Cold Facts INTERNATIONAL

The Magazine of the Cryogenic Society of America, Inc.

Revisiting a Trailblazer | 17

Volume 40 Number 1 2024

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* New member since last issue

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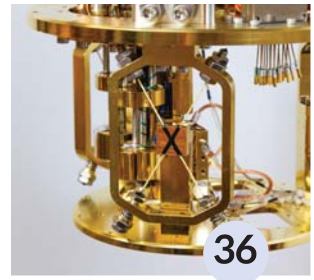

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ON OUR COVER

Angela Krenn, pictured in 2020, is the principal technologist for Thermal Management Systems within NASA's Space Technology Mission Directorate. She has been working in cryogenics for more than two decades.
Credit: NASA

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Cold Facts

Cold Facts Magazine

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

From the Editor

For this edition of ***Cold Facts***, I am honored to pen an editor's letter while our executive director, Megan Galeher, is on maternity leave. We extend our warmest congratulations to her on the joyful arrival of her third baby, Liam Joseph Galeher, born on February 1. Both mother and baby are healthy, and Megan is looking forward to returning to her regular CSA duties further into spring.

On the subject of celebrations, we also recognize the importance of acknowledging the diverse and groundbreaking work being done in our dynamic field by women around the world. In this issue, we feature one of my favorite annual segments, "Women in Cryogenics and Superconductivity," in which we spotlight the pioneering contributions of women in our industry. From cryobiology to aerospace, quantum mechanics and beyond, these 10 individuals represent the diverse and game-changing work being done today. Additionally, we are excited to include a follow-up with a woman we previously highlighted in this feature, Angela Krenn of NASA, a trailblazer whose continuing impact serves to further the importance of recognizing and amplifying the voices of women in science.

Looking ahead, CSA is excited to attend the International Cryocooler Conference (ICC23), June 3-6, 2024, at the University of Wisconsin in Madison. Conference early registration is anticipated to open in mid-March via cryocooler.org. Moreover, CSA will once again be offering our prestigious Foundations of Cryocoolers short course on Monday, June 3, at the same venue as ICC23. Led by renowned experts Dr. Ray Radebaugh and Dr. Alphons De Waele, this course will explore various cryocooler applications, delve into thermodynamic principles and emphasize gas-cycle cryocoolers, including a special focus on dilution refrigeration for millikelvin temperatures. Early registration discounts are available until May 2. For more information and registration, please visit **www.cryogenicsociety.org/foundations-of-cryocoolers-short-course-2024**.

CSA will also be attending the Applied Superconductivity Conference (ASC 2024) in Salt Lake City, Utah, September 1-6, and we look forward to discussing our involvement in that event as well as conference details in our next issue of ***Cold Facts*** and in upcoming CryoChronicle newsletters. In the meantime, you can learn more about ASC 2024 at **www.appliedsuperconductivity.org/asc2024**.

Finally, I'd like to welcome Dr. Van Sciver to CSA's online learning and publications. Dr. Van Sciver's helium cryogenics lecture series is now available and dives into fundamental topics from cryogenic heat transfer to low temperature refrigeration. With nine concise modules, this series offers a comprehensive understanding of the field. Set up an account and start learning today by following **www.cryogenicsociety.mclms.net/en/package/tag/6473/list**.

As always, we hope you find this issue of ***Cold Facts*** enjoyable and informative!

Cold Facts Editorial Board

Jo Bartlett

Lead Scientist—Mullard Space Science Laboratory, University College, London, UK

What projects are you working on now?

I am developing a novel, fast-thermal response, miniature, tandem-style continuous adiabatic demagnetization refrigerator called the Millikelvin Cryocooler (mKCC), which is the first one of its kind in the world. The mKCC is being developed for both space- and ground-based applications and has required many individual component advancements and developments over the last 10 years.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?

I've worked on designing and developing ADRs for almost 20 years, and there are several accomplishments that I am really proud of. During my Ph.D. I focused on accurately modeling the thermal performance of an ADR that we were building for the European Space Agency; my model was so accurate that it was also used as a diagnostic tool to understand the performance limitations that we were seeing in terms of thermal boundary resistance within the paramagnetic salt pill. This model has also been used to design the mKCC that I have been working on for a large part of my career and has been proven to be accurate to within a few percent. Developing the mKCC is also one of my proudest achievements – I was both lead scientist and project manager and have seen this project through from its initial conception, preliminary design and individual component development to its building and testing, working with a range of mechanical, electronic and software engineers. To put this into context, we had a single-shot ADR with a mass of 45 kg, a diameter of 215 mm and a height of 400 mm, plus the mKCC is a continuous ADR with a mass of <5 kg and dimensions of 56 mm x 120 mm x 228 mm. The recycling time was reduced from 15 hours to 82 seconds. To make this enormous leap in capability we had to redesign each of the main components and work with the industry to push through technological advancements in manufacturing that were needed to realize the mKCC. It required a combination of physics, engineering and creativity! As part of the development of the mKCC, we built one-half of the cooler – a miniature adiabatic demagnetization refrigerator, the publication of which won the Cryogenics Best Paper Award of 2015. I was also selected to be in Elsevier's virtual special issue on Women in Physics in 2018 because of this paper. Seeing the mKCC successfully provide continuous cooling in the lab is one of the highlights of my career so far.

What advancements in cryogenics are you hoping to make in the future?

I am focused on driving the mKCC development program forward to achieve multistage continuous cooling and sub-100 mK, as well as converting what is a ground-based prototype into a space-worthy system. Beyond that, I hope to continue down the path of miniaturization to open up ultralow temperature research to a wider range of users including non-cryogenic specialists, with the goal of maximizing applications and usability.

What advances for women would you like to see in the fields of cryogenics and superconductivity?

I would like to see true equality for women in cryogenics, with women undertaking careers in cryogenics considered the norm rather than the exception. I would also like to see more women doing hands-on experimental physics in laboratories and given equal opportunity to do so, rather than being encouraged into data analysis and desk-based roles. We are just as capable of working on a cryostat and designing, building and testing instrumentation as anyone else.

What would be the best approach to getting more women into your field?

I believe the best approach to getting more women into this field is encouragement and support from an early age and empowering young women to have the confidence to choose and carve out their own career. I think a lot of young women are interested in STEM but are wrongly influenced and put off along the way by various people, starting at school. This happened to me and I'm glad I didn't listen! It can also feel intimidating being a woman in a male-dominated research environment, and it can be even more difficult when you disagree with those male peers. We need to make sure women feel confident in their ability and within their environment to have a voice and to be assertive when necessary. I believe more women in senior positions would help to change this dynamic. While unfortunately there are still people with outdated opinions on women working in this field, I do believe those people are now in the minority, and that most people are accepting, welcoming and willing to provide support. I would like to encourage more women to consider a career in cryogenics as I personally find the research very rewarding and wouldn't want to do anything else.

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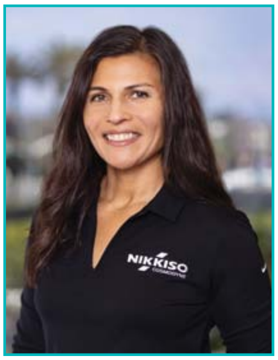

Melania Charles

Vice President of Global Sales and Marketing, Cosmodyne, LLC of Nikkiso Ltd.

What projects are you working on now?

I am currently very involved in several hydrogen liquefaction systems for clients that are developing green hydrogen projects. I am also involved in several natural gas liquefaction opportunities for utility peak shaving applications in the US as well as merchant natural gas liquefaction plants for overseas clients that are using LNG to produce power. Finally, I'm working with my team on a handful of international industrial gas opportunities for cryogenic air separation plants with clients that sell these air gases in the marketplace. My team and I directly interface with a variety of customers from EPCs working on large LNG export facilities to natural gas utility companies and independent and major industrial gas companies around the world.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?

I'm most proud of several awards where I developed a strategic approach using overall value analysis to come up with the best solution for a client. By using my engineering and business background and listening very closely to the customer, we were able to develop very creative solutions that surpassed a client's expectations and were the best fit for their requirements. As a result of this approach, we have been awarded several strategic projects both in the US and abroad. This has helped us be a leading provider of peak shavers in the US and for air separation plants all over the world.

What advancements in cryogenics are you hoping to make in the future?

Given the very aggressive push towards greener energy in the US and abroad, cryogenics have a very important role in getting the world there. I'm hoping that, like in natural gas and air separation, we also become a strategic and key supplier for hydrogen liquefaction systems. I believe that there is a big opportunity in the market for an independent agnostic company like us with a proven history of providing optimized cryogenic solutions to meet the growing need for hydrogen liquefiers.

What advances for women would you like to see in the fields of cryogenics?

I would like to see more outreach in engineering schools to promote our field and to have more women talk about what a great and varied field this is and how many different paths the work can lead you to. My work has always been technically challenging and full of many rewards.

What would be the best approach to getting more women into your field?

I think there should be more outreach in high schools and universities by businesses like ours that are in the cryogenics industries. Shadowing opportunities, summer internships, participation in university job fairs, etc., with women in the field would be effective. And in all the marketing, showing how cryogenics can improve the world would be effective at attracting not only more women but a lot more young people. We've recently used this approach at a job fair and had a very long line of candidates waiting to talk to us.

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Juliette DeLoye

Master's Candidate in Applied Science in Engineering at Laurentian University, Education and Outreach Coordinator—SNOLAB

What projects are you working on now?

I am currently working on building a radon trap for the SNO+ experiment, a large-scale neutrino detector at SNOLAB.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?

Beginning my career at SNOLAB is an accomplishment of which I am extremely proud. I have the privilege of working in a world-renowned lab with some of the most influential people in the physics world today. Each day I can contribute meaningfully to the scientific work happening in the lab. When I am wearing my education and outreach hat, I get to demonstrate how fun and interesting our work truly is!

What advancements in cryogenics are you hoping to make in the future?

Well, this is a tough one. I am hoping that cryogenics will be made more accessible in a variety of industries. For example, we have had interest from other people about safely using

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cryogenics in mines where they are interested in using cryogenics to cool mining environments.

What advances for women would you like to see in the fields of cryogenics and superconductivity?
I would love to see more networking opportunities where we can meet other women working in a variety of different industries. This would be highly beneficial for students, especially, to gauge if there is a place for them individually in the field of cryogenics.

What would be the best approach to getting more women into your field?
Providing outreach opportunities is always a fantastic way to meet and encourage other women to get into this field. Inspiring them through work led by women, highlighting the intriguing work currently in progress, and expressing the passion we share for it at SNOLAB are crucial elements in sparking the interest of others.

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Nasim Fatemighomi
Staff Scientist—SNOLAB

What projects are you working on now?
I am working on the DEAP-3600 experiment which is a dark matter liquid argon detector. I am also a radon assay scientist; this work supports many of the experiments at SNOLAB, an astroparticle physics lab focused on neutrino and dark matter physics, deep underground in Canada. For my assay projects, I work with liquid nitrogen that is produced by the nitrogen plant located at SNOLAB to trap radon atoms. I have recently joined the nEXO experiment, which is a next-generation neutrino experiment using liquid xenon.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?
I am proud that we can measure radon levels from experimental components here at SNOLAB. I am especially proud of the new gas assay procedures that we have developed recently.

What advancements in cryogenics are you hoping to make in the future?
I think we need more automation in the future to use cryogenic liquid for assays.

What advances for women would you like to see in the fields of cryogenics and superconductivity?
I hope to see more women in supervisory and leadership roles in the field of cryogenics.

What would be the best approach to getting more women into your field?
I think we need more outreach activities at the various school levels to introduce students to cryogenic technology and also to talk about its applications in other fields, including astroparticle physics.

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Hailee Morgan
Design Engineer—CPC Cryolab (CSA CSM)

What projects are you working on now?
Currently, I'm working on five different new product development projects of different stages in design. Most of these I cannot discuss at the moment, due to their nature. However, we have made public the new upcoming safety relief valves designed primarily for liquid and gaseous hydrogen. One of the unique features of this valve is the balanced bellows seal to ensure backpressure insensitivity and repeatable valve setting. This will be a full-family product line with two different body designs for various applications and sizes from one-half inch to 10 inches and rated up to 42 bar. Additionally, I am always working on existing product improvements for performance, durability and serviceability.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?
I have one new product development project that came out of nowhere. I was sick one night and couldn't sleep. I spent the next seven hours thinking about a new design concept not seen before in the industry. This valve could potentially solve several problems and the challenges of vacuum jacketing a particle style of valve for serviceability in the field.

What advancements in cryogenics are you hoping to make in the future?
I've always liked to think of myself as an out-of-the box thinker and hope that my designs will help industry reach a high level of safety as hydrogen becomes a major factor in our everyday lives. I'm hoping to help build the groundwork for that.

What advances for women would you like to see in the fields of cryogenics and superconductivity?
Having women in STEM is crucially beneficial to bringing new ideas and different perspectives, regardless of the area of industry. However, I would love to see this industry be a trendsetter to highlight the amazing accomplishments and contributions women have made, whether it be in research, design or leadership roles that empower the next generation of women.

What would be the best approach to getting more women into your field?
Eliminating stereotypical gender roles early on in life is the first step we need to take. We tend to put boxes around the genders of younger people, and this makes breaking that barrier more difficult, almost stigmatized, but it's improving every year. Secondly, engaging in hands-on activities really helps development but also shows the amazing phenomena that occur in these fields and the potential benefits for the planet and future generations to come.

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Atefeh Najafi

Ph.D. in Reproductive Biology, University of Saskatchewan

What projects are you working on now?
I am currently working on optimizing the ovarian tissue cryopreservation technique. This technique aims to preserve the fertility and endocrine function of young women and girls who must undergo sterilizing cancer treatments. Ovarian tissue cryopreservation is a process where ovarian tissue is extracted and stored in liquid nitrogen before it gets harmed by cancer treatments. Once the individual has successfully overcome cancer, the goal is to either transplant thawed ovarian tissue or isolate the follicles from the tissue, mature them in vitro and use them for in vitro fertilization. This technique could potentially provide female cancer survivors with the opportunity to have their own children in the future. However, this technique still has points to improve.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?
One of the accomplishments I am most proud of is being part of a team that aims to establish Saskatchewan's first, and likely Canada's leading, fertility preservation program for women and girls with cancer. The challenge was that there was no such option in Saskatchewan. I played a significant role in the success of this program through designing and conducting research, holding workshops and co-writing grants and papers. The program's goal is to offer advanced fertility preservation services to women and girls with cancer across Canada. This accomplishment is particularly meaningful because it provides hope and a positive fertility outlook for women and girls in need during a particularly challenging time in their lives.

What advancements in cryogenics are you hoping to make in the future?
In the future, I hope to develop more optimal and safer freezing techniques for the preservation of reproductive cells and tissue that can be widely applicable in clinics for the fertility preservation of cancer survivors, individuals facing fertility challenges, and healthy women who want to postpone their pregnancy or menopause.

What advances for women would you like to see in the fields of cryogenics and superconductivity?
I would like to see more women leading research and development in these fields. Additionally, I hope that advancements in these fields can lead to better healthcare options for women, such as improved fertility preservation methods.

What would be the best approach to getting more women into your field?
Encouraging more women to enter my field requires initiatives such as education and awareness programs, role models, mentorship programs, grants and funding for women, supporting work/life balance, creating networking events and platforms, and creating inclusive work environments that value diversity and equality. These strategies are key to attracting more women to any field of research and enhancing the quality and impact of research. I believe that everyone has a unique superpower that can contribute to scientific advancement.

