2	99230	2.1x10^4	125.4	5170	3551	9901	0.0186
Saturated, G	4.2	99230	-	16.49	9033	8504	3074	0.0089
Saturated, L	2	3129	2.3x10^4	145.7	5187	957.8	1642	-
Saturated, G	2	3129	-	0.794	5975	1258	2504	0.0038
Supercritical	4.5	2 bars	-	124	5434	3755	1159	0.0195
Supercritical	5	2 bars	-	102.4	1658	4608	1568	0.0193
Subcooled	2	99230	-	147.5	5249	965.7	2319	-

L – liquid, G – gas, Lv – latent heat, 1 atm ~ 99230 Pa ~ about 1 bar

Table 1. Key parameters of He I & He II at important operational T & P of SC Machinery. *Edited: Q-S Shu & J. Demko*

Cooling SC Devices: Saturated LHe vs Supercritical He I

Saturated 4.2 K LHe at 1 atm finds diverse applications in cryostats, particularly with SC magnets in fields like physics, materials science, and MRI. Its temperature can be finely tuned between 4.2 K and 2 K (Figure 5, points A to C) using a pumping system to regulate vapor pressure. Also, saturated 4.2 K He I can effectively cool SRF accelerating cavities in cryomodules, ensuring both effective removal of RF heat and stable temperatures to maintain cavity frequency, as seen in projects like **LEP, KEKB, CESR, and MRI** (Figure 5, point A).[1] In saturated LHe cooling, the cooling power is directly proportional to the mass of LHe vaporized, denoted as Q1 = m·Lv. Where Q1 − heat transferred (J), m − mass of LHe vaporized (kg), and Lv − latent heat of LHe at corresponding P and T (J/kg) as listed in Table 1.

Forced-flow of subcooled/supercritical He I (Fig. 5, point B) is crucial for cooling SC magnets in large-scale particle accelerators and Tokamak, such as for **Tevatron** (4.5 K, 2.5 bar), **HERA** (4.5 K, 2.5 bar), **RHIC, SSC** and **ITER**.[7-8] It offers superior heat transfer properties and less sensitivity to heat inleak compared to saturated He I. This supercritical phase enables more efficient cooling in penetrating the magnets to remove AC-ramping heating, providing flexibility in operation and cost-effectiveness. In supercritical LHe cooling, the cooling power is determined by mass and specific heat (Cp) of LHe at corresponding P and T (Table 1). Q2 = m·Cp=ΔT, where Q2 − heat transferred (J), m - mass (kg), Cp − specific heat of LHe (J/kg`K), and ΔT − temperature changes.

At Tevatron of 6.5 km, the largest SC accelerator, supercritical He I is utilized to cool its numerous dipoles (Figure 6), quads, and correction elements. The single phase He (input at 3.5 atm, 4.6 K & output 2.8 atm, 5.5 K) is cooled by the two phase LHe. As another example, eighteen "D"-shaped toroidal field

▶ ***continues on page 30***

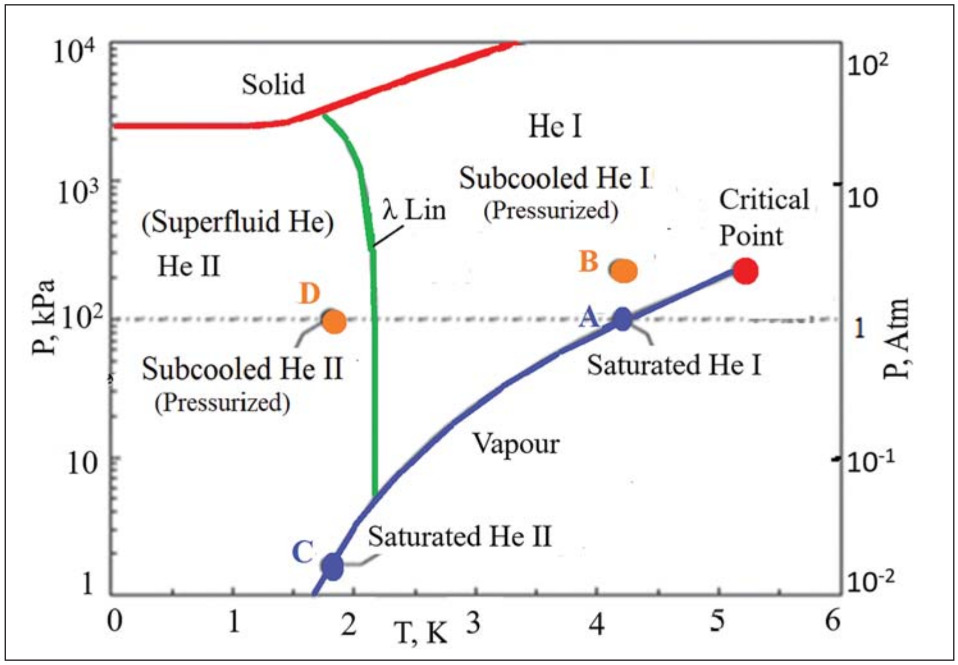

Figure 5. Operation points in He phase diagram (P vs T). Points A, B, C & D represent typical operational parameters of large superconducting machines worldwide. *Edited: Q-S. Shu & J. Demko*

magnets (Nb_3Sn) are placed around the ITER vacuum vessel and cooled by force-flow supercritical He I. The maximum magnetic field is 11.8 tesla, capable of storing 41 giga-joules of energy.

Nb sheet is the optimal material for SRF cavity due to its high Tc (9.2 K), high RF critical magnetic field Hc(RF) = 200 mT at 2 K, low surface resistance (Rs), and excellent thermal/mechanical properties. For frequencies at or above 325 MHz, using saturated He II at 2 K (P ~ 0.031 atm) balances low temperature with cryogenic costs. Below 325 MHz, 4.2 K He I at 1 atm is preferred. Thus, saturated superfluid He II (Figure 5. Point C) is chosen for applications like **CEBAF, TTF, SNS, XFEL,** and **LCLS-II.**[1,4,6] Figure 7 depicts an SRF cavity cooled in a saturated He II container within a cryomodule for TESLA/TTF.[9]

SRF cavities dissipate significant power due to their large surface area (1-2 m²), reaching up to 20 W at 2 K. However, they have a relatively low stored energy. Efficient heat transfer is vital, especially for managing local hot spots. In a pumped LHe II pool, pressure changes are minimal (~1 mbar), favoring cavity frequency stability. The small hydrostatic pressure head enables operation in a slightly pressurized state, absorbing heat