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Dominika Porwisiak

Engineer with a Master of Science in Power Engineering—US Department of Energy's Fermi National Accelerator Laboratory (Fermilab—CSA CSM) Cryogenics Department

What projects are you working on now?
Currently, I am working on a helium recovery project. With my team we are developing the system that will allow us to save huge amounts of money and make Fermilab more sustainable. Helium is a nonrenewable resource, and its extraction and processing have environmental impacts. Thanks to this system, most helium used for testing superconductors will be purified and reliquefied, ready to use for other purposes.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?
One accomplishment that fills me with pride is earning the title Best Student in my faculty at Wroclaw University of Science and Technology. The challenge was substantial, encompassing not only academic excellence but also active participation in extracurricular activities and contributing to the university community. To meet this challenge, I dedicated myself wholeheartedly to my studies, striving not just for good grades but for a deep understanding of my subjects. This meant going beyond the curriculum, engaging in self-driven research and seeking opportunities for practical application of my knowledge. Apart from academics, I was gaining experience at one of the cryogenics companies in my country. Balancing these diverse commitments was not easy, but it taught me valuable lessons in time management, prioritization and perseverance. My efforts paid off when I was recognized as the best student, an honor

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that symbolized not just academic achievement but also my personal development during my time at the university.

What advancements in cryogenics are you hoping to make in the future?

In the future, my goal is to focus on developing a physical model and modeling dynamic cryogenic systems, integrating artificial intelligence to enhance the accuracy and efficiency of these models. This endeavor will involve creating a comprehensive and precise representation of the physical processes in cryogenic systems, using AI to analyze and predict system behaviors. This approach is crucial for improving and optimizing cryogenic operations at Fermilab.

What advances for women would you like to see in the fields of cryogenics and superconductivity?

I would like to see advancements for women, both in terms of representation and contribution. First, increasing the number of women working in these fields is crucial. This can be achieved through encouraging more girls and young women to pursue STEM education, offering scholarships and internships and creating mentorship programs where established female scientists in these fields mentor young aspirants.

Second, fostering an inclusive and supportive work environment where women scientists can thrive is vital. This includes implementing policies that support work/life balance, such as flexible working hours and parental leave, and ensuring equal opportunities for career advancement and leadership roles. Ultimately, these advances will not only benefit women but also enrich these fields with diverse perspectives and ideas, driving innovation and progress.

What would be the best approach to getting more women into your field?

My proposal includes four key strategies. First, focus on early education and encouragement: We should introduce STEM concepts to girls at a young age through engaging and interactive learning experiences. It's important to promote role models – women who have achieved success in these fields – to inspire young girls. Second, emphasize mentoring and networking. Establishing mentorship programs where established female professionals in these fields mentor young women is crucial. Additionally, networking events and conferences can provide vital opportunities for women to connect and collaborate.

Also, advocate for inclusive curriculum and teaching methods: Ensuring that STEM curricula are inclusive and do not reinforce gender stereotypes is critical. Teaching methods should be engaging and supportive for all students, regardless of gender. Finally, increase visibility and recognition. It's important to celebrate and publicize the achievements of women in cryogenics and superconductivity. This provides visible role models for aspiring female scientists and engineers, helping to encourage more women to enter and thrive in these fields.

Renée Tozer

Design Engineering Manager—Bluefors Cryocooler Technologies, Inc. (CSA CSM)

What projects are you working on now?

Currently, I am working on cold helium circulation systems and magnet precoolers design for manufacturability updates. I am also working on the production release of Bluefors' PT450 / CP3000 two-stage pulse tube cryocooler system that can produce 5W at 4 K.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?

I'm most proud of my team's ability to meet the demands of our rapidly growing company and adjust to new expectations of design and production capacity. Without adding new resources, we have found ways to get ahead of demands from manufacturing and sales and standardize designs for better engineering time efficiency.

What advancements in cryogenics are you hoping to make in the future?

I'm hoping for high market adoption of our low vibration reliquefier for NMR applications in order to reduce the infrastructure needed for helium recapture and reliquefaction in a laboratory setting.

What advances for women would you like to see in the fields of cryogenics and superconductivity?

I would like to see more women working in commercial manufacturing and design, continuing the progress of breaking barriers in traditionally male-dominated fields.

What would be the best approach to getting more women into your field?

I have a few ideas: company policies that support individuals in their role as primary caregivers, such as maternity/paternity leave and flexible work-from-home arrangements; educating men to become upstanders and allies rather than bystanders, fostering inclusive working environments for women; and recognizing diverse perspectives, learning styles and communication styles as contributors of equal value to design and innovation.

Anne-Marie Valente-Feliciano

Senior SRF Accelerator Physicist and SRF Process & Materials Group Leader, Jefferson Science Associates, LLC (the management and operations contractor for the US Department of Energy's Thomas Jefferson National Accelerator Facility – CSA CSM)

What projects are you working on now?
I'm working on several projects right now: superconducting radiofrequency (SRF) thin film development, including niobium on copper; alternate superconductors to niobium (NbTiN, Nb3Sn…); superconductor – insulator – superconductor (SIS) multilayers; superconducting film development for superconducting digital electronics (ACCELERATE) and quantum applications (QIS); and field emission mitigation in CEBAF accelerator and green process development for niobium surface preparation.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?
We were able to develop techniques and processes to develop high quality niobium films and other superconducting materials that can solve some issues currently limiting the performance of film-based accelerating cavities. It was a long and tedious development. Jefferson Lab committed to the thin film R&D in past decades, despite some skeptical views expressed by experts in the field. The high quality superconducting films and structures produced are now sought after, and we are actively engaging with our extended community to explore their applications beyond particle accelerators.

What advancements in superconductivity RF are you hoping to make in the future?
Now that we have successfully developed the deposition techniques to produce high quality superconducting films and structures, we are excited about the perspective that one day thin film based SRF cavities would ultimately outperform the bulk niobium cavities that are widely used today in the field. We also want to expand our developments to synergistic applications such as detector devices, superconducting digital electronics and quantum qubits. Some of these developments may prove to be game changers.

What advances for women would you like to see in the fields of cryogenics and superconductivity?
I would like to see women continue to join the field and reach all levels. It is encouraging to see that not only more and more women are joining the field of physics, but they are also striving for and getting into leadership positions. When I joined CERN as a research fellow years ago, I was the only female scientist in a group of 200. There

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were no women in leadership positions. Now, there are international laboratories that host accelerators, such as CERN and DOE's Fermi National Accelerator Laboratory, that are directed by women.

What would be the best approach to getting more women into your field?
I think more mentoring opportunities are needed, beginning in high school and all the way through university. Engaging students in internships where one can be introduced to our field or any other STEM field, and where one can meet professionals of different levels and backgrounds is paramount. There is nothing better than experiencing a field hands-on. I would like to see more programs like the National Science Foundation's research experiences for undergraduates and the DOE's Science Undergraduate Laboratory internships and perhaps initiate similar programs for students who may not necessarily look academically exceptional on paper. There are many bright young people who are left behind because they don't test very well. Out-of-the-box thinking is generally praised for scientific and technological developments. Maybe research institutions should also think outside of the box in recruiting and developing the next-generation workforce.

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Saee Vyawahare

Cryogenic Process Engineer—SLAC - Stanford National Accelerator Laboratory (CSA CSM)

What projects are you working on now?
I have worked on the LCLS-II project, which is an upgrade to SLAC's original copper accelerator (LCLS-Linear-Accelerator Coherent Light Source) to make it superconducting. Superconductivity allows making the accelerator beam 10,000 times brighter than the original. The LCLS-II accelerator consists of 37 cryomodules equipped with niobium RF (radio frequency) cavities; niobium becomes superconductive at cryogenic temperatures (<9 K). This application requires 2 K refrigeration which is delivered by the two LCLS-II cryoplants, each capable of delivering an equivalent of 18 kW @ 4.5 K, including 4.0 kW at 2.0 K.

Currently I am working on the LCLS-II cryoplant operation and on SLAC's future cryogenics infrastructure which includes LCLS-II HE, the next upgrade to the LCLS-II project, and CRMF, a novel cryomodule facility at SLAC. I am also involved in projects aimed at providing cryogenics to support the development of quantum computing.

What accomplishment are you most proud of? What was the challenge and how did you and/or your team meet it?
The cryogenic team formed at SLAC for the LCLS-II cryoplant is young and did not exist in 2016 at the beginning of the LCSL-II Project. The team had to integrate, install, automate and commission two world-class cryoplants in parallel and connect them with a 700 m linear accelerator. Most of the commissioning was accomplished during the pandemic amid travel restrictions and with very limited local support from vendors and partners. Despite the challenges, the project was a success and most of the system commissioning was completed as planned. The team achieved 2 K temperatures for the first time in April 2022. This was an important milestone for the LCLS-II project and the lab. The following year the team faced power outages in California due to wildfires, causing the cryoplant to fail. It needed a lot of coordination between the process, controls and operations teams to recover from trips and reestablish stable conditions. In September 2023, more than a year later, the lab achieved its "first light" (generated X-rays in a superconducting environment), which was celebrated across DOE as an historic moment for the scientific community. Achieving and maintaining 2 K temperatures is central to the success of LCLS-II, and I am very proud of this achievement as a part of the cryogenic team.

What advancements in cryogenics are you hoping to make in the future?
It is an exciting time to be working for the SLAC cryogenics division in the heart of Silicon Valley while tech companies actively explore the quantum world. Though SLAC is engaging in some exciting projects, I expect to see further development in cryogenics to support quantum technology initiatives. I am keen on working for such initiatives.

What advances for women would you like to see in the field of cryogenics and superconductivity?
It is encouraging to see more women in the C-suite when we look at the statistics and reports on women in the workplace. At the Department of Energy, for example, the secretary, Jennifer M. Granholm, and other top leaders in science are women. Despite the trends, one of the challenges we face is the ratio of women/men applicants, which is still very low in open positions. I would like to see more women with STEM backgrounds apply and continue to stay in STEM jobs. SLAC conducts a summer internship program called SAGE, exclusively for high school girls to develop early interest in science. Other national labs also have good summer camps/internship programs in the field. Further, creating more networking opportunities for women at the workplace is essential for advancement in cryogenics.

What would be the best approach to getting more women into your field?
Every year SLAC organizes a weeklong summer camp for high school girls in the area called SAGE. As a volunteer, I did job shadowing to give the students an idea of what a typical day at the cryoplant looks like. The on-site experience proved to be quite immersive and a major takeaway for the students. They got really involved and curious while touring the facility, interacting with the staff, asking questions and understanding the science behind cryogenics. SAGE is a great platform for female students to learn about science. Also, the activities and interactions through various sessions with physicists and cryogenic experts could go a long way in inspiring and creating the cryogenic women of tomorrow. Extending such programs into internships would give students more comprehensive experience in the field.

Cryo Legacy: Angela Krenn's Reflections on Cryogenics and Space, a Trailblazer Revisited

In our annual "Women in Cryogenics and Superconductivity" feature, ***Cold Facts*** explores the profound contributions of outstanding women in the field. Drawing on its popularity, we wanted to have a candid conversation, reconnecting with a trailblazing woman in cryogenics, previously spotlighted as one of our "Women in Cryogenics." In this interview, Angela Krenn, with over 21 years of experience at NASA's Kennedy Space Center, offers an insightful glimpse into the industry's evolution over two decades and her impact on space exploration. Currently serving as the principal technologist for Thermal Management Systems and Surface Systems in the Space Technology Mission Directorate, Angela is at the forefront of developing investment strategies and coordinating technology advancements across NASA. In her role, she seamlessly transitioned from a focus on cryogenics to overseeing all thermal-related technology developments for the agency. Angela's expertise extends from extreme cooling for rocket fuel efficiency to ensuring instruments' function in lunar exploration conditions. A Florida native, Angela's childhood dream of working for NASA became a reality and her commitment to identifying gaps in thermal technologies reflects her dedication. With a remarkable career that started with a dream job working with liquid hydrogen, Angela continues to inspire as a leader in advancing NASA's capabilities for future space exploration and as a powerful role model to industry women.

Cryogenics demonstration at a public outreach event. *Credit: NASA*

What inspired you to pursue a career in this specific area?

I never intended to pursue a career in cryogenics. I wasn't even aware that cryogenics could be a career choice when I was making such decisions. However, as a bit of a dreamer, I find inspiration in a million little things every day. Influential figures like Christa McAuliffe and Sally Ride, as well as movies like *October Sky* and *Apollo 13*, have consistently inspired me. I also draw inspiration from deep within every time I gaze into the night sky. So when it came to making career choices, all I knew was that I wanted to contribute to the space shuttle program in any way possible. It was only by good fortune that my first job out of college landed me in the liquid hydrogen system, where I had the privilege of participating in cryogenic propellant tank loadings for the space shuttle's external tank. Falling in love with cryogenics has proven to be a remarkably rewarding experience.

"Falling in love with cryogenics has proven to be a remarkably rewarding experience."

Over your more than two decades at NASA, you've had diverse roles, including operations, design, analysis and technology development. How have these experiences shaped your perspective on cryogenic systems?

Regardless of your role in cryogenics, physics presents essentially the same challenges. However, that might be where the

▶ *continues on page 18*

Angela Krenn. *Credit: NASA*

Angela with other team members from NASA and the German Aerospace Center (DLR) at the Robotics and Mechatronics Center in Oberpfaffenhofen, Germany. *Credit: NASA*

commonality ends. There are fundamentally different objectives for a cryogenics operator than for an analyst/designer or a technologist. This leads to very different approaches to tackling problems and can sometimes create communication challenges when collaboration is necessary. I've learned that when faced with a technical challenge, it is vital to first establish a common understanding of the non-technical constraints, such as safety, risk tolerance, cost, schedule and reliability, along with operational life.

Could you tell us more about your current role at NASA?

Currently, I am serving in a couple of different roles at NASA. I have been the principal technologist (PT) for Thermal Management Systems within the Space Technology Mission Directorate (STMD) for the last three years. PTs develop investment strategies and technical content across the entire technology readiness level (TRL) pipeline. They also provide technical assessments for key project reviews and solicitation responses, coordinate with other capability teams and NASA mission directorates and maintain awareness of relevant emerging technologies across other government agencies, industry, academia and international partners. Additionally, I am serving as the technical integration lead within the Strategic Planning and Integration office. In this role, I interface with the lunar and Mars architecture teams throughout the Artemis architecture concept review process to ensure the appropriate new technologies are being developed and incorporated into NASA's exploration plans.

As a woman in a field that has traditionally been male dominated, have you encountered any specific challenges or obstacles in your career?

I have not really encountered too many gender-related impediments. Sometimes when I first cross paths with people, they may initially dismiss me, but I've found it relatively easy to earn the respect of my colleagues because of my technical depth and broad experience.

Why do you think there aren't as many women entering the fields of cryogenics and superconductivity (physics, engineering, aerospace, quantum, magnetics, materials, HTS, etc.), and what do you think can be done to encourage more women to pursue careers in these areas?

There generally are not classes focused on cryogenics in most college degree programs. Perhaps the lack of a broad understanding of the field and its enabling implications across many different areas results in fewer women entering the field. Including more niche areas, such as cryogenics, as electives in degree programs might help. Universities could also partner with industry to bring in guest lecturers to provide real-world insights into some of the opportunities that may not be as well known. I also believe it helps to start young by exposing elementary-age students to cryogenics, as well as other STEM areas. This could be an excellent way to attract women to the field. Classroom demonstrations using liquid nitrogen can be a fun and interesting way to get kids excited about cryogenics, and that interest may carry forward into future careers.

How do you see the future of cryogenics and superconductivity evolving, especially in the context of space exploration?

From the perspective of extending human presence deeper into the solar system, the ability to store cryogens for extended durations in space and on the lunar and Martian surfaces will be critical. From a scientific standpoint, delving into our origins, the ability to return cryogenically cold samples to Earth will be crucial.

The tools to make these feats possible are currently in development. New refrigerators, integrated heat exchangers, improved coatings and insulation, methods of reducing conductive loads and more, are all in progress. Achieving the vision of long-term cryogenic storage in space will provide a significant piece of the puzzle for turning the seemingly impossible into reality—enabling long-duration in-space transit of crews, in-space refueling, in-situ propellant production and storage, expanded scientific knowledge and more. While these technologies are being developed for in-space applications, many are cross-cutting and can have countless benefits back on Earth.

Are there any exciting developments or projects in these fields that you're particularly optimistic about?

NASA's Kennedy Space Center has developed a new thermal control coating affectionately known as Solar White. The concept for this coating began as a NASA Innovative Advanced Concepts (NIAC) project and successfully progressed through all of NASA's technology readiness level stages. It has now been licensed to multiple companies. The coating dramatically reduces the heat load from solar absorption, contributing significantly to NASA's goal of long-term cryogenic storage in space.

Who or what has been the most significant inspiration in your career, and how have they influenced your approach to your work?

Over the course of my 21-plus-year career, I've been very fortunate to find exceptional mentors at every stage. It would be impossible to pick the most inspirational person because each has inspired me in a unique and invaluable way. This handful of people has influenced every aspect of how I approach work, whether it's technical rigor, laser focus, systems thinking, deliberate communication, research techniques, humility, active listening, or stepping beyond my comfort zone. My genuine appreciation for these mentors has also made me a more willing and capable mentor as I have matured in my career. While I have formally served as a "mentor" to many interns and new hires over the years, I try to maintain a constant mentality of both mentorship for those who seek it and receptiveness to those offering mentorship to me.

"It will be hard and there will be times when it's tempting to give up; however, success is built on the back of perseverance."

What advice would you give to young women aspiring to enter the fields of cryogenics and superconductivity or other male-dominated STEM fields?

Never give up. Einstein once said, "It's not that I'm so smart; it's just that I stay with problems longer." It will be hard and there will be times when it's tempting to give up; however, success is built on the back of perseverance.

Are there specific skills or qualities you believe are crucial for success in your line of work?

Research skills are critical in this field because, as applications expand, so does the body of work needed to support developments. Continuous, deliberate research into the current status of work released by credible publications can be tedious, but it provides a critical foundation to build from. Additionally, the ability to apply systems-level thinking is crucial for my work because when dealing with highly complex systems, seemingly small choices can have sweeping consequences. The last quality I'll mention is something I believe to be important in all lines of work and at every level: responsiveness. The most challenging tasks cannot be done alone. We must all rely on each other, and the first step is to be responsive to collaboration.

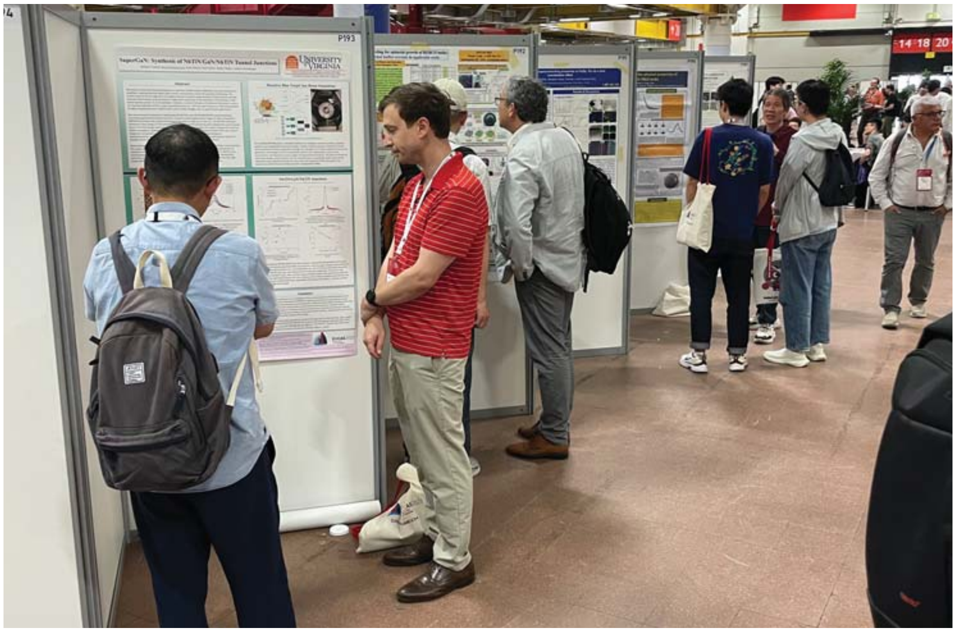
Launch Pad 39-B during roll out of STS-114 return to flight. *Credit: NASA*

EUCAS Unveils a Superconductive Symphony in Bologna

by Professors Marco Breschi and Antonio Morandi, University of Bologna, Italy, EUCAS Co-Chairs

The 16th European Conference on Applied Superconductivity (EUCAS) took place in Bologna, Italy, September 3-7, 2023, at the Palazzo della Cultura e dei Congressi. The charming city of Bologna, described as "one of Europe's great medieval cities" by feedback from conference participants, served as an excellent backdrop for a highly fruitful and memorable meeting. The conference was organized with precision and dedication by the collaborative efforts of the European Society for Applied Superconductivity (ESAS). ESAS, founded in 1989, has been at the forefront of promoting and advancing the application of superconductivity in various domains. With a strong commitment to fostering interdisciplinary collaboration, the society has facilitated numerous conferences and events that contribute to the dissemination of knowledge and the progress of applied superconductivity.

EUCAS 2023 Co-Chairs Professors Antonio Morandi and Marco Breschi, University of Bologna, Italy. *Credit: EUCAS*


Oral and poster sessions, along with industrial exhibitions, were highly successful, fostering comprehensive discussions and a collaborative atmosphere. *Credit: EUCAS*

Bologna, the capital of the Emilia Romagna region, is among the top 50 destinations in Europe, known for its wealth and development. Home to the oldest university in Europe, the city boasts a rich cultural heritage, with a well-preserved medieval center, towers and 40 km of arcades, nominated as a UNESCO World Heritage Site. More than 50 museums contribute to the city's cultural richness. Its rich history and pleasant September climate, with average temperatures around 24 °C, added to the overall appeal of the conference.

A total of 1,043 participants from 39 countries attended the event, with 50% coming from Europe and 34% from Asia. ESAS's collaboration with international sponsors and exhibiting companies showcased its ability to bring together key stakeholders in

A total of 1,043 participants from 39 countries attended EUCAS 2023. *Credit: EUCAS*

the field. The conference received generous support from 17 international sponsors and had 37 exhibiting companies, highlighting the industry's engagement and interest in the latest developments.

Professors Marco Breschi and Antonio Morandi from the University of Bologna co-chaired the conference. Both are esteemed members of the applied superconductivity community with a substantial research record in the large-scale application of superconductors for high-energy physics and energy. The conference featured a diverse program, including plenary and focus talks on cutting-edge topics such as quantum computing, sustainable energy, material development and advances in high-field magnets technology. Oral and poster sessions, along with industrial exhibitions, were highly successful, fostering comprehensive discussions and a collaborative atmosphere.

The live streaming session on room temperature superconductivity, hosted on the University of Bologna's YouTube channel, further demonstrated ESAS's commitment to leveraging modern communication platforms for knowledge dissemination. The session's impressive viewership, with nearly 1,000 connected attendees and over 9,100 views, highlighted the global reach and impact of ESAS-led initiatives.

Social events added a delightful touch to the conference experience. An opera

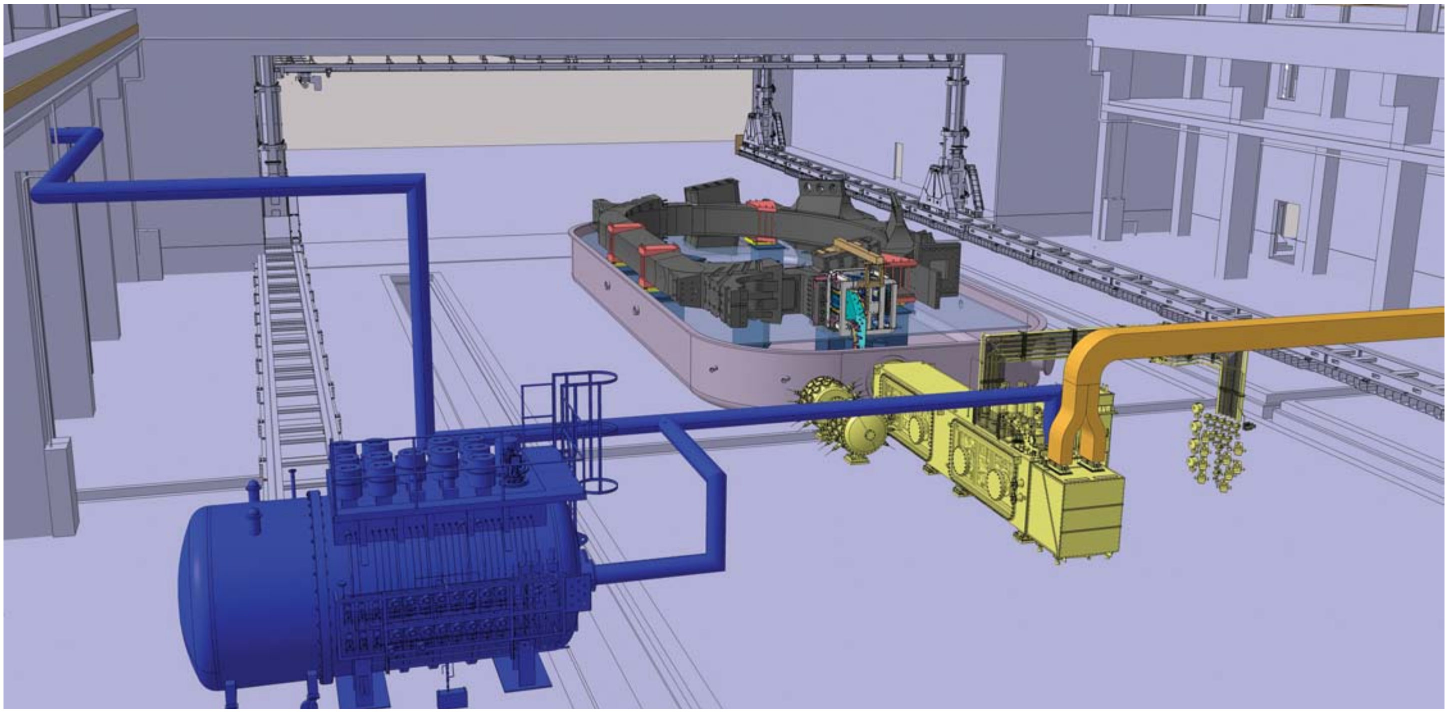
EUCAS 2023 continued its tradition of hosting a 4.2 km fun run, this time around the Parco Nicholas Green and the Certosa di Bologna. *Credit: EUCAS*

interlude during the welcome reception, featuring the talents of Gaia Pizzirani on piano, Valeria D'Astoli as soprano and Riccardo Gatto as tenor, was warmly received by attendees. The sponsors went on to host a salumi and wine tasting event, a showcase of Emilia Romagna's culinary tradition, featuring typical cheeses and a tortellini preparation banquet. Another highlight was the social dinner at DUMBO, Bologna's social district, which not only provided a picturesque setting but also featured a concert by the local band, Joe di Brutto. This particular event garnered enthusiastic acclaim and was labeled by some attendees as the "best party ever." The fusion of music, local cuisine and vibrant social interactions created a memorable and enjoyable atmosphere, contributing to the overall success of the conference.

Overall, the 16th European Conference on Applied Superconductivity not only showcased the vibrant and rich scientific landscape of the field but also underscored ESAS's pivotal role in advancing and shaping the future of applied superconductivity. **www.eucas2023.esas.org**

ITER's Magnets Conquer the 4 K Cryostat Challenge

by ITER Communications Team



The cold test facility will be located in the partially vacated poloidal field coil winding facility. Supercritical helium at 4 K will be delivered by way of a cryogenic auxiliary cold box (blue) interfacing with the cryoplant; electrical power will be fed by a busbar (orange) originating in a dedicated power supply system. Both cryogens and electrical power will be delivered to the magnet by way of a feeder (yellow). As the coil will be in the horizontal position, a new design is required for connecting it to the feeder. *Credit: ITER*

Embarking on the frontiers of innovation, ITER, the International Thermonuclear Experimental Reactor, heralds a new era with its superconducting magnets—a groundbreaking technological marvel designed to operate at an astonishingly low temperature of 4 K (-269 °C), just above absolute zero. ITER's primary purpose is to explore and demonstrate the potential of nuclear fusion as a clean and sustainable energy source for the future. With the capacity to carry an immensely powerful electrical current, reaching up to 68 kA, these magnets are poised for rigorous testing within a specialized cryostat infrastructure. The question of how these first-of-a-kind components navigate such extreme conditions becomes a pivotal inquiry at the forefront of scientific exploration.

"Testing at 4 K and at 80 K are completely different operations," explains David Grillot, ITER deputy program manager for plant systems and former leader of the Cryogenics Section. "Considering that a toroidal field coil's mass is in excess of 300 tonnes, the colder test requires considerable infrastructure—a large cryostat, a dedicated power supply, an electrical feeder and associated instrumentation and an interface with a large refrigerator located inside the cryoplant. It's not comparable at all to testing at 80 K, which is relatively simple and has been done routinely."

While testing at 80 K provides insights into 90% of the thermal and mechanical constraints, it falls short of capturing the true electrical behavior of the coils. Superconductivity is only fully established at 4 K, necessitating a specialized and challenging testing approach.

"All six ITER ring-shaped poloidal field coils and 14 out of 19 D-shaped toroidal field coils will have been tested at the more clement temperature of 80 K before their installation in the ITER machine," says Neil Mitchell, ITER's historical magnet expert. However, testing at 4 K was only done for the US-procured central solenoid modules. "US ITER demanded that a full-current 4 K factory acceptance test be performed on each central solenoid module before shipment to ITER," adds Mitchell. "It definitely made sense as a 4 K test can achieve conditions pretty close to a module's operating point in ITER."

Proceeding to 4 K tests has long been discussed inside ITER, with experts and management confronting analyses and debating the pros and cons. Confidence in the manufacturing process and other considerations eventually led to the decision not to proceed.

"Although we are not starting from scratch – coils at JT60-SA and W7-X have been tested at 4 K – the size of the ITER coils and hence the dimensioning of the installation present considerable challenges," says David Grillot. "Also, we need to finalize the facility in two years when it would normally take twice that time."

The cold test facility's design, located in the vacated part of the winding facility, faces significant technical and organizational challenges. The project team aims to set up the infrastructure in less than two years, with plans for testing at least one coil from each manufacturer (Mitsubishi and Toshiba in Japan; ASG-SIMIC in Europe).

The cryogenic distribution system is another critical aspect, ensuring the supply of cryogenic fluids to superconducting magnets, cryopumps and other components. The auxiliary cold boxes, positioned in the Tokamak Building, play a crucial role in distributing cooling fluids to various clients inside the ITER machine.