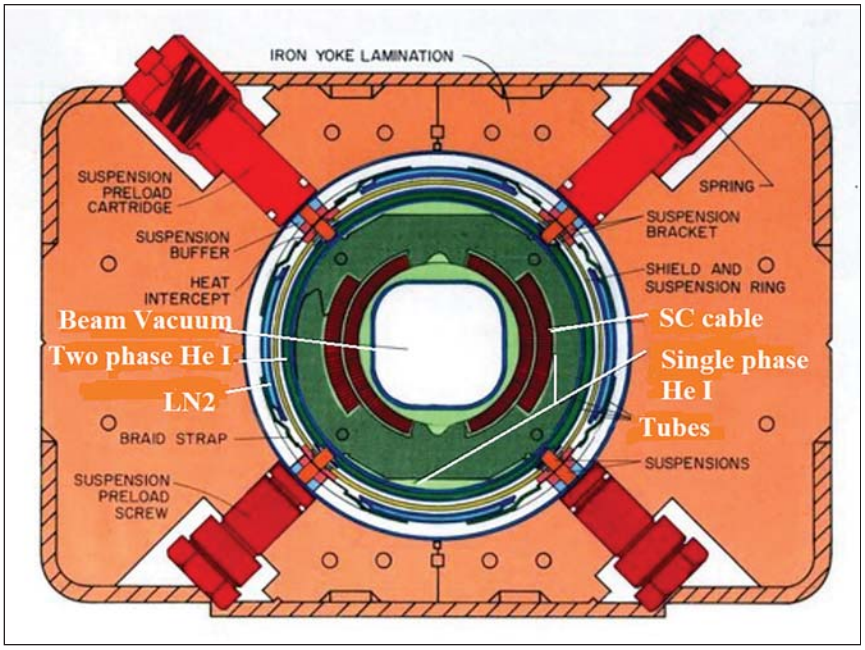

Figure 6. Tevatron SC magnets cooled by forced flow of supercritical LHe I. Credit: Fermilab

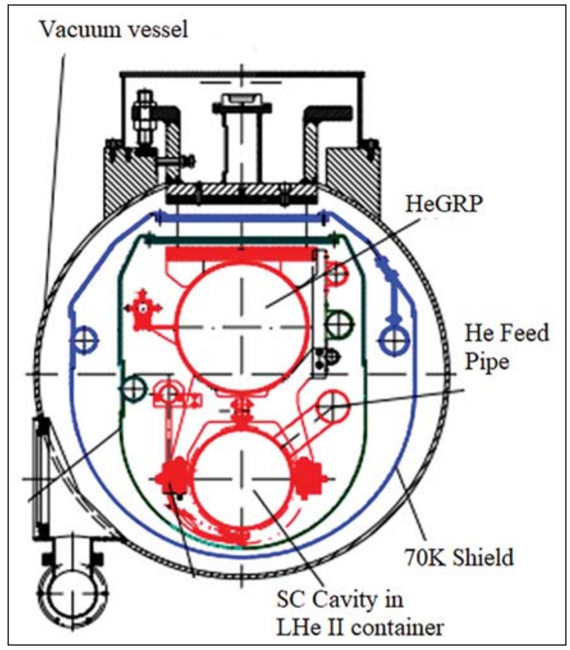

Figure 7. TESLA/TTF SRF cavity pool-cooled by saturated LHe II in cryomodule.[9] *Credit: C. Pagani*

from the Nb surface without phase change until crossing the saturated line.

Subcooled Superfluid He II for SC-Magnets-Based Machine

Accelerator SC magnets are often cooled with subcooled He II (**Fig. 5, point D**), particularly working near the B-Jc limit of the SC cable with large, stored energy. Forced-flows cooling of subcooled/pressurized He II require an additional level of heat transfer from a subcooled He II to saturated He II, but they offer several significant technical advantages, as demonstrated with **LHC and Tore-Supra**.[10]

The distinctive aspect of subcooled He II in SC magnet operations are briefly summarized as follows: Improving stability and heat transfer of subcooled helium flows (He II or He I) come from providing maximum penetration of helium mass in magnet coils. Subcooled He II can absorb heat deposition in its bulk, up to the temperature at which the lambda line is crossed. Local boiling starts only then, due to the low thermal conductivity of He I. Avoiding low-pressure operation in extensive cryogenic systems mitigates the risk of air inleaks. Although heat flow results in a temperature rise in subcooled He II, SC magnets are not as sensitive to it as SRF cavities. Figure 6 depicts an LHC SC magnet.[5] In the case of supercritical LHe II cooling, the cooling power directly for superconducting components: $Q = m \cdot Cp \cdot \Delta T$, and Cp data are presented in Table 1.

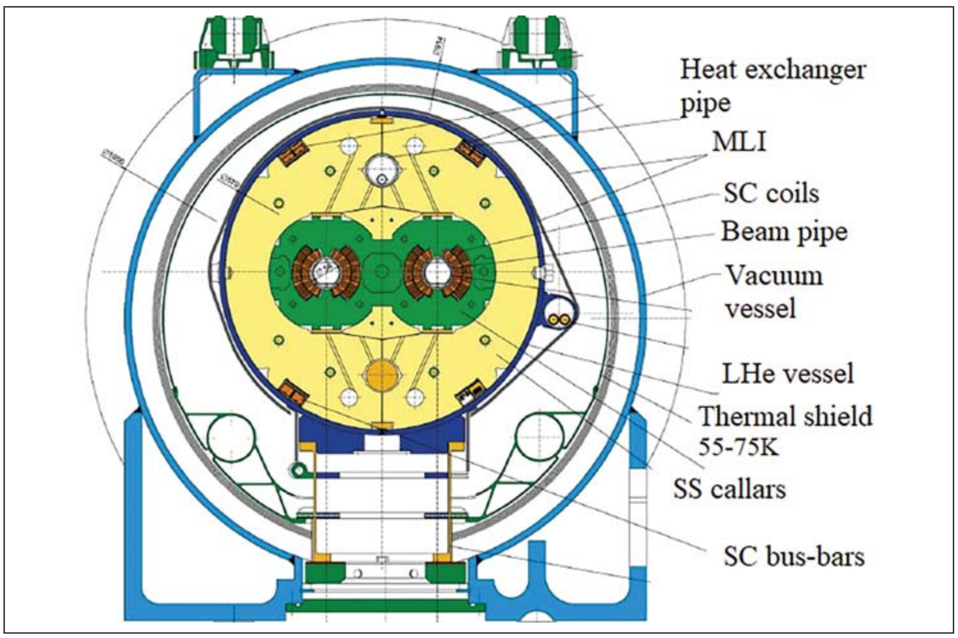

Figure 8. LHC SC magnet cooled by force flow of subcooled He II. Credit: Ph. Lebrun

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Clean Energy Future

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

Managing Positive, Zero and Negative Boiloff in LH_2 Storage

Last time, we examined the industry jargon term "boiloff" and how it is both used and misused in liquid hydrogen (LH_2) system applications. We can also think of boiloff as "positive boiloff" to contrast it with the "zero boiloff" storage capability that is provided by including active refrigeration as an integral part of the total system. But there is also "negative boiloff" which is even more important for well-managing the transfer or dispensing of LH_2.

From the ambient environment there is a continuous, unending heat flow into the liquid. We can call this heat flow Qin. With a refrigeration system employed, there can be a constant heat flow from the stored liquid. This heat flow is called Qout. If Qin is greater than Qout, there will be a positive boiloff condition. If Qin is equal to Qout, there will be a zero boiloff condition. And if Qin is less than Qout, there will be a negative boiloff condition. Negative boiloff is a good thing, providing utility to make LH_2 flow like water. The thermodynamic term for negative boiloff is called enthalpy margin, or the ability for the liquid to absorb heat.

Based on the temperature difference (ΔT) between environments and boiling points, the keeping of LH_2 is same as the keeping of water in the two situations: cup of LH_2 on Earth at 75 °F (left) and cup of water in pizza oven at 700 °F (right).
Credit: James Fesmire

This situation of keeping LH_2 (with a normal boiling point [NBP] of -423 °F) in the ambient environment of say 75 °F is the same as for keeping water (with an NBP of +212 °F) in a pizza oven at about 700 °F as shown in the images above. In both cases, the temperature difference (ΔT), and the driver for heat ingress, is 500 °F. Quite simply, the liquid must warm up to the boiling point temperature before it begins to evaporate into the atmosphere. For example, GenH2 offers innovative helium-cycle refrigeration systems that can remove heat at required rates and cold power to meet zero boiloff or negative boiloff conditions.[1] With sufficient enthalpy margin, the liquid can absorb the heat ingress from the ambient and thus be transferred, conveyed, or otherwise dispensed to a receiving tank with zero loss of hydrogen.

However, zero boiloff, or even negative boiloff, is not the goal but a means to an end. The goal is zero loss of hydrogen by the right combination of design, manufacture, technology and operational technique that makes the most thermo-economic sense. One example of this principle in action is the new Daimler-Benz long-haul Class 8 hydrogen electric truck with LH_2 onboard. This vehicle, called the GenH2, also includes an electric battery in a hybrid but pure electric architecture. The pair of 40-kg high-performance, super-insulated tanks will still "boiloff" to a minor degree when idle, but this hydrogen gas can be fed to the hydrogen electric cell to generate power and charge the battery.[2] Venting hydrogen to the atmosphere is avoided and the goal of zero loss of hydrogen is achieved in this approach. The continued evolution of modern technologies, design architectures, and novel operational approaches are critical for moving LH_2 around and putting LH_2 to the end-use points with zero loss of hydrogen along the way.

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Cool Down Time	60 minutes to 4 K
Base Temperature	<2.8 K

CRYOMECH

Cool Fuel

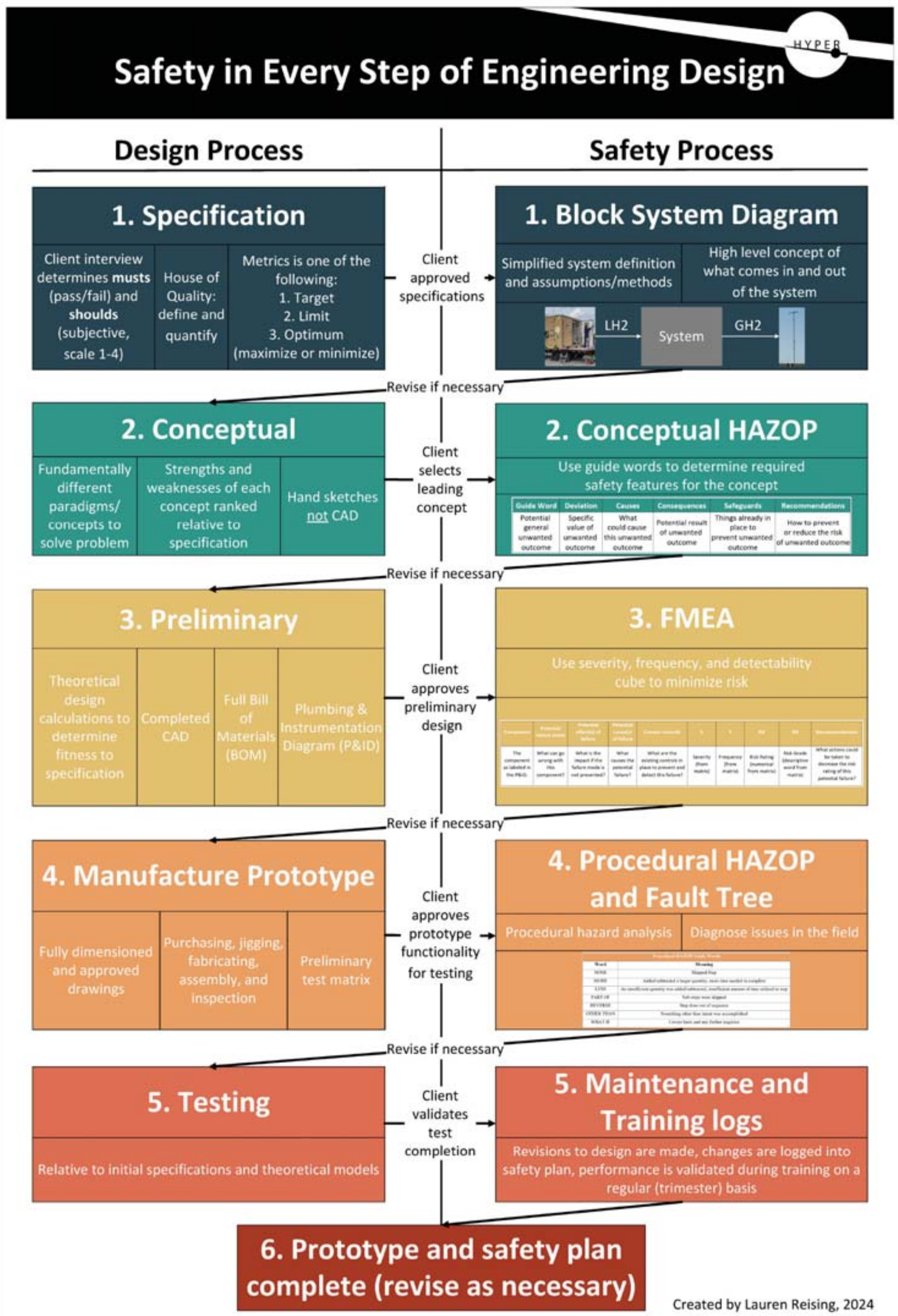
by Dr. Jacob Leachman, Associate Professor, Washington State University, jacob.leachman@wsu.edu

How I Stopped Fighting for Safety

The conventional approach to hydrogen safety was on display recently at the Center for Hydrogen Safety Americas Conference. An expert panel advocated that “safety cultures take a lot of continuous work” and “safety needs a champion in every organization.” I somehow found myself shaking my head in disagreement, which felt odd. After all, I had fought this very same safety battle for over eight years, done as the panelists suggested, and struggled. Only recently did I learn how to stop fighting for safety by creating a culture where safety is the natural outcome.