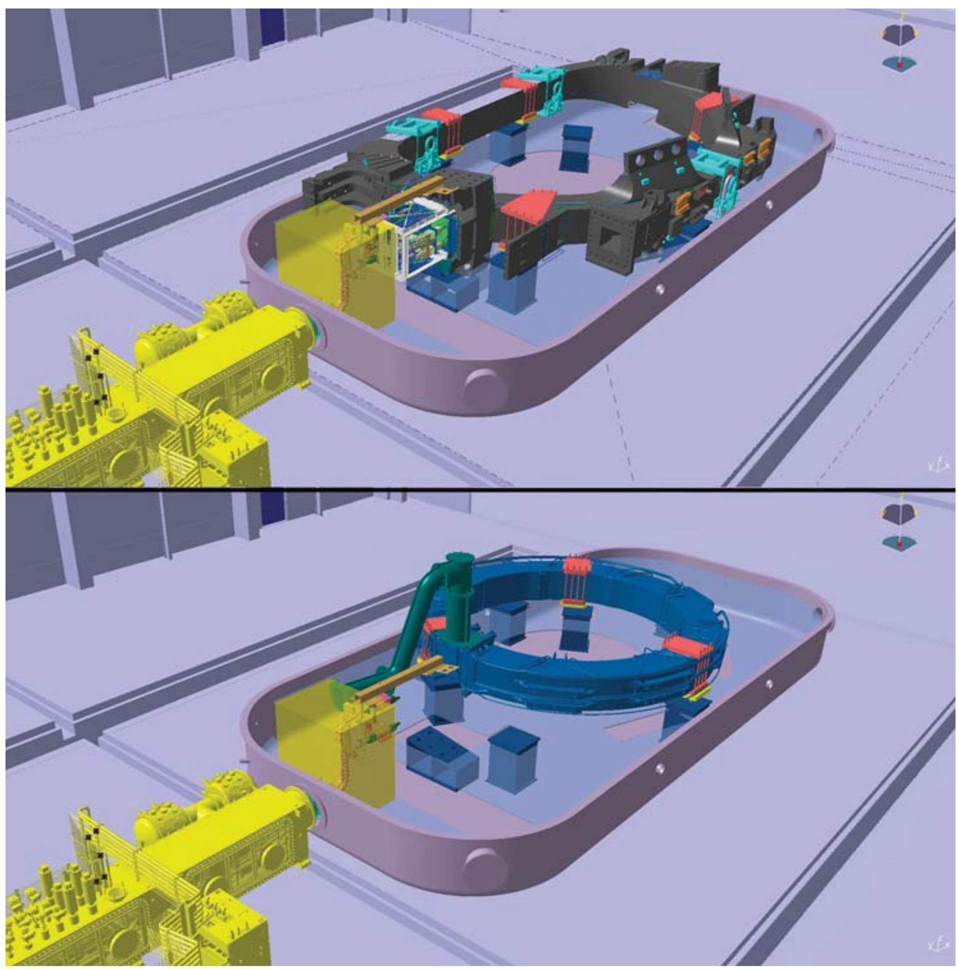
"Providing cryogenic fluids to the superconducting magnets, cryopumps, and other 'clients' in the ITER machine requires a sophisticated distribution system that ramifies to deliver the cryoplant-originating fluids to their final destinations," as described in a recent ITER update.

The involvement of domestic agencies extends beyond component delivery. Alessandro Bonito-Oliva, Head of the Tokamak Program at ITER, emphasizes the collaborative effort in procuring superconducting toroidal field coils. The completion of this project marks a significant achievement, with Sandro now overseeing the integration of coils into the ITER machine.

"Relations between the ITER Organization and the domestic agencies are complex because within a shared objective, the approach can differ depending on whether you are reasoning as a supplier or as the machine owner," says Sandro Bonito-Oliva. The ITER Organization's reorganization aims to integrate diverse perspectives and talent from domestic agencies to optimize the entire process from design to operation.

It is important that a domestic agency's involvement does not stop with the delivery of components. "When you've produced a technically complex component and accumulated all the technical know-how, you can make a real contribution onsite during integration and commissioning," adds Bonito-Oliva. "My first months here have been an incredible source of motivation, which at this advanced stage of my career I thought would be impossible to find. I would strongly encourage others to follow in my steps!"
www.iter.org

The dedicated, fully matrixed project team that was established will face a major technical and organizational challenge: setting up the cold testing infrastructure in less than two years. *Credit: ITER*



Designed to accommodate the tokamak's D-shaped toroidal field coils, the dimensions of the cold test facility's cryostat (11 m x 22 m) will also allow for the testing of poloidal field coil #1 (10 m in diameter). *Credit: ITER*

Cryo Bios

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

Theodore C. Nast

Theodore (Ted) Charles Nast was a pioneer in space cryogenics, making important contributions in cooling by solid cryogens, mechanical cryocoolers and the use of multilayer insulation (MLI). His career extended from the earliest days of space exploration to the 21st century.

Ted Nast was born in Douglas, Wyo., and earned his Bachelor's degree at the University of Wyoming. Upon graduation, Ted started work at Convair and then moved to Lockheed Missiles and Space (now Lockheed Martin) where he spent the rest of his career. While working at Lockheed, he earned a Master's degree at Santa Clara University in California. His first work was on airframe heating for the Polaris missile. Shortly afterward, he worked on the Reactor In-Flight Test (RIFT) nuclear rocket. This project, which required the transport and storage of liquid hydrogen, was Ted's first work in the field of cryogenics. Cryogenics then became the focus of Ted's career.

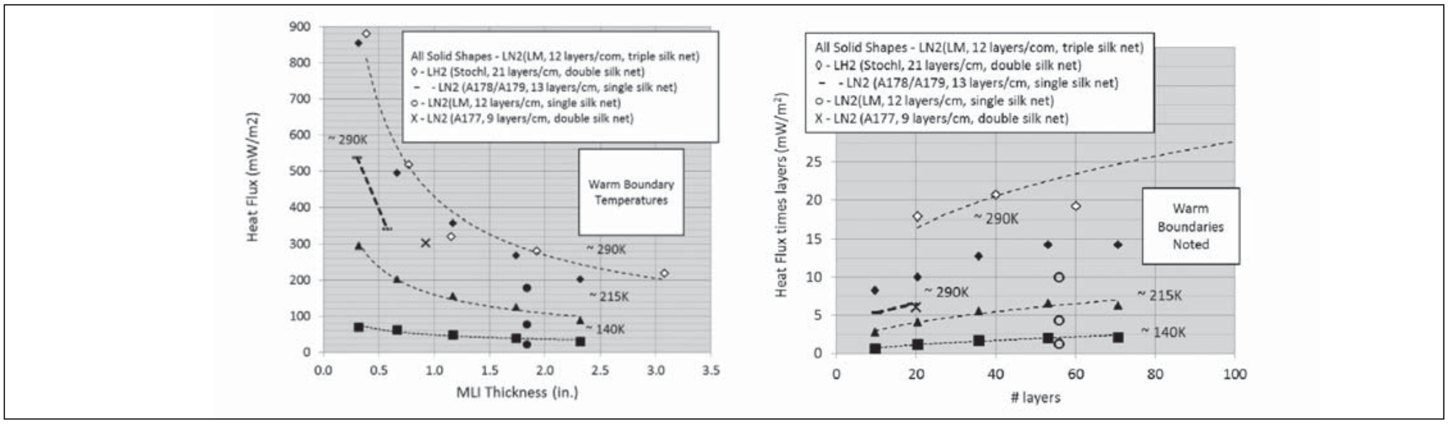
One can almost see the evolution of space cryogenics in Ted's contributions to it. Early efforts involved the use of solid cryogens for the cooling of satellite instruments. Ted contributed to many of these systems, including the first solid cryogen cooler to be flown in space and the first two-stage (methane and ammonia) solid cryogen cooler flown as part of the Nimbus F weather satellite (see Figure 1). Other solid cryogen coolers developed by Ted and the Lockheed team included the solid hydrogen dewar built for the Cryogenic Limb Array Etalon Spectrometer (CLAES).

Figure 1: Ted Nast with a two-stage solid methane/ammonia cooler built for Nimbus-F. *Credit: Lockheed Martin Corporation. All rights reserved.*

As the technology of small mechanical cryocoolers developed and began to replace solid cryogen coolers, Ted made major contributions to this effort, including "leading the Lockheed Martin team that developed two-stage pulse tube cryocoolers for cooling below 35 K, three-stage pulse tubes for cooling below 10 K and four-stage pulse tubes for cooling below 4 K. He also led the development of high capacity cryocoolers and microcryocoolers."

Over his career, Ted worked on and published papers on many other aspects of space cryogenics, including getter-based cryogenic thermal switches (1985), a superfluid helium tanker (1990), phase separation of superfluid helium by porous media (1990), an on-orbit liquid hydrogen test bed (2015) and a Joule-Thomson microcompressor (2015).

Another of Ted's significant contributions came in the investigation of multilayer Insulation (MLI). He made numerous careful, experimental and theoretical studies of MLI systems. These included the effect of gas pressure within the MLI, the effect of various metallic coatings and the use of MLI at very low boundary temperatures.



Johnson, W. L., Frank, D. J., Nast, T. C., & Fesmire, J. E. (2015). "Thermal Performance Testing of Cryogenic Multilayer Insulation with Silk Net Spacers." In IOP Conference Series: Materials Science and Engineering (Vol. 101). *Credit: W. L. Johnson, D. J. Frank, T. C. Nast and J. E. Fesmire*

This work led to valuable figures and parametric equations that are used to this day by the cryogenics community. Ted produced a very valuable section on MLI for the Handbook of Cryogenic Engineering (1998). One of his last published papers was on "Thermal Performance Testing of Cryogenic Multilayer Insulation with Silk Net Spacers," by W. L. Johnson, D. J. Frank, T. C. Nast and J. E. Fesmire (2015 IOP Conf. Ser.: Mater. Sci. Eng. 101). An example figure from this paper is shown as Figure 2. Note that it incorporates historical data from Ted's earlier work.

Ted was a frequent conference attendee and organized the 10th International Cryocooler Conference in Monterey, Calif., in 1998. I had the pleasure of speaking with Ted on a number of occasions and found him to always be enthusiastic and interested in collaboration, the exchange of ideas or assisting with reviews. His collaboration with me on the Handbook of Cryogenic Engineering was both valuable and enjoyable.

Many thanks to Rob Nast and Jeffrey Olson for their assistance with this column.

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[1] Olson, J.R. "In Memoriam, Ted Nast, 1934-2022 -- A Lifetime Legacy in Space Cryogenics." ***Cold Facts***. 2022.

Space Cryogenics

by Wesley Johnson, NASA Glenn Research Center

Performance Testing of Liquid Hydrogen Tanks

Testing the performance of liquid hydrogen in tanks brings many unique challenges. Often, methods used even for liquid nitrogen need to be modified to be able to address the details required to fully understand the performance of the tank. During the development and characterization of many novel insulation systems, both for in-space and ground applications, NASA has tested many liquid hydrogen tanks where performance was a key outcome. Over the course of analyzing the performance of multiple different hydrogen tests, including several with both hydrogen and nitrogen, differences in the details of test data interpretation become clear. One of these key details is the thermal stratification of the tank and what it can tell you about the heat load dispersion. Let's explore this more fully using several tests recently performed by NASA.

First, we examine the Structural Heat Intercept, Insulation, and Vibration Evaluation Rig (SHIIVER) test.[1] During SHIIVER, a 4-meter-diameter tank was tested with both liquid nitrogen and liquid hydrogen in several different insulation configurations. Testing was performed by allowing the tank to boil off from 90% full to 25% full, only stopping for self-pressurization tests at key fill levels. From Figure 1 and Figure 2, we can see differences in the heat load and the boiloff rate as a function of the fill level for liquid hydrogen. In general, for all tests, the heat load stays fairly constant as a function of fill level (for a given test configuration), at least until the liquid-vapor interface starts to interact with the flange between the aft skirt and barrel of the tank (a few inches above the start of the barrel; see Figure 3 for the SHIIVER test configuration). However, the boiloff flow rate decreases significantly with fill level. This is caused by the increasing temperature of the ullage. Figure 4 shows us that for the pre-acoustic LH_2 test, the ullage started out

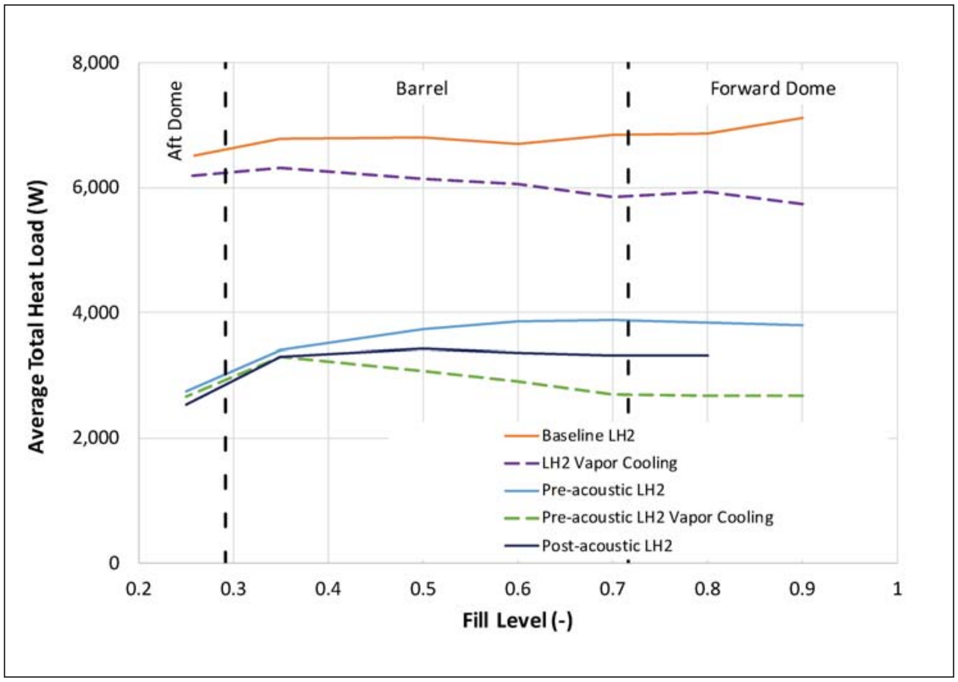

Figure 1: SHIIVER calculated heat loads as a function of fill level. Note that MLI was applied to the tank for pre-acoustic and post-acoustic testing, but after baseline testing. *Credit: Wesley Johnson, NASA Glenn Research Center*

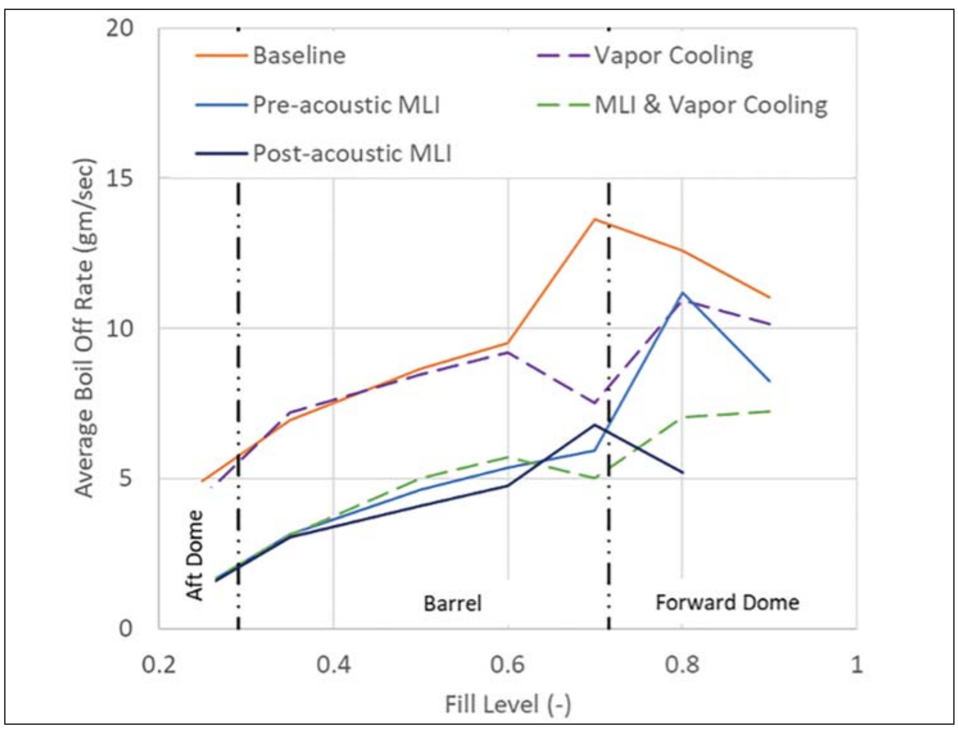

Figure 2: SHIIVER measured boiloff rates as a function of fill level with liquid hydrogen. *Credit: Wesley Johnson, NASA Glenn Research Center*

with temperatures as high as 80 K at 50% full that got up to 160 K at 25% full.