In many projects I found myself taking the role of safety champion to do the noble effort of forcing the team to go back and retroactively complete a safety plan. Typical safety plans involve HAZard and Operability (HAZOP) studies, Failure Modes and Effects Analyses (FMEA), risk analysis, fault trees and more. These tools inevitably uncovered problems that required teams to go back and redesign or engineer workarounds to mitigate the issues. When all the tools were bundled together, the safety plans began approaching theses or dissertations in length. Students often lamented, “We’re early-stage researchers. Everything we do is one-off. What’s the point in developing an extensive safety plan if we’re just going to change the design in a few months?” To my dismay, ‘safety’ had become a chore that I didn’t enjoy forcing any more than the students liked doing. Eventually, I had to dismiss the only two graduate students in HYPER history for willful safety violations. This was not the positive relationship with safety that I wanted for HYPER.

Good designs are safe designs. The fact that safety planning wasn’t completely integrated with our design process was the core of the issue. Looking back at HYPER’s design process, it became clear how the many parts of a safety plan directly map to design. Figure 1 shows a flowchart of this integrated



design and safety planning process created by HYPER undergrad Lauren Reising. The left column describes Washington State University's (WSU's) traditional engineering design processes. The first layer is a client interview where a design specification is developed where the musts and should of a design are fully defined and mutually agreed upon. The second layer is the conceptual design phase where many, mutually exclusive, design paradigms are presented and assessed at a high level relative to the specification. Once a leading concept is mutually approved, the design moves into the third layer and preliminary design. Theoretical performance models, bills of materials, plumbing and instrumentation diagrams (P&ID), complete CAD models and other analysis is completed at this phase. Once the design's theoretical performance is verified to meet the specification, the preliminary design is mutually approved to begin prototype manufacturing. With key functionality of a working prototype and a test plan mutually approved, the design moves into proof-of-concept testing, which is typically where design stops for university research labs. The challenge was how to use the safety tools to improve this process.

The right column of Figure 1 shows the corresponding safety planning phases synergistic with each layer of our design process. A block system diagram helps to understand at the most basic level what must come into the system and what must come out. A Conceptual Hazard and Operability (HAZOP) study during the conceptual phase uses guide words to identify all the components required for the leading conceptual design to be safe. These components are important to identify before moving into the preliminary design phase. The Failure Modes and Effects Analysis (FMEA) goes through all the failures possible for the design and how to minimize the risk if any of those failures occur. This is the last easy place to make changes to a design before moving into production where changes become significantly more expensive. With a prototype made, an operational HAZOP goes through the procedures for utilizing the prototype and uses guide words to identify all the ways a user could make a mistake – pretty important to resolve before starting tests. Finally, maintenance and training logs are defined once a system is fully operational.

When implemented at the right time in the design process, the safety tools actually reinforce and analyze the outcomes from that design layer in new ways. Several interesting things happened after Figure 1 became our (new) design process:

1. Our design plans became our safety plans and eventually (with some additions) theses and dissertations.

2. We had fewer redesigns, less lost work, and started delivering more reliably on time. This, in turn, meant everything was going according to plan and thereby became faster.

3. I quit having to fight for safety plans to be completed. Instead, safe designs became the natural and expected outcome of our process.

4. Our client companies started sending their engineers to intern with us to learn our safety design process for early-stage hydrogen research.

5. New graduate student applications started coming in from experienced people in industry wanting to learn our design and safety planning process.

Was this progression, hard work, and evolution of our safety culture necessary? Or would it have been less of a fight if the process was presented and the now obvious synergies shown from the beginning? Regardless, we're all happier now that we don't have the stress and anxiety of having to fight for safety.

Barber-Nichols Optimizes Cryogenic Turbomachinery

by Jeff Shull, Barber-Nichols

Accurate predictions for performance and life of motors and bearings in cryogenic turbomachinery have become more critical than ever with rapid advancements in space as well as for the burgeoning hydrogen economy. The use of cryogenic propellants for space application includes both needs for rockets and landers, as well as for in-space propulsion and transfer. For the hydrogen economy, there is the need to pump LH_2 to higher pressures in vehicles for feeding into engines or fuel cells as well as to transfer with power dense solutions. For these applications, reliable long-term operation, small size and efficiency are paramount to successful adoption. Two of the most critical components to achieve the necessary requirements in these applications are long-lasting bearings and high-speed, efficient motors. While Barber-Nichols (BN) has successfully implemented cryogen immersed motors and ball bearings in turbomachinery for over 35 years, the requirements for these new applications are pushing advancement beyond the current state of the art.

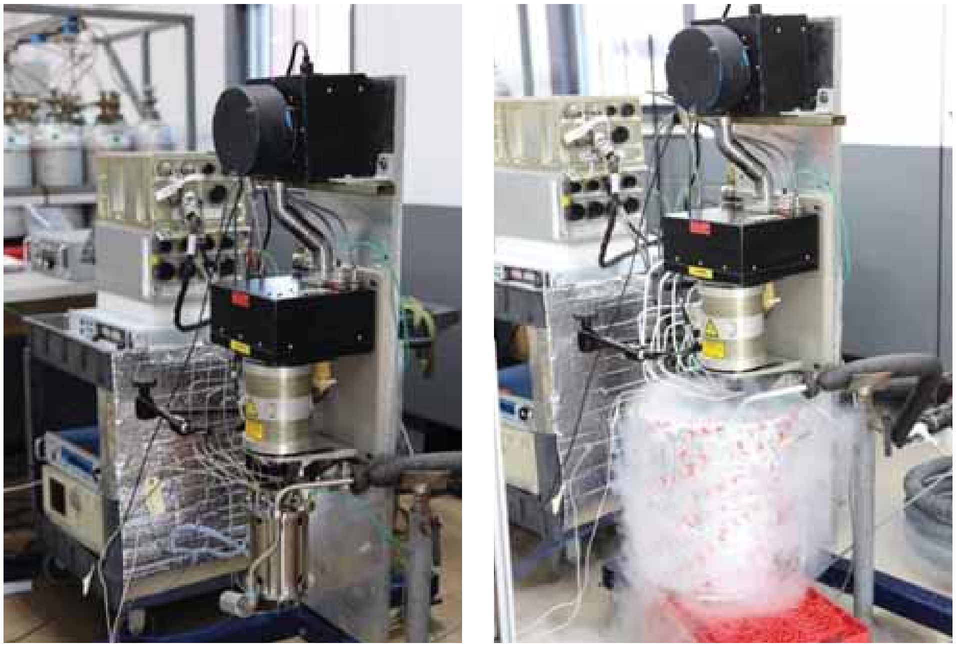
Recently, a cryogenic N_2 test rig was commissioned and first utilized to operate bearings at 45,000 rpm to simulate conditions for an LH_2 pump that must operate at these speeds in space. *Credit: Barber Nichols*

When BN started working with customers that needed cryogenic motors such as one made to drive a LH_2 pump for NIST in 1989, there was very limited data available for reference to design the motor. In the early days, BN engineers worked with custom motor suppliers to identify motor construction techniques and materials that were compatible with a particular cryogen but were otherwise quite similar to standard motors. The motors would then be integrated into designs much the same way a room temperature motor would be, with consideration of fits and clearances at cryogenic temperatures. In many cases, the pumps were not tested at cryogenic temperatures until put in systems at customer sites due to budget limitations on projects. Performance feedback from customers helped guide new designs but usually did not isolate motor performance at cryogenic temperature to understand exactly how close predictions were to reality.