The second adjustment that should be made is for the density ratio between the liquid and vapor phases. Any liquid that boils off or evaporates in a fixed-volume system must be replaced by vapor. To account for the fraction of boiloff vapor that replaces the liquid, a term must be added to the energy balance.[3] Thus, the heat load from the boiloff rate becomes:

$$\dot{Q} = \dot{m}_{boil-off}\left(h_{Texit} - h_{liq}\right)\left(\frac{\rho_{liq}}{\rho_{liq} - \rho_{vap}}\right)$$

where h_{Texit} is the temperature of the gas at the exit of the tank and ρ_{vap} is the saturated vapor density. This factor is plotted for parahydrogen, helium, and nitrogen in Figure 5 as a function of saturated liquid pressure. The correction for nitrogen is very small, especially around 100 kPa (1 bar), less than 0.2%. However, parahydrogen and helium have much larger density correction factors.

While SHIIVER was a more complicated and quasi-transient test, the Cost-Efficient Storage and Transfer (CESAT) test was an intentionally quasi-steady state test.[2] During the test, the annulus of the vacuum-jacketed tank was filled separately with perlite and glass bubbles for testing with both liquid hydrogen and liquid nitrogen. Test data was reported at approximately 80% full. The published heat loads and system thermal conductivities are simply based on the boiloff flow rate times the heat of vaporization. However, using the data provided at the top of the tank (see Figure 6), we can adjust the data. If we make the assumptions that the differential temperature between the saturated liquid and the top of the tank is approximately the same for liquid nitrogen testing as liquid hydrogen testing (which is probably incorrect, but we will do so for comparison), we can do similar calculations. Table 1 shows the published heat load and boiloff rate data, along with the heat of vaporization for nitrogen and parahydrogen at 101 kPa. Based on the plotted gas exit temperature, a new enthalpy change is calculated. The heat load and total system thermal conductivities can then be multiplied by the ratio of the new enthalpy change to the heat of vaporization and the density correction factor (1.02). This adjustment causes a 58% change in the heat load calculated for the liquid hydrogen tests, but only a 13% change for the liquid nitrogen tests. While 58% seems like a large adjustment for this value, at 80% full, nearly 30% of the surface area of a sphere is still in the vapor. The much lower 13% change for nitrogen indicates that either the temperature at the top of the tank was much higher than we assumed in the calculation, or more thermal energy was able to conduct down the tank wall from the vapor space to the liquid.

A third test can also be examined that reinforces this point. During Cryogenic Boiloff Reduction system test series 2,[4] a test was run at 25% full to compare to the 90% full baseline. Both tests were run in a quasi-steady state configuration. On this test, a cryocooled shield was inserted into the multilayer insulation (MLI) and attached to the tank's structural and plumbing lines. For both tests, the cryocooler was run at

▶ *continues on page 31*

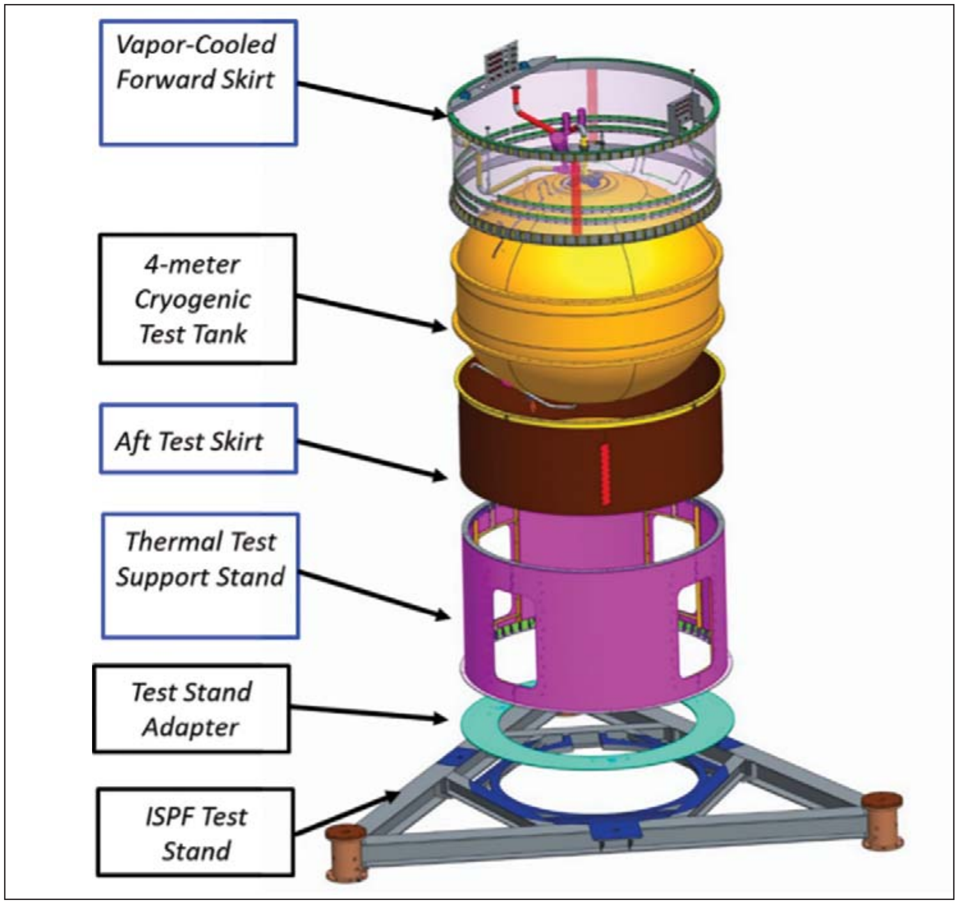

Figure 3: SHIIVER test article. *Credit: Wesley Johnson, NASA Glenn Research Center*

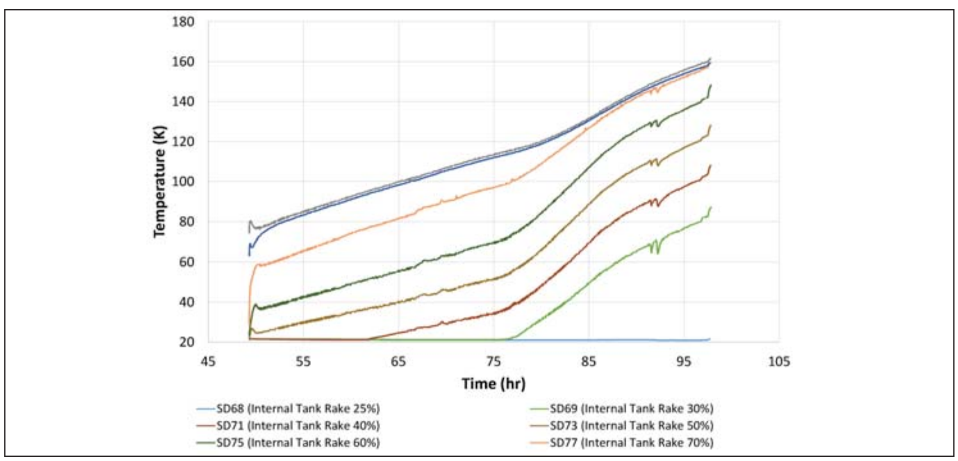

Figure 4: SHIIVER hydrogen ullage temperatures during pre-acoustic testing between 50 and 25 percent full. *Credit: Wesley Johnson, NASA Glenn Research Center*

Zero Resistance Zone

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

The Development of High Temperature Superconducting (HTS) Power Cable Systems

The need to transmit power to meet an ever-increasing demand has been a challenge for decades. This article is focused on the cooling of high temperature superconducting (HTS) cables for power transmission and distribution. Many of the concepts presented can be applied to other HTS cable applications that might be found on ships and aircraft electrical power systems. A significant advantage of HTS cables is the reduction in the right of way required, compared to conventional overhead lines, as shown in Figure 1. This feature is especially important in urban areas where there is no room to use conventional overhead lines. In addition, electrical losses are greatly reduced since higher currents can be carried by superconductors in smaller cross-sections compared to conventional conductors. This has the advantage that the power transmitted can be at a lower voltage with superconductors for the same power, or significantly more power can be transmitted at the higher voltage due to the higher current-carrying capability.

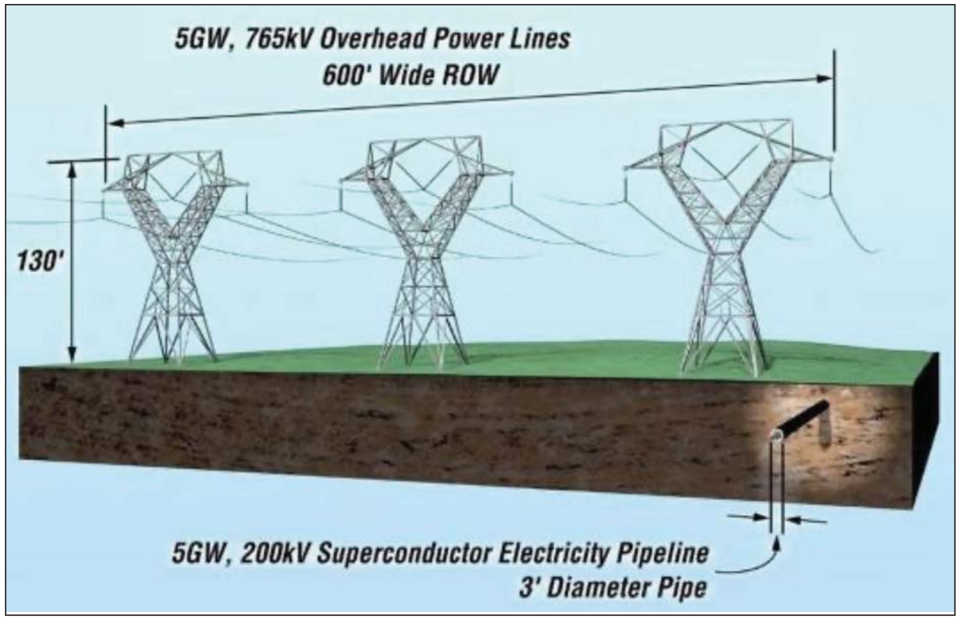

Figure 1: Comparison of conventional transmission installation with potential reduction of size for high temperature superconducting cable. *Credit: DOE SPI Program*

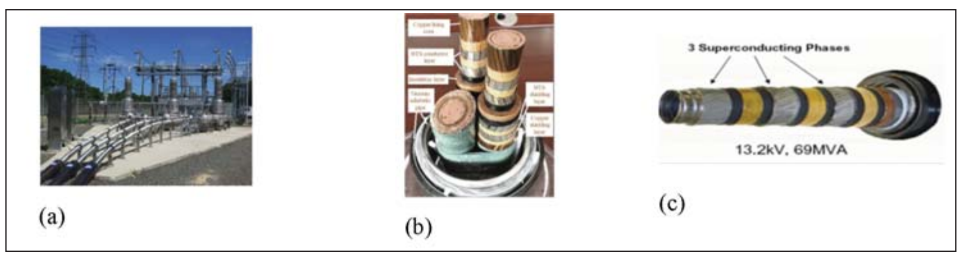

Figure 2: Typical HTS cable configurations. (a) Three separate coaxial HTS phases; (b) Cold-dielectric with an HTS shield triad layout; and (c) A concentric Triax™ design cable. *Credit: McGuire, Zong and Demko* [5, 7, 2]

High temperature superconductors are generally considered to be those conductors that have a critical temperature that can be cooled using liquid nitrogen, which typically falls in the range of 65 K to 90 K. Before the discovery of high temperature superconductivity, other cryogenic concepts were considered because of the advantages of low temperature power cables. The use of cryoresistive cables was an early solution discussed in Weedy and Rigby.[1] These systems relied on the decreased resistivity of conventional conductors, such as copper and aluminum, as temperatures were lowered. The designs for these cables would use liquid nitrogen as the coolant with pressures between 10 and 25 atmospheres and temperatures from 65 K to 100 K.

Superconducting power cables are generally found in three main arrangements, as shown in Figure 2. Conventional and cryoresistive are only suited for the three separate co-axial phases, Figure 2a, and the triad configuration, Figure 2b. The triaxial cable was much more recently developed particularly for HTS cables.[2] The triaxial cable configuration offers several advantages over the two other cable arrangements. First, the triaxal cable uses about half of the superconductor. The separate cable and triad require superconducting shield layers, which must carry the same current as the main conductor. The triaxial cable does not need the shield but only a conductor layer for current imbalance in the three-phase circuit.

When low temperature superconductors could be produced in long lengths and in large quantities, researchers focused their attention on superconducting power transmission cables. One notable early project was tested at Brookhaven National Laboratory (BNL).[3] The BNL cable used a Nb_3Sn superconductor with a critical temperature $T_c \approx 16.6$ K. This required the use of supercritical helium as the coolant. The three-phase cable system was rated at 1000 MVA (330 MVA per phase) with 80 kV line-to-neutral or 138 kV three-phase rating with a design current of 4,000 A. The system, operated at BNL from 1982 to 1986, had a length of 115 meters. There were two cables in the demonstration with an outer diameter of 5.85 cm. The cables were enclosed in a flexible cryostat with a 40-cm outer diameter. Cooling was in a counterflow arrangement, as shown in Figure 3. Supercritical helium leaving the refrigerator would be sent down the superconducting cables, and at the end there was an expansion engine that dropped the temperature of the helium, which flowed back through the cable cryostat to the refrigerator. BNL investigated the possibility of installing this in several locations.

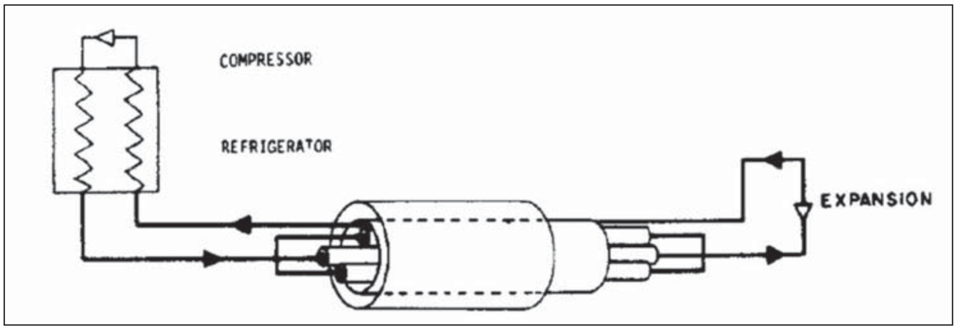

Figure 3: Counterflow cooling arrangement of the BNL low temperature superconducting cable. *Credit: E.B. Forsyth and R.A. Thomas* [3]

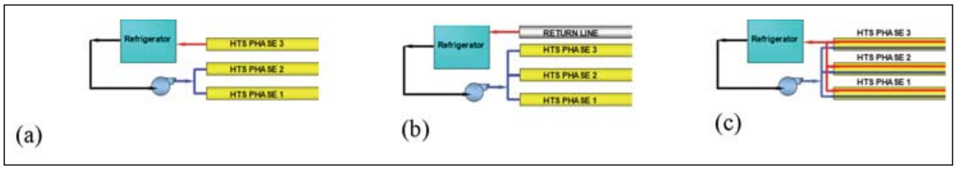

Figure 4: HTS cable cooling arrangements. *Credit: Demko*

Requirements of a HTS Cable System and Cryogenic System

HTS cables offer many advantages over conventional cables. There are requirements for the cryogenic system to meet. Since the preferred cooling is typically based on liquid nitrogen (except for special applications such as on electric-powered aircraft and ships), the operating temperature range is between 65 K and 80 K. The cable design considers the required critical current needed and, in turn, the ac loss associated with the conductor.

In many designs, liquid nitrogen is impregnated into the dielectric. The formation of bubbles would reduce the dielectric strength so the pressure must be maintained above the saturation pressure for all locations with high voltage. The cable cooling system would circulate liquid nitrogen under normal operating conditions, so sufficient refrigeration is required.

Cable Layout	3-Separate Phases	Triad	Triaxial
Parallel flow	Yes	**No**	No
Parallel Flow Separate Return	Yes	Yes	Yes
Counterflow	Yes	Yes	Yes

Table 2: Possible cooling arrangements for HTS cable systems. *Credit: Shu and Demko*

Country	Year	Cable Type	Rating	Length	Manufacturer Site
US	2006	Three in one	34.5 kV/0.8 kA	350 m	SEI Albany
US	2006	Triaxial	13 kV/3 kA	200 m	Ultera Columbus
US	2008	Single core	138 kV/1.8 kA	600 m	Nexans Long Island
JP	2012	Three in one	66 kV/1.75 kA	250 m	SEI Yokohama
DE	2014	Triaxial	10 kV/2.3 kA	1000 m	Nexans Essen
KR	2011	Three in one	23 kV/1.25 kA	410 m	LS Cable Icheon
KR	2020	Three in one	23 kV/1.26 kA	1035 m	LS Cable Shingal
CN	2013	single core	35 kV/2 kA	50 m	SECRI Shanghai
CN	2023	Three in one	35KV/2,2KA	1200m	Shanghai

Table 3: Partial list of HTS AC cable projects.[8] *Credit: Shu and Demko*

Cooling Configurations

There are two basic cooling arrangements for these systems. The first is a parallel flow where the coolant is circulated through the HTS cable in one direction. This lends itself to two possibilities for three-phase cables. The first sends coolant from the refrigerator through two phases and returns through the third, which is illustrated in Figure 4a. This is only applicable when there are three separate cables. The parallel flow arrangement in Figure 4b sends the cooling stream one way through the cable but uses an extra return line to bring the coolant back to the refrigerator. Weedy and Rigby suggest that the return line could be a second circuit used for redundancy.[1] The counterflow arrangement sends coolant out through the center of the cable and returns it over the outside of the cable (Figure 4c). In the case of the Triax™ it would be the most compact cooling arrangement. Table 2 shows cooling schemes suitable for different superconducting cable systems.

High Temperature Superconducting Power Transmission Cable Projects

Several HTS cable projects have investigated different aspects of these systems. The three separate HTS cable phases have been demonstrated by Southwire Co. with a counterflow cooling scheme for a 30-meter-long demonstration rated at 12.4 kV, 1250-A, 60 Hz.[4] Cooling was provided by a pressurized liquid nitrogen system operating between 70 K and 80 K using a counterflow cooling arrangement as shown in Figure 3c. The cable system provided 100% of the customer load, which was an early demonstration of the feasibility of this technology.

▶ ***continues on page 30***

A 600-meter-long demonstration project for the Long Island Power Authority (LIPA) was developed to operate at 138 kV, 2,400 amps, with a total power carrying capacity of 574 MVA.[5] This also used three separate cables, but the cooling arrangement was as shown in Figure 3a, where coolant is sent down two phases and returned through the third phase.

The triad, or three-in-one HTS cable configuration, was used in the Albany Project which installed a HTS cable with a 350-meter length in 34.5 kV and 800 Arms in the real power grid of the National Grid Power Company.[6] Recently, a 35-kV, kilometer-scale HTS cable demonstration project has been operating in Shanghai.[7] Table 3 is a partial list of other HTS cable projects around the world that extended the length, voltage and current-carrying capacity of these cable systems.

Future of HTS Power Cables

The feasibility of using HTS power transmission and distribution cables has been demonstrated and offers advantages for certain applications over conventional cables. Reliability of the cryogenics and insulating vacuum are ongoing concerns that many have. The fault current capability of these cables is a feature not present with conventional conductors. Fault current limiting was demonstrated on a 25-meter prototype for the Hydra Project.[8] The 25-m HTS-FCL cable consisted of a three-phase (3-Φ) HTS Triax™ design with a cold dielectric between the phases. The HTS-FCL cable had an operational voltage of 13.8 kV phase-to-phase (7967 V phase-to-ground) and an operating current of 4,000 Arms per phase, which was the highest operating current of any HTS cable of that period. The 25-meter HTS-FCL cable was subjected to a series of cryogenic and electrical tests.

Another potential application of HTS cables would be for direct current (DC) applications, as discussed by Chowdhuri et al.[9] Comparing alternating current (AC) and DC superconducting cables, the power-handling capability of an AC superconducting cable is limited by the stability limit of the power system; the DC superconducting cable has no such constraint.

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the same return temperature. At 25% full, the vented hydrogen exit temperature was 36.9 K compared to 23.4 K at 90% full, accounting for a 33% increase in enthalpy absorbed by the boiloff gas). Even though the mass flow rate decreased from 2.43 to 1.84 slpm at 153 kPa constant pressure (a decrease of 32%), the net heat load didn't change (1.71 W at 90% full and 1.70 W at 25% full)

The results of these tests imply that determining a tank's performance with liquid hydrogen is much more sensitive to several key parameters than testing with liquid nitrogen. Accurate measurement of the temperature of the effluent gas as it vents from the tank should be required to fully account for all the heat coming into the tank. Additionally, properly accounting for the boiled-off liquid in the tank when testing with hydrogen and helium can also eliminate a possible source of error. Understanding the difference between boiloff and heat load going into the tank and the different environments that may cause within a tank, especially as a function of fill level, is a key aspect of operating the tank efficiently.

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Variable	Perlite LN2	Perlite LH2	Glass Bubbles LN2	Glass Bubbles LH2
Published boil-off flow rate (sccm) [2]	4142	20125	3001	13212
Published heat load (W) [2]	15.9	12.6	11.5	8.3
Heat of Vaporization (J/g)	199.2	446.1	199.2	446.1
ks Published (mW/m/K) [2]	1.63	1.03	1.19	0.68
Temperature at Tank top (K) [2]	100	43	100	43
Change in Enthalpy (J/g)	224	693	224	293
Adjusted Heat Load (W)	17.8	19.5	12.9	12.8
Adjusted k-value (mW/m/K)	1.84	1.63	1.35	1.08
% Change	13%	58%	13%	58%

Table 1: CESAT data. *Credit: Wesley Johnson, NASA Glenn Research Center*

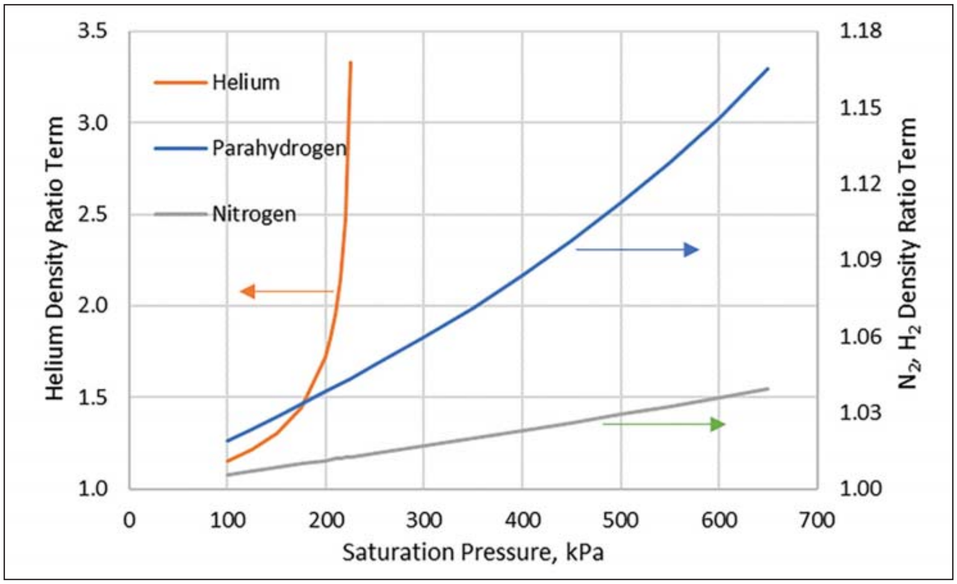


Figure 5: Density term adjustment factor for nitrogen, parahydrogen and helium. *Credit: Wesley Johnson, NASA Glenn Research Center*

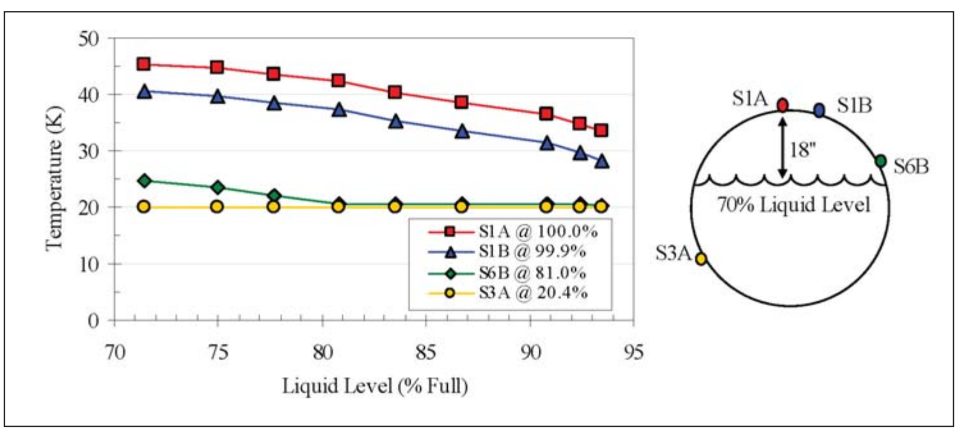


Figure 6: CESAT tank wall temperature profiles for liquid hydrogen boiloff tests with glass bubbles insulation (Figure 7 in Ref. 2). *Credit: NASA*

Cool Fuel

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

Weeping Over Weep Ports

The worst safety event we've had in the HYPER Center occurred back on a sunny morning in August 2016 when a bird flew into a substation and knocked out power to campus. Normally this wouldn't have been an issue, but on this particular morning we were prepared to do a liquid hydrogen test and had one of our experiments full. When the power shut off, so did our cryocooler, allowing heat to reach liquid and boil, rapidly pressurizing our storage tanks. Per standard, all of our pressure vessels have dedicated, redundant, pressure relief devices (PRDs) connected to hydrogen vent stacks in case of this situation. However, when one of our PRDs opened, a jet of hydrogen of unknown origin streamed up the back of some of our electronics.

Even though none of our experiments contained enough hydrogen to reach the lower flammability limit in the room, the uncontrolled hydrogen release prompted me to pull the fire alarm and get everyone out of the building. In the end, the hydrogen dissipated quickly, and the firefighters couldn't detect any, no fires started, and nobody got hurt. The question burning inside me was: How could we have missed this leak during our semesterly safety testing?

The cause of the leak remained elusive. There was nothing visbily wrong, and we couldn't find any leaks with our mass-spectrometer leak detector. So we recreated the event by testing our PRDs with cold helium – and found our leak to be a small hole in the side of a PRD body. The hole, known as a weep port, is designed to drain water from the downstream side of a PRD to limit ice buildup that could prevent a PRD from properly functioning. Weep port leakage is not an issue with most cryogens, but it certainly is with hydrogen. We couldn't detect this leak with the valve closed during normal safety testing: we had no need for such a hole as the experiment wasn't outdoors and the hole was so small (see photo) that nobody noticed it. How did nobody notice it? It's the size of a ballpoint pen head, and I train people new to plumbing and fittings. To prevent this from happening again, I banned PRDs with weep ports from the lab, switched PRD suppliers, and changed our safety testing procedures to require PRD testing every semester to be signed off by a second person. That should've been the end of this story.

A weep port is a small opening or hole in a pressure relief device (PRD) designed to allow the drainage of fluids, typically water, from the downstream side of the PRD. *Credit: Ian Wells*

Seven years later, a supply crunch forced us to order PRDs from different suppliers. Sure enough, during the commissioning of some new PRDs, we found leaky weep ports when operated. However, the students had followed lab policy and ordered valves without weep ports. What happened? The company that makes the PRDs had directly conflicting information on the ordering page – one place says to include a P in the part number for the weep port, another says to include a P for no weep port. We notified the company right away. The company is doing the right thing and has created a new line of PRDs specifically for cryogenic hydrogen – no weep ports and spring materials resistant to hydrogen embrittlement.

Facing this same problem seven years later sadly means there are likely many PRDs in service unknowingly with unnecessary weep ports that can result in significant leaks when operated. These leaks could be a significant safety concern depending on the type of cryogen used. Since PRDs are not designed for repeated operation, they are likely not tested routinely for the type of leakage we experienced – significant leakage through closed valves after less than five cycles.

We all know that if you're in a situation where you are relying on a PRD to operate, the last thing you need is another safety concern, like a hydrogen leak where one shouldn't be. If you're noticing periodic leakage from your cryogenic system, this could be the culprit. Please check for unnecessary weep ports on cryogenic PRDs, and that the spring materials are compatible with hydrogen, you may be glad you did.

Airbus ASCENDs to New Heights

by Airbus Communications Team

The ASCEND team used these test benches, designed and built in-house, to test the powertrain's components by exposing them to extreme temperature cycles. *Credit: Airbus*

This ASCEND-built electric motor receives power from superconducting tape which experiences next to no current loss, thanks to its very low resistance at cryogenic temperatures. *Credit: Airbus*

ASCEND, Airbus' superconductive powertrain demonstrator, has achieved a world first. Over the last three years, a small team of experts has developed and manufactured a cryogenic superconducting electric propulsion system purposely built to aerospace specifications.

In November 2023, ASCEND took its final step. The team successfully powered the 500-kilowatt powertrain at the system's core. It's an exciting breakthrough. In the quest for cleaner transportation, the marriage of hydrogen-powered fuel cells and high temperature, or cryogenic, superconductivity could be a game changer.

The current density of superconducting tape is 100 times that of a copper equivalent. Cryogenically freezing that tape enables it to carry electrical power from a fuel source to a propulsion system with practically no resistance. That's why, nestled inside a large warehouse just outside of Toulouse, France, Airbus UpNext's Advanced Superconducting and Cryogenic Experimental powertraiN Demonstrator (ASCEND) team has spent the last three years exploring the impact of cryogenic superconductivity on the electrical infrastructure that could power the next generation of low-carbon aircraft.

ASCEND concluded in November 2023 with the successful powering-on of a 500-kilowatt powertrain consisting of superconducting tape, a cryogenic motor control unit and cooling system and a superconducting motor. For context, getting the equivalent of today's city-hopping turboprops off the ground using electric power alone would require around eight megawatts.

Based on scientific research carried out by Airbus's Central Research & Technology, the powertrain was developed at UpNext's headquarters near Toulouse. Then, for the final stage of the project, Airbus engineers put it through its paces at Airbus's E-Aircraft System testing center in Ottobrunn, Germany, the largest facility of its kind in Europe. Culminating in the November power-on, the tests confirmed that it is possible to develop, assemble and control a complete superconducting and cryogenics chain built to aeronautical specifications. This successful power run—a first for cryogenic technology in aerospace—is a step closer to real-world conditions. How did the ASCEND team get here?