In the 1960s, NASA began to experiment and develop ball bearings for use in space applications that could not utilize traditional lubricants. They developed dry film lubricants such as tungsten disulfide, mostly in the form of coatings that could be applied to bearing races and cages. In the late 1970s during development of the Space Shuttle they further advanced other bearing materials such as cronidur for races, silicon nitride for balls and PTFE with molybdenum disulfide for cages that provided the lubrication. BN engineers made use of these materials in early development efforts but were driven to lower cost alternatives in many applications. BN has hundreds of pumps successfully operating today utilizing cryogenic ball bearings with the majority operating at lower speeds and loads that will be needed to meet many of these future applications in Space and Earth-bound hydrogen vehicles.

To meet the aggressive targets required in these applications, BN engineers identified the need for cryogenic test equipment to validate bearing and motor designs. Recently, a cryogenic N_2 test rig (Figure 1) was commissioned and first utilized to operate bearings at 45,000 rpm to simulate conditions for an LH_2 pump that must operate at these speeds in space. The primary goal of the testing was to ensure the bearing design was capable of operating at these speeds and able to meet the lifetime requirements. These bearings successfully ran at 45,000 rpm, and once the life requirement was met, the bearings were disassembled and the bearing cage ball pockets were checked for amount of wear. These cages are designed to wear to provide lubrication to the balls and races. The ball pocket wear was well within expectations, so the bearings were validated for this application while still in the product design phase.

For another space program, BN needed to validate its cryogenic induction motor design tools and actual performance of the motor and bearings in a LOX application. Figure 2 (or 2b) shows this test setup that utilizes a dynamometer to measure motor performance across a range of speeds. It also provides loads to the bearings to simulate actual conditions in the application. During this testing BN learned valuable lessons about design and operation of induction motors at cryogenic temperatures, such as the electromagnetic behavior of the induction rotor at cryogenic temperatures and its effect on rotor slip, efficiency and torque, as well as motor speed control. Premature bearing failures informed BN engineers of required clearances between components for operation at cryogenic temperatures. Several different dry film lube cage materials were also tested to determine the optimum selection.



For another space program, BN needed to validate its cryogenic induction motor design tools and actual performance of the motor and bearings in a LOX application. Figures 2 and 2b show this test setup that utilizes a dynamometer to measure motor performance across a range of speeds. *Credit: Barber Nichols*

BN has several early-phase projects using cryogenic bearing and motor testing to optimize designs. Lessons learned will validate design methodologies for motors and bearings in applications for space, the H_2 economy and more in the future. **www.barber-nichols.com**

SPOTLIGHT ON A CORPORATE SUSTAINING MEMBER (CSA CSM): Equigas, Inc.

Equigas' Strategic Acquisition is a Catalyst for Innovation

by Rafael Arvelo, President and CEO, Equigas, Inc.

Solidifying US Presence

Equigas, Inc., a North Carolina-based gas equipment distributor, has embarked on an exciting new chapter with its recent acquisition of Correct Cryogenics, a respected cryogenic service provider headquartered in the Southwest US. This strategic move is a pivotal moment for Equigas as it seeks to expand its service offerings and solidify its presence in the US cryogenic and industrial gas markets.

Founded in 2003 by industry veterans Rick Davis and his son, Scott Davis, Correct Cryogenics brings decades of experience and a stellar reputation to the table. As Rick Davis prepares for retirement after more than 40 years in the field, Scott Davis will assume a leadership role within Equigas, ensuring a seamless integration process and upholding the company's commitment to excellence.

The inception of Equigas was driven by a vision to address unmet needs in the industrial gas market. Antonio Arvelo, along with Stanley Kokoszka and Stephen Kokoszka, identified opportunities to serve independent gas distributors, a segment often overlooked by larger players. Antonio was the founder of EQUIGAS in 1985 in Venezuela. Rafael together with Stanley and Stephen started EQUIGAS in the USA on 2017. Leveraging their industry insights and collective expertise, Equigas was founded seven years ago with a mission to provide unparalleled service and support to customers across North America.

Since its establishment, Equigas has experienced remarkable growth and evolution. Initially focusing on distributing gas equipment for industrial applications, the company has expanded its product range to include solutions for LNG, hydrogen and ammonia, among other gases. Notable milestones, such as partnerships with US space companies and investments in technology infrastructure, highlight Equigas' commitment to innovation and customer satisfaction.

Equigas, Inc. acquired Correct Cryogenics to expand its service offerings and strengthen its presence in the US cryogenic and industrial gas markets. *Credit: Equigas*

The acquisition of Correct Cryogenics represents a strategic alignment of capabilities and resources aimed at unlocking new avenues for growth and innovation. By combining Equigas' expertise in gas equipment distribution with Correct Cryogenics' proficiency in cryogenic services, the merged entity is anticipated to offer a comprehensive suite of solutions to customers across industries. Moreover, the acquisition strengthens Equigas' presence on the West Coast, enabling the company to better serve clients in that region and beyond.

The integration process between Equigas and Correct Cryogenics has been a meticulously planned endeavor, designed to maximize value for all stakeholders. A dedicated transition team comprising representatives from both companies is overseeing the merger, ensuring operational continuity and a seamless customer experience throughout the transition period. Clear communication, meticulous planning and a shared commitment to excellence are guiding principles driving this integration effort.

As Equigas prepares for the leadership transition, Rick Davis's advisory role and Scott Davis's position as Vice-President of Operations show a commitment to continuity and excellence. Rick's extensive industry experience and knowledge will continue to inform Equigas' strategic direction, while Scott's leadership will drive operational efficiency and growth initiatives within the organization. This transition ensures a smooth transfer of responsibilities and sets the stage for continued success.

Looking ahead, Equigas is poised for sustained growth and expansion in the cryogenic and industrial gas markets. Short-term objectives include optimizing operations, leveraging synergies from the acquisition and enhancing customer service capabilities. Long-term goals encompass further market penetration, product innovation and strategic partnerships to solidify Equigas' position as a leader in the industry.

Customer Confidence Through Strategic Growth

Customer feedback regarding the acquisition has been overwhelmingly positive, with clients expressing confidence in Equigas' ability to deliver exceptional service and value. The acquisition will allow the company to remain firm in its commitment to such customer satisfaction and also future innovation. With the acquisition of Correct Cryogenics serving as a catalyst for future success, Equigas is well positioned to capitalize on emerging opportunities and shape the future of the cryogenic and industrial gas industry.

This openness to opportunity is why Equigas was able to provide a smooth integration process between it and Correct Cryogenics. A vision for the future allowed a meticulously planned process that maximized synergies. A key focus of the company is on aligning organizational cultures to foster collaboration and teamwork. Both Equigas and Correct Cryogenics prioritize a customer-centric approach and a commitment to excellence, making the cultural integration relatively seamless. Regular communication channels, such as town hall meetings and internal newsletters, are established to keep employees informed and engaged throughout the integration process. Cross-functional integration teams are formed to address various aspects, including operations, sales, marketing and finance. These teams work collaboratively to identify opportunities for process optimization, resource sharing and best practice sharing.

Driven by its recent acquisition and commitment to innovation, Equigas has its eyes on continued movement forward. Key objectives include expanding market reach and customer base by leveraging an extended service portfolio and geographical presence. Additionally, Equigas plans to invest in R&D to drive product innovation, focusing on emerging trends like sustainable energy solutions such as hydrogen fuel cells and renewable natural gas. Recognizing the importance of strategic partnerships, Equigas aims to collaborate with industry leaders and academic institutions to develop new solutions and address evolving customer needs.

Furthermore, Equigas remains committed to sustainability and social responsibility, investing in energy-efficient technologies and community initiatives. Through careful integration and strategic planning, Equigas aims to unlock synergies, drive innovation and create sustainable value for its stakeholders, positioning itself as a leader in the industrial gas industry. **www.equigas.net**

Fives Pioneers Renewable Energy Storage and Hydrogen Mobility

by Diana Alves, Fives Group

The Largest Renewable Energy Storage Project

Fives, a global industrial engineering group, has been selected by Zhonglv Zhongke Energy Storage Technology Co. to supply cryogenic equipment for the largest renewable energy storage project on an industrial scale. This project, located in Golmud, Qinghai province, China, is set to be operational by the end of 2024 and marks the first industrial-scale implementation of Liquid Air Energy Storage (LAES) technology.

The LAES unit will store 60 MW of solar energy, which will be redistributed into the grid to meet the energy needs of local industries and homes. This project not only signifies a milestone for Fives but also for the renewable energy sector as a whole. The main advantage of alternative energy is it is 100% decarbonized but also a major inconvenient for manufacturers: once they are produced, they need to be used almost instantly. However, the LAES technology showcases a viable and efficient alternative to traditional lithium-ion batteries for large-scale energy storage. At the heart of the LAES technology are six heat exchangers, supplied by Fives, that will liquify the air required to stock the solar energy produced so it can be released at a given time. These heat exchangers are produced in Fives' workshops in Golbey, in the East of France.

Fives has been a leader in cryogenics for more than 65 years, designing key equipment that optimizes performance and reduces CO_2 emissions. Vincent Pourailly, President of the Business Line Energy/Cryogenics at Fives, highlighted the company's role in supporting the transition to decarbonized energy sources. "This ambitious project is another proof of Fives' ability to support change in the industry and the emergence of decarbonized energy sources," he says. Dr. Wei Ji, Chief Scientist at Zhonglv Zhongke Energy Storage Technology Co., echoed this sentiment, emphasizing the

Brazed Aluminum Heat Exchangers (BAHX) are essential in cryogenics due to their efficient heat transfer with minimal temperature differences. *Credit: Fives*

The HyGen project is focused on scaling up the equipment necessary for liquid hydrogen use, aiming to increase existing capacities by a factor of ten. *Credit: Fives*

Cryogenic heat exchangers, known for their high reliability and low energy consumption, are widely used, for their high reliability and low energy consumption.
Credit: Fives

efficiency and sustainability of LAES technology. "The energy storage market offers vast opportunities for new applications, with LAES technology seeming the most efficient solution for a more sustainable world. We are happy to work with Fives on this breakthrough project," he declares.

HyGen: Advancing Carbon-Free Mobility with Liquid Hydrogen

In another significant development, Fives has launched the HyGen project, aimed at enhancing carbon-free mobility through the use of liquid hydrogen. The project, in collaboration with the French Alternative Energies and Atomic Energy Commission (CEA) and the École des Mines de Saint-Étienne, has secured €3.4 million in funding from the French government under the France 2030 program. The HyGen project is focused on scaling up the equipment necessary for liquid hydrogen use, aiming to increase existing capacities by a factor of ten. This initiative is part of a broader strategy to strengthen France's competitiveness in the hydrogen sector and support the global demand for green mobility solutions. In addition to this growth in France, Fives Cryo Inc. based in Houston is currently manufacturing LH_2 brazed heat exchangers and cold boxes for eight green liquid hydrogen plants based in North America.

"As a leader in hydrogen liquefaction equipment, we are proud, with the HyGen project, to participate in the growth of this sector in France. A pioneer in the decarbonization of industry, Fives aims, with its partners, to support the energy transition and green mobility," says Vincent Pourailly of Fives, highlighting the project's goals.The project will also contribute to regional economic development, creating 85 new jobs in the Grand Est region of France, where Fives has been established for more than 120 years. The new positions will span various roles, including preliminary design, engineering, quality control, welding and production.

A Legacy of Innovation

For two centuries, Fives has been at the forefront of industrial innovation. From the construction of the first railway lines to the development of the Eiffel Tower lifts and the advent of Factory 4.0, Fives has consistently provided disruptive solutions and technologies. As a pioneer in both decarbonization and digitalization, the company's ability to anticipate and respond to market needs has positioned it as a leader in industrial efficiency and sustainability. With operations in 25 countries and a workforce of 9,000 employees, Fives combines economic and environmental performance, tailoring its solutions to meet the specific requirements of each market. This approach has cemented its reputation as a trusted partner in driving industrial progress and environmental stewardship.

The projects in China and France illustrate Fives' commitment to advancing renewable energy storage and hydrogen mobility. By leveraging its extensive expertise in cryogenics and industrial engineering, Fives is helping to pave the way for a more sustainable and energy-efficient future. The collaboration with Zhonglv Zhongke Energy Storage Technology Co. on the LAES project demonstrates the potential for scalable, efficient and sustainable energy storage solutions. Meanwhile, the HyGen project underscores the importance of hydrogen as a key element in the transition to green mobility. As global energy demands continue to evolve, Fives remains dedicated to supporting the development and implementation of innovative technologies that drive the energy transition. Through its strategic partnerships and pioneering projects, Fives is poised to play a crucial role in shaping the future of energy. **www.fivesgroup.com**

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) and one high-resolution JPEG of the product using the form at **www.cryogenicsociety.org/submit-a-product-showcase**.