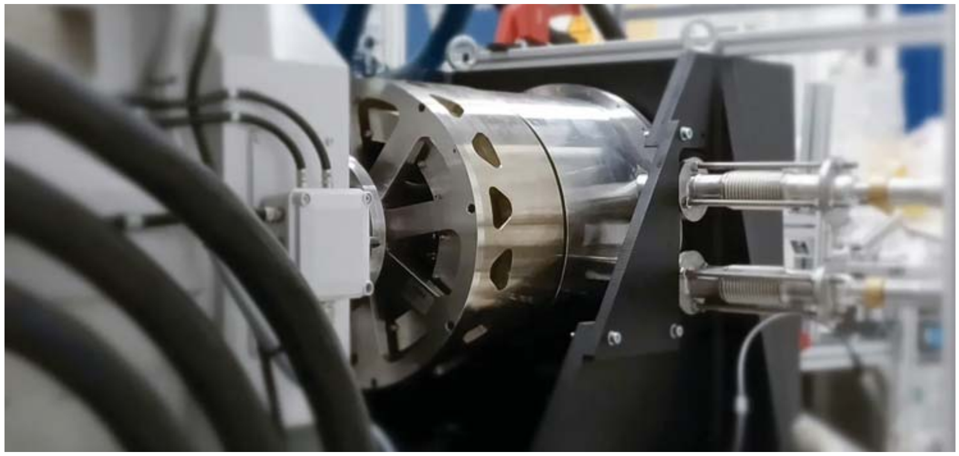
Superconducting technology may seem like science fiction, but it has been around for decades. Today, it is mainly used in medical imagery scanners, scientific experiments requiring a high magnetic field, such as CERN's Large Hadron Collider or ground transportation for electricity. However, testing facilities on the open market are few and the international ecosystem is immature. "The technology we need already exists," says ASCEND Project Head Ludovic Ybanez.

As Airbus's innovation lab, UpNext does things differently. Given the freedom and flexibility of a start-up, ASCEND's engineers – who divide their time between UpNext's Toulouse headquarters and Ottobrunn – hand-built the test bench environments with their German colleagues. You'll find some of these unassuming white boxes in a small backroom inside that Toulouse warehouse. While they may look simple from the outside, the boxes house complex systems.

At about a meter and a half tall and resembling an outsized domestic appliance, each of these homemade devices is where the ASCEND team tests how superconducting materials perform when exposed to an aircraft's thermal cycles. The electrical resistance of such materials becomes zero when exposed to extremely low temperatures, usually below -170 °C. That might seem very cold, but liquid nitrogen, widely used in industrial processes, is around -200 °C. The powertrain components are exposed to repeated extreme thermal shock tests within these environments to determine the potential impact of cryogenics on the performance of electrical propulsion systems.

Conventional electric powertrains require a high voltage to limit power loss. On board an electric aircraft, a superconductive powertrain could reduce voltage and practically eliminate losses, while keeping the weight and size of the overall system in check. The conditions for superconductivity would be created by the same cryogenic process used to maintain liquid hydrogen on board the aircraft at -253 °C, where the hydrogen is used to generate power through electrolysis inside a fuel cell.

After a halting start, the aerospace superconductivity ecosystem is maturing. As the ASCEND chapter closes, another opens. The race is on to mature and accelerate the technology in time to meet Airbus' ambition of flying a hydrogen fuel-cell-powered aircraft by 2035. **www.airbus.com/en**



The ASCEND powertrain drove this superconducting electric motor during a successful power-on at Airbus's E-Aircraft System testing facility in Ottobrunn, Germany. *Credit: Airbus*

Airbus UpNext engineer Reda Abdouh peers into an ASCEND superconducting cryogenic test bench. When the liquid nitrogen it contains is released, the sudden chill causes air around it to condense. *Credit: Airbus*

The Airbus UpNext team built their own electric demonstrator motor. ASCEND has shown it is possible for a superconducting powertrain to create a major power shift in electric propulsion, from several hundred kilowatts to multi-megawatts. *Credit: Airbus*

Danaher Delivers Sub-Kelvin Pony Cryostat to Argonne

by Charlie Danaher, President, Danaher Cryogenics

Scientists should spend their efforts on research, not on infrastructure! Scientists often need a reliable source of sub-kelvin cooling. Historically, because no reliable provider of such systems existed, many scientists were resigned to build their own. No longer.

Identifying this unmet need in the science community, Danaher Cryo stepped up to offer several elegant solutions. Teaming with Chase Research Cryogenics (CSA CSM), Danaher has established a line of sub-kelvin cryostats that provide long-awaited, convenient solutions. One such system is the Model DC2 Pony cryostat that Danaher recently delivered to Argonne National Laboratory (ANL) (CSA CSM). The Pony incorporates Chase's CC4 cooler, which provides continuous sub-kelvin temperatures.

The Pony cryostat hosts a Cryomech PT405 Pulse Tube cryocooler, generating intermediate cooling stages at 50 K and 3 K. The Chase CC4 sorption cooler is a self-contained module that, unlike a dilution refrigerator, requires no gas handling system. Rather, operating the Chase cooler simply requires a handful of electrical connections for operating a series of heaters.

For comparison, dilution refrigerator systems typically consume at least twice as much lab space due to the required plumbing, including vacuum pumps, valves and all the associated complexity, electricity draw, etc. Lastly, the Pony cryostat, as with all Chase-outfitted systems, is immune from helium-3 mixture loss due to vacuum pump failure.

System Construction

The Pony's vacuum jacket is constructed from lightweight aluminum and is conveniently sized to ISO conventions.

Model DC2 Pony cryostat delivered to Argonne National Laboratory. *Credit: Danaher Cryogenics*

In order to offer the user maximum flexibility, many standard ports are included in the 300 K top plate. And the 50 K and 3 K stage plates include many customizable ports for wiring, etc. To thermally protect the cold space, nickel-plated aluminum radiation shields are employed. Stage plates are suspended by slender but rigid SST struts. To maximize thermal conduction, all components at or below 4 K are made of gold-plated copper. In order to minimize mechanical vibrations, special copper braid assemblies are employed to attach the pulse tube to the corresponding thermal stages. In the experimental space, a large (20-mm-diameter) cold plate is provided for users to install their devices. Further, provisions are included for adding a 1 K radiation shield.

HorsePower Software and Control System

Danaher's HorsePower software controls the cryostat, including automating the cooldown, warmup, data acquisition and user interface. Using the HorsePower control system, via a touch screen, the user can command a pumpdown and cooling cycle with a single push of a button. All the while, they can monitor and control the system through a network interface. For a rapid system warmup, the user simply selects the warm-up option, and current is delivered to high power heaters on the cryostat stage plates. To provide ample experimental space and provisions, the Pony offers a Kevlar suspension.

By implementing Kevlar, the Chase cooler is protected from any of the typical stresses associated with attaching experimental masses directly to the cooler. Additionally, the Kevlar suspension allows for large masses to be suspended and cooled, masses larger than would ever be considered to be attached directly to the Chase cooler.

HorsePower software allows the user to regulate the temperature of the sample plate anywhere between ~0.9 K and 4 K. Without any elaborate control methodology, a stability of ~+/- 25 µK is readily achievable.

Tool-Less, No-fastener Vacuum Jacket Attachment

The opening and closing of a cryostat is always more burdensome than it needs to be. The proprietary design of the Pony brings a welcomed convenience. No tools are required, nor are any fasteners removed (and possibly lost!). Rather, the vacuum jacket has a bayonet (patent pending) feature on the interface between the

▶ *continues on page 38*

vacuum jacket and the cryostat chassis. The result is that a single operator can quickly and easily open or close the cryostat. The vacuum jacket is simply lifted and rotated into place, and then cam-levers are actuated to create the vacuum seal.

Argonne National Laboratory Planned Use of Device

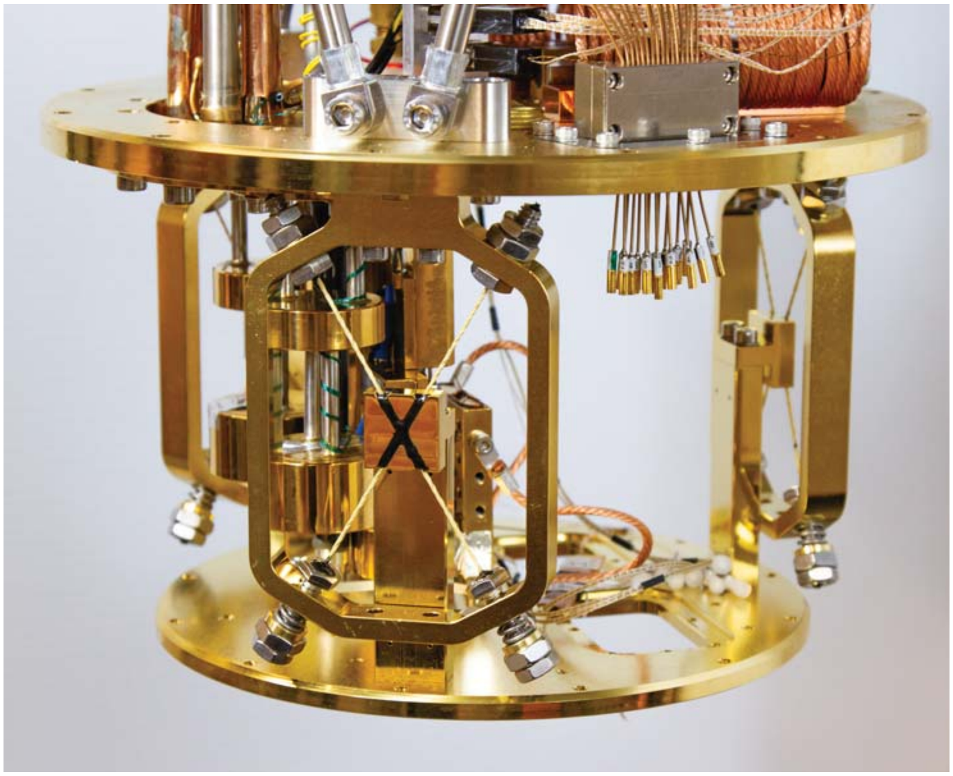
The primary purpose of the Danaher cryostat at ANL will be to test and characterize superconducting nanowire particle detectors, mostly focusing on nuclear physics applications. More specifically, due to the cryostat's large experimental space, the system will be used to test full wafers (prior to dicing) and gather statistics on the array of chips present. Subsequently, the wafer will be diced, and the selected chips will be used for experiments on a beamline.

Moving the Science Forward

Scientists seek to develop a charged particle detector. During experiments at accelerators, one of the byproducts of the particle collisions is a whole segment of particles not typically detected. However, there is much to learn from these generated, charged particles. Such as the origin of a proton's mass and distribution function. Many such mysteries can be solved by the ability to place a cryogenic particle detector deep inside an accelerator. The Pony cryostat may well be instrumental in this quest.

Additional Offerings by Danaher Cryogenics

The Pony cryostat is just one member of an extensive family of cryostats offered by Danaher Cryogenics. Other Chase coolers and their associated cooling performances include GL4, One-shot 1 K; GL7, One-shot 300 K; CC7, Continuous 300 mK; GL10, One-shot 225 mK; and CMD, Continuous 85 mK. Additionally, these family members fall into three chassis sizes: Mini, Standard and Major. This allows the user to select the system that offers the proper amount of experimental space, somewhat independent of the desired base temperature.



Model DC2 Pony cryostat Kevlar suspension and 1 K stage plate. *Credit: Danaher Cryogenics*

System Integration, Custom Solutions, and Developments

Danaher Cryo is equipped to outfit any cryostat with added features, including instrumentation wiring, fiber optics, experimental field magnets, etc. Additionally, Danaher Cryogenics is partnering with the University of Colorado and NIST laboratories in Boulder, Colo. to commercialize the Adaptive Cooling Technology (ACT) Pulse Tube invention. This product offers promise in the quest for more rapid and efficient cryogenic research. By speeding up system cooldown speed, and doing it without expending more energy, ACT will facilitate quantum research and development.

In support of the commercialization of the ACT invention, Danaher Cryogenics was recently awarded a $50,000 Translational Seed Grant from Colorado's Office of Economic Development and International Trade. This grant will help accelerate the progress on this exciting technology. Lastly, Danaher Cryogenics was selected to participate in the Innosphere Ventures incubator program for 2024. This program offers mentoring for startups in the high-tech field. **www.danahercryo.com**.

Model DC2 Pony cryostat with vacuum jacket and radiation shields removed. *Credit: Danaher Cryogenics*

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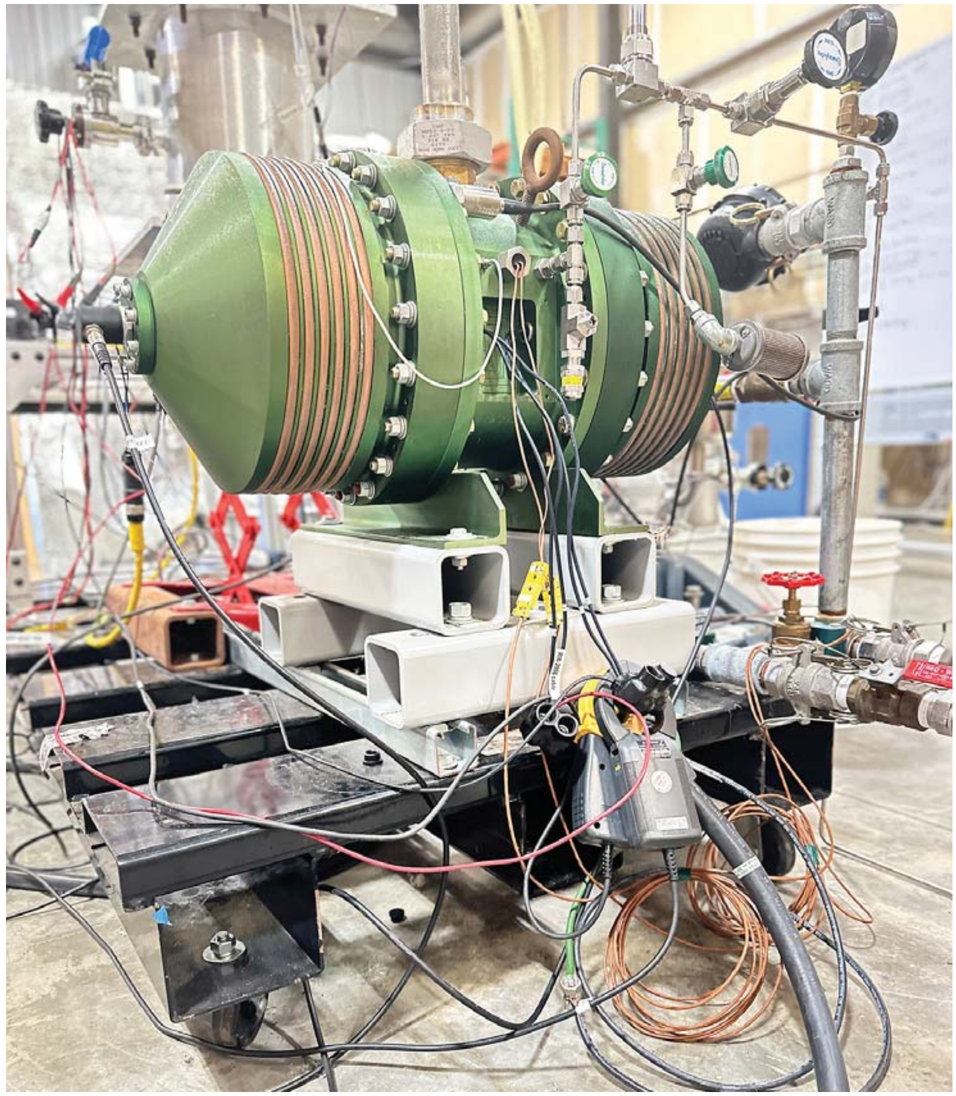
RIX Liquid Oxygen Generation Plant Supports US Navy's Newest Aircraft Carriers

by Gregg Baldassarre, Director of Business Development, RIX Industries



Navy testing criteria encompasses extensive shock, noise, and vibration tests, as well as power quality analysis. The RIX Industries' LOX system is validated to MIL-S-901D and also passed the Navy's extreme builders and acceptance trials performed at sea. *Credit: RIX Industries*

Aircraft carriers use highly concentrated gaseous and liquid oxygen for aviation and medical applications. These legacy systems consume large amounts of valuable ship space and require constant attention and adjustment to meet purity and production rates. With the development of USS *Gerald R. Ford* (CVN-78) – the "first-in-class" nuclear-powered aircraft carrier designed to replace the aging Nimitz-class carriers in service for over 50 years – the Navy and its contracted partners determined an opportunity for improvement. By implementing a modern liquid oxygen plant in the new Ford-class fleet design, the Navy could achieve its key goals of reducing cost of ownership, decreasing operational manpower, and significantly reducing overall maintenance demands.