VARODRYKE

Leybold

Leybold has introduced the VARODRYKE, an innovative modular dry vacuum system designed to meet the increasing demand for advanced mobile solutions. This system is ideal for evacuating and leak-testing double-walled spaces, vacuum chambers and piping. Key benefits of the VARODRYKE include its air-cooled design, which operates efficiently without external cooling systems, and its dry pump technology, which eliminates oil migration and emissions for a clean, safe environment. The system's portability allows it to be easily moved around job sites or manufacturing facilities. It is energy-efficient, reducing operational costs and environmental impact, and features an advanced filtration system that removes particulates before they enter the pump, enhancing longevity and efficiency. Additionally, the quick-acting Leybold SECUVAC inlet valve protects the vacuum level in the event of power failure. Selectable features include cold trap technology and an integrated leak detector for optimal performance and faster leak-testing response times. **www.leybold.com**

Six- and Eight-Inch Valves Added to Model CV Valves

ACME Cryogenics

ACME Cryogenics, part of OPW Clean Energy Solutions, announces the expansion of its Model CV valve product line with the development of new 6" and 8" valve sizes. This innovation responds to the increasing demand for larger hydrogen infrastructure components. The new valves are available in actuated and manual versions with a Class 150 pressure rating, and a bellows-sealed option for pressures up to 550 psi is in progress. These valves are ideal for hydrogen applications and compatible with vacuum jacketed systems. Compliant with ASME B31.3 and CSA B51 standards, the Model CV valves are suitable for various industries, including aerospace, electronics, and vehicle refueling. Further developments include models with bore sizes of 10" and larger. For more details on ACME Cryogenics' expanded valve offerings, visit OPW Clean Energy Solutions. **www.opwces.com**

HeRL02-RM

Bluefors

Bluefors announces the Cryomech HeRL02-RM – a new helium reliquefier designed specifically for helium recovery from a single nuclear magnetic resonance (NMR) unit. Helium reliquefiers help to conserve the use of valuable helium, safeguarding users against helium supply issues and protecting against helium price fluctuations. The system creates a closed-loop, zero-boiloff system for NMR magnets. Boiled off helium is passed through a vapor return line to the pulse tube cryocooler-powered reliquefier, which instantly liquefies the boiloff and returns it to the magnet's helium bath. The new helium reliquefier model utilizes a remote motor to minimize vibrations that might otherwise interfere with sensitive NMR spectroscopy. The HeRL02-RM has been field-tested on multiple units of varying magnet strength with no effect on the results. The Cryomech HeRL02-RM can be easily installed through an existing fill port, and operates reliably and safely 24 hours a day, seven days a week. For facilities with greater helium boiloff, Bluefors continues to offer full scale helium recovery solutions. **www.bluefors.com**

Gate Valves

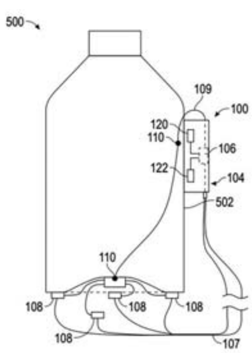
Oswal Industries Ltd.

Oswal Industries Limited's Gate Valves reflect decades of manufacturing excellence and reliability. Precision-engineered in advanced in-house facilities, these valves ensure top-quality production from design to inspection. The company operates a dedicated foundry, producing high-grade materials that guarantee durability and performance. With streamlined operations, Oswal offers rapid delivery to meet urgent demands without compromising quality. Additionally, the company provides comprehensive after-sales support for installation, maintenance, and troubleshooting. Oswal's Gate Valves are recognized for their reliability and high standards, making them a trusted choice in the industry. **www.oswalvalves.com**

TTPX Probe Station

Lake Shore Cryotronics

The TTPX probe station is an affordable entry-level device designed for a variety of non-destructive, standard electrical measurements. Its compact tabletop design suits academic and laboratory research settings. The TTPX efficiently operates and controls cryogenic temperatures using liquid helium or liquid nitrogen, covering a temperature range of 4.2 K to 475 K, with options to extend from 3.2 K to 675 K. It accommodates wafers up to 51 mm in diameter and offers a wide selection of probes, cables, and sample holders to meet specific measurement needs. The TTPX is Lake Shore's premium design for electro-optical materials characterization, featuring backside optical access and compatible optical sample holders. Standard measurement options include I-V, C-V, and microwave measurements. Its versatility and affordability make the TTPX a popular choice for researchers globally. **www.lakeshore.com**



DeTech Solution

DeTech

DeTech Solution by DeTech is an advanced, patented system for liquid nitrogen (LN_2) containment monitoring, overcoming long-standing industry challenges. This innovative solution features a sensor array for predictive analytics, fault tolerance, and early warning systems without internal sensors, ensuring superior asset protection. Real-time sensor data is transmitted to an on-site gateway and then to a cloud-based interface, offering customizable tank status levels and alerts for efficient management of LN_2 levels. Key benefits include automated tank level display, virtual tank level app, and tank-specific refill audit trails. The system provides fixed pricing, technology upgrades, and unmatched multisensor protection with six independent telemetry points. Additionally, it features advanced fault tolerance with multisensor notifications, self-supervisory sensor arrays, and local alerts for cloud communication loss or unauthorized weight changes. DeTech's exclusive patent and innovative features significantly reduce labor, administrative, and component costs while enhancing reliability and efficiency in LN_2 monitoring and laboratory asset management. **www.detechus.com**

People & Companies in Cryogenics

INOXCVA has supplied a 560-m³ LNG marine fuel gas tank featuring a double tank connection space within a single tank. Weighing more than 225 metric tons, it stands 7.45 meters high and has a diameter of 6.9 + 5 meters, making it one of the largest tanks ever shipped from INOXCVA's Kandla Works. Upon arrival at the shipyard, the tank will be installed in a Japanese-flagged cruise vessel currently under construction. Once commissioned, this cruise vessel will join the growing fleet of LNG-powered ships worldwide, significantly contributing to the reduction of carbon footprints in the marine industry.

....

Meyer Tool & Mfg. announced that **Eric Cunningham, Kenny Urban and Christian Cunningham** have completed the Technology and Manufacturing Association's (TMA) Manufacturing Leadership Program.

Eric Cunningham, Kenny Urban, Christian Cunningham receiving their MLP Certificate. *Credit: Meyer Tool & Mfg*

This 10-month program aims to enhance leadership skills and expand knowledge in various manufacturing roles. Participants engage in sessions designed by TMA executives, covering critical business and manufacturing topics such as management styles, accounting and finance, all taught by industry experts. The program culminates in a capstone project where participants create a three-year improvement plan for their organization. Meyer Tool values this investment in developing its third-generation leaders.

....

On May 30, 2024, **Galactic Energy** successfully launched four Tianqi Network satellites from a sea-based platform in the Yellow Sea in China using its Ceres 1 rocket. Developed by Guodian Gaoke, these satellites are intended for Internet of Things (IoT) applications, which involve a network

The commercial launch vehicle Ceres-1, carrying four satellites, blasts off from waters near Haiyang in Shandong province. *Credit: EPA-EFE/Xinhua*

of physical objects embedded with sensors and software to connect and exchange data over the internet, enhancing efficiency and automation across various sectors. This marks the second sea-based launch of Ceres 1, following a similar mission in September 2023.

....

Web Industries received the BAE Systems "Partner 2 Win" Silver Tier Award. The company was chosen from a group of suppliers for its exceptional performance and contributions to the success of BAE

Credit: BAE Systems

Systems' Electronic Systems sector in 2023. The Partner 2 Win program aims to achieve operational excellence and eliminate defects in the supply chain by raising performance expectations to meet customer demands. BAE Systems collaborates regularly with its suppliers through this program to share best practices and ensure the highest quality of components and materials in its products.

....

Zurich Instruments, a quantum technology and test and measurement instrumentation company, has appointed **Andrea Orzati** as its new CEO, succeeding founder **Sadik Hafizovic**. Hafizovic grew the company from a start-up to a major player in the field. Orzati, with a background in scaling tech businesses at u-blox, Sensirion and TEQABLE, is set to further this growth. Hafizovic highlighted Orzati's role in maintaining innovation and focus as the company aims to double in size.

Andrea Orzati and Sadik Hafizovic. *Credit: Zurich Instruments*

Zurich Instruments, founded in 2008, values scientific excellence, a tradition Orzati continues with his Ph.D. from the Swiss Federal Institute of Technology and an EMBA from HEC Lausanne.

....

Torghatten Nord A/S, a Norwegian ferry company, has contracted MAN Cryo to design and engineer two hydrogen-powered RoPax ferries, part of Norway's initiative to make major vessels on the mainland-Lofoten Islands crossing emission-free. MAN Cryo, a division of MAN Energy Solutions, will provide detailed

Credit: MAN ES

designs for bunkering mechanisms, hydrogen pipes and vent masts, and it will act as the system integrator for the hydrogen process plant. The Norwegian Ship Design Company is designing the vessels, which will be built by Cemre shipyard in Türkiye and outfitted in Norway. Scheduled for delivery in 2026, these ferries mark a significant step towards zero-emission maritime transport.

....

Dutch cryotechnology specialist **Stirling Cryogenics B.V.** has opened an office in Helsingborg, Sweden, to focus on the Nordic market. **Jack Åstedt**, with experience in the bio-LNG sector, has been appointed sales manager for bio-LNG applications. The company plans to hire a service engineer later this year to improve local service operations. Stirling Cryogenics aims to expand in the Nordic region, with bio-LNG projects already underway in Västerås, Östersund and Härnösand. Stirling Cryogenics, established in 1954 as part of Philips, remains headquartered in the Netherlands and has more than 4,000 installations worldwide.

Credit: Jack Åstedt, Stirling Cryogenics B.V, Helsingborg, Sweden

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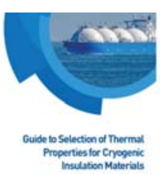

The **Korean Register** has released the "Guide to Selection of Thermal Properties of Cryogenic Insulation Materials" to ensure safe storage of cryogenic fuels like LNG and liquid hydrogen. This follows the International Maritime Organization's 2023 Greenhouse Gas Strategy, which aims for carbon neutrality in international shipping by 2050, with significant emission reductions by 2030 and 2040. In response, the maritime industry is focusing on alternative fuels, emphasizing advanced insulation technology for safe storage. Liquid hydrogen, requiring storage at -253° C, necessitates advanced insulation systems. To support this, KR collaborated with research institutions to develop and publish the report, which details insulation systems for LNG and liquid hydrogen and analyzes heat transfer mechanisms and design elements. KR aims to use this guide as a standard for material selection and to support decarbonization efforts in maritime transport. The guide is available on the KR Decarbonization Portal. The document can be downloaded on the KR Decarbonization Portal: decarbonization.krs.co.kr/eng/

....

The **University of Waterloo's Institute for Quantum Computing** completed the development of a quantum source for Canada's first quantum satellite, QEYSSat. This milestone follows years of rigorous testing and collaboration with international partners, including Honeywell Aerospace, CraftProspect, the University of Strathclyde and the University of Bristol. The quantum source, named Reference-Frame Independent Quantum Communication for Satellite-Based Networks (ReFQ), will facilitate secure quantum key distribution by sending polarization-encoded photons between the satellite and ground stations. Scheduled for launch next year, QEYSSat aims to pioneer a global quantum communications network secured by quantum mechanics principles. The University of Waterloo team is now preparing ground stations to support the mission post-launch.


Credit: The University of Waterloo

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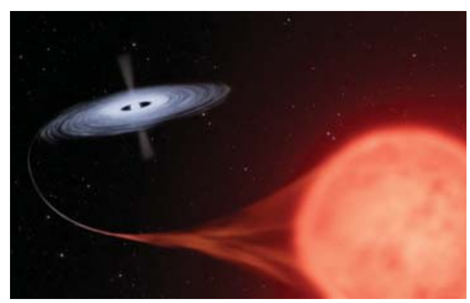
NASA astronomers have revisited the binary star system HM Sagittae (HM Sge) using new data from the Hubble Space Telescope and the retired SOFIA observatory, along with archival data. HM Sge, known for its unusual 1975 nova that increased its brightness 250 times and maintained luminosity for decades, consists of a white dwarf and a red giant in an eccentric orbit. Recent observations revealed that the system has become hotter yet slightly dimmer, with strong emissions of highly ionized magnesium indicating a temperature increase in the white dwarf and its accretion disk. This system continues to fascinate astronomers for its insights into the physics and dynamics of stellar evolution in binary systems. The findings, including the detection of water, gas and dust around the system, were published in the *Astrophysical Journal* and presented at the American Astronomical Society meeting.


Credit: NASA, ESA, Leah Hustak (STScI)

Meetings & Events

Cryogenic Operations 2024
July 17-19
Grenoble, France
www.cryo-ops-2024.fr

International Cryogenic Engineering Conference/ International Cryogenic Materials Conference 2024
July 22-26, 2024
Geneva, Switzerland
https://icec29-icmc2024.web.cern.ch

Cryogenic Engineering and Safety Course
August 5-9
Golden, Colorado
https://cryocourses.com/courses

European Course of Cryogenics
August 19-September 6
Multiple Locations
https://tu-dresden.de/ing/maschinenwesen/iet/kkt/studium/internationale-angebote/european-course-of-cryogenics

2024 Applied Superconductivity Conference
September 1-6
Salt Lake City, Utah
www.appliedsuperconductivity.org/asc2024

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