Early in the vessel's development process, the Navy, in conjunction with Huntington Ingalls and Northrop Grumman, recognized that traditional liquid oxygen-generating systems were very difficult to operate, required routine maintenance, and consumed large amounts of energy. Many legacy production plants utilize fractional distillation column technology to produce high-purity oxygen and turbo Brayton cryogenic plants for liquefaction. In addition, each plant typically takes 20 or more hours to reach stability, an unacceptable amount of time for the Navy to reach operational readiness.

The RIX Solution:

To meet the need for improvement, RIX Industries, in partnership with Chart Industries/Qdrive, developed a state-of-the-art Liquid Oxygen, or LOX, plant utilizing a large Thermoacoustic Stirling Cryocooler (TASC) and a militarized Vacuum Pressure Swing Adsorption (VPSA) oxygen generator. Together, these sophisticated technologies promise benefits in safety, performance, and reliability. The system operates at 50psi, liquefies oxygen at approximately 100 K, and operates autonomously to start liquefying LOX in under 20 minutes.

The TASC consists of three (3) coldheads that have absolutely no moving parts. The compressor, or Pressure Wave Generator (PWG), utilizes two 10kW linear reciprocating motors opposed to each other, cancelling vibration and reducing noise, another significant advantage for naval installations. The motors feature flexure bearings that do not require lubrication, and the pistons utilize non-contact clearance seals that eliminate wear, creating an efficient, maintenance-free design. In addition, the size/weight of the RIX cryocooler is approximately 50% the size of its predecessor and the TASC is impervious to ship movement.

"I've not experienced a better example of teamwork during the development of this system," says Jerry Stultz, former director of DOD/Navy Programs and current Chief Operations Officer at RIX. "We dramatically reduced the size and weight of the plant while satisfying the ship's production and crew member reduction requirements. It's truly satisfying to participate in building an increasingly bright future for the US Navy's aircraft carrier fleet."

Rigorous Testing:

All Navy-approved shipboard equipment must pass a series of rigorous tests that prove the equipment is suitable for extreme use in mission-critical scenarios. Testing criteria encompasses extensive shock, noise, and vibration tests, as well as power quality analysis to ensure signals generated by the equipment do not interfere with other critical shipboard systems. During a particular naval shock test, (MIL-S-901D) the complete RIX system was subjected to multiple shock episodes, with the highest test imparting an impressive 80-Gs of acceleration directly on the cryocooler. Although it was not required to operate after this test, the TASC not only survived with very little damage, but it was able to reach cryogenic temperatures in 10 minutes and LOX liquefaction temperatures in 20 minutes. The RIX system also passed the Navy's extreme builders and acceptance trials performed at sea.

Conclusion:

Historically, startup and operation of legacy liquid oxygen production plants deployed on Navy aircraft carriers and hospital ships required highly trained personnel. Today, RIX Industries provides a fully autonomous system that starts at the push of a button and produces liquid oxygen in 20 minutes. The RIX liquid and gaseous oxygen production plant also uses maintenance-free cryogenic cooling technology and provides an intuitive user interface that communicates with other shipboard machinery systems. The RIX LOX plant's rugged, reliable design and extraordinary test results have validated its performance during mission-critical scenarios and in harsh environments. In fact, the USS *Gerald R. Ford* recently returned from an 8-month mission in the Mediterranean Sea after successfully conducting operations in the US Sixth Fleet. RIX is proud and honored to be part of that CVN-78 mission and future CVN missions. **www.rixindustries.com**

Validated for mission-critical performance, the RIX liquid and gaseous oxygen production plant features maintenance-free cryogenic cooling technology. The fully autonomous system starts at the push of a button, produces liquid oxygen in ~20 minutes and readily communicates with other shipboard machinery systems via an intuitive user interface. *Credit: RIX Industries*

The USS Gerald R. Ford - CVN 78's modern liquid oxygen plant is a lighter, high-performance system with no moving parts. Its efficient, maintenance-free design replaces traditional liquid oxygen-generating systems characterized by operating challenges, maintenance demands and high energy consumption. *Credit: US Navy*

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 **https://cryo.memberclicks.net/index.php?option=com_mcform&view=ngforms&id=2135545#!/**.

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RJT-100 4 K Cryocooler

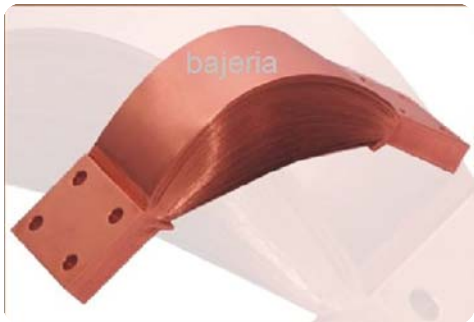
SHI Cryogenics Group

The SHI Cryogenics Group has added a unique product offering to its cryocooler line with the introduction of the RJT-100 4 K Cryocooler. The RJT-100 Gifford-McMahon/Joule-Thomson (GM-JT) Cryocooler is SHI's newest and highest-capacity 4 K cryocooler, with a capacity of up to 9.0 W at 4.2 K (50/60 Hz). Distinguishing itself from standard 4 K Gifford-McMahon and Pulse Tube cryocoolers, the RJT-100 showcases superior efficiency at 4.2 K. Its innovative design incorporates a Joule-Thomson cryocooler alongside a two-stage Gifford-McMahon cryocooler that pre-cools the helium gas. This unique configuration eliminates valve pressure pulsation, delivering unmatched temperature-stabilizing performance and reducing maintenance costs by minimizing the required number of systems for each application. The RJT-100 is available in two configurations. The standard stage configuration is ideal for superconducting radio frequency cavities, superconducting magnet applications, low-temperature systems and other applications requiring high cooling capacity at 4.2 K, while the optional recondensing configuration is tailored for helium recondensation. **www.shicryogenics.com**

ST Small Capacity Liquid Nitrogen Containers

Heyi

The portable liquid nitrogen storage container is a cost-effective and practical solution for the frequent transport and storage of biological samples. Crafted from a high-strength, lightweight aluminum alloy, this small dewar flask ensures safety, efficiency and portability. Its compact design, coupled with multiple layers of robust thermal insulation, minimizes evaporation loss. The lockable cover adds an extra layer of security for storing biological samples, while the protective jacket, equipped with straps, facilitates easy portability. The numbered canister system with goblets simplifies the storage process. With a two-year standard warranty and an impressive five-year vacuum warranty, this container guarantees reliability and longevity for the safekeeping of valuable biological specimens. **www.heyilabs.com**



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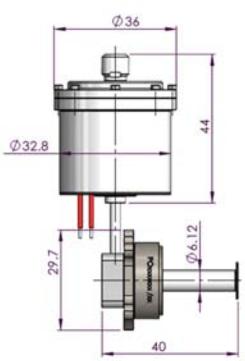
Bajeria Industries is a prominent manufacturer and exporter specializing in high-conductance solderless flexible thermal straps. Recognized by various names such as flexible thermal links, heat straps, cryogenic thermal braids and mechanical thermal straps, these innovative products serve as efficient, flexible heat-transferring devices. Renowned for their exceptional conductivity, these thermal straps play a crucial role in diverse applications, ensuring optimal heat management across various industries. Bajeria Industries continues to be a leading force in delivering cutting-edge solutions for thermal conduction needs, upholding a reputation for excellence in manufacturing and exporting these essential components. **www.bajeria.com**

Ionex Type Ag400

Molecular Products

Ionex Type Ag400 effectively eliminates gaseous hydrogen emanating from the steel container shell into the vacuum space. Cryogenic equipment manufacturers trust Molecular Products' Ionex® Type Ag400 as the secure solution for H_2 removal in their systems. Key reasons include its high performance, established as a hydrogen gettering solution with a working capacity of 20 to 25 Torr-liters per gram. Additionally, Ag 400 offers exceptional value, being a cost-effective alternative to palladium oxide (PdO) getters. Most importantly, it ensures supreme safety, especially in vacuum break conditions with low-temperature liquid hydrogen. Unlike PdO, Ag 400 prevents hydrogen auto-ignition when exposed to hydrogen, making it an optimal and reliable choice for cryogenic applications. **www.molecularproducts.com**



CryoTech Ltd.

Free piston Stirling cryocoolers traditionally use mechanical springs in compression and expansion units to match acoustic impedances and prevent overstroking. However, this method has drawbacks, including side forces, friction, debris generation, fatigue and complex anchoring. In contrast, CryoTech's innovative designs incorporate magnetic springs, providing a fatigue-free solution with minimal side forces and no debris generation. These magnetic springs can be easily customized for linear, softening, or hardening behavior, resulting in cost savings and a more efficient design. CryoTech is excited to announce the recent approval of its patent expander unit with magnetic spring for a split Stirling cryogenic refrigeration device (US 11,854,858B2) by the USPTO on December 26, 2023. This milestone underscores CryoTech's steadfast commitment to advancing cryogenic refrigeration technology. **www.cryotech-vision.com**

ZPC Model L

Zero Point Cryogenics

When extensive experiments or intricate wiring are essential, the ZPC Model L (L for large) emerges as the ideal solution. Meticulously designed to maximize cold time and minimize user intervention, its standard configuration includes three ISO63 feedthroughs for swift mounting of sizable wiring harnesses and five KF40 line-of-sight feedthroughs, all fully customizable. An extended-life cold trap integrated into the fridge eliminates the hassle of monitoring and refilling a liquid nitrogen cold trap. The fully automated touchscreen gas handling system is remotely accessible and controllable for added peace of mind. The Model L is also adaptable, offering upgrades for a cryogen-free magnet, magnetic shielding, or optical access. Inquire about Zero Point's expertise in additional customizations to tailor the Model L to your specific needs. **www.zpcryo.com**

Oxford Cryosystems' Evolution From Lab to Global Innovation Hub

by Jonathan Shaxted, Oxford Cryosystems

In the 1980s, John Cosier and Professor Mike Glazier from Oxford University pioneered the creation of an open-flow cooler, initially designed for exclusive use in Oxford University's Clarendon Laboratory. Its remarkable efficiency quickly gained recognition within the crystallographic community, leading researchers worldwide to seek similar systems. Responding to this demand, Oxford Cryosystems was founded in 1985 to provide cryogenic solutions globally. Over the years, their cryogenic devices have become integral components in laboratories, beamlines, radio telescopes, and various other applications.

A key element of these devices is their range of Gifford McMahon (GM) coldheads, which can also be supplied separately for integration into custom setups. Renowned for their compact size, rapid cooldown, and extended service intervals, these GM coldheads are particularly favored in radio telescopes to minimize thermal noise in receivers. Customized versions of the '6/30' and '2/9' coldheads have been adapted for use in harsh desert environments. These rugged coldheads feature insulated electrical connectors to protect against dirt and moisture, with over 100 units in use at the MeerKAT array in the Karoo, South Africa.

AC3 helium compressor. *Credit: Oxford Cryosystems*

Image 1: 0/12 and 0/40 single-stage cryocooler. *Credit: Oxford Cryosystems*

Image 2: 2/9 and 6/30 two-stage cryocooler. *Credit: Oxford Cryosystems*

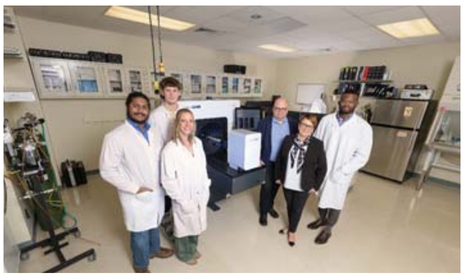
These rugged coldheads have been paired with a new AC3 air-cooled helium compressor, specially designed for desert use. With the capability to withstand 93% humidity up to 45 °C (113 °F), the AC3 includes four lifting eyes for easy mounting. It can simultaneously run two GM coldheads and communicates through a ruggedized Ethernet connection. The AC3, which was in its final phase of development last year, is set to launch commercially before the end of 2024.

Looking ahead, Oxford Cryosystems plans to expand the GM range with two single-stage coldheads, the 0/90 (90 W @ 77 K) and 0/200 (200 W @ 77 K), along with a new two-stage coldhead, the 12/60 (60 W @ 77 K / 12 W @ 20 K). A suite of new helium compressors will also be available, including the air-cooled (AC1) and water-cooled (LC1) models, providing smaller single-phase alternatives to the larger AC3 and K450. This expanded range marks the beginning of a new phase of innovation for Oxford Cryosystems.

Having emerged from Oxford's Clarendon Laboratory as a pioneer of cryogenic solutions for crystallography, and with a legacy of providing reliable and efficient cryogenic devices across the world, Oxford Cryosystems is poised for a future defined by innovation and expansion into new markets. **www.oxcryo.com**

People & Companies in Cryogenics

The **Beckman Institute**'s Molecular Imaging Laboratory has introduced a cutting-edge ultrahigh performance PET-CT scanner, made possible by support from the Roy J. Carver Charitable Trust. This state-of-the-art imaging system replaces the previous PET-SPECT-CT scanner and offers improved spatiotemporal resolution, stationary detectors and simultaneous multi-isotope PET imaging modalities. Funded by the University of Illinois and the Carver Trust, the scanner facilitates interdisciplinary research, including the dynamic tracking of tracer molecules, stem cell pathways and metabolomics. Beyond research, it is expected to attract faculty hires, benefit graduate-level instruction and foster collaborations with institutions like the Carle Illinois College of Medicine and the Department of Bioengineering. Interested researchers can utilize the PET-CT scanner by contacting the Molecular Imaging Laboratory.



From left: Researchers Michael Nelappana, Nicolas Dovalovsky, Catherine Applegate, Wawrzyniec Dobrucki, Iwona Dobrucka and Goodluck Okoro. Credit: Beckman Institute.

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Baker Hughes announced key milestones at its 24th Annual Meeting in Florence, supporting the hydrogen economy. The company unveiled a cutting-edge hydrogen testing facility for its NovaLT™ turbines and completed manufacturing and testing for hydrogen projects in Canada and Saudi Arabia. Collaborations include partnerships with HyET for advanced hydrogen compression and Green Energy Park for various aspects of the green hydrogen value chain. Lorenzo Simonelli, CEO of Baker Hughes, highlighted the significance of innovation and collaboration in achieving net-zero goals.

Baker Hughes announced hydrogen economy milestones in line with its broader new energy strategy. Credit: Baker Hughes

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South Korea's inaugural liquid hydrogen plant has been successfully completed. A dedication ceremony marking the achievement was held on January 31, 2024, at the **Doosan Enerbility** factory in Changwon, which is located 298 kilometers southeast of Seoul, unfolded. The facility stands as the country's pioneering liquid hydrogen production site, with a daily capacity of five tons. Participants took a comprehensive tour of the facilities during the ceremony.

Image: Yonhap News

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Acme Cryogenics (CSA CSM) marked a significant milestone as the team celebrated the extraordinary 46-year career of **Dave Edge**. Having joined the company in 1977, Dave has embodied commitment and leadership, playing a pivotal role in shaping the organization's growth and success. As he transitions into retirement, Dave's profound impact is a legacy characterized by resilience, innovation and pursuit of excellence, which has left an indelible mark on the team.

Acme Cryogenics honors Dave Edge. Credit: Acme Cryogenics

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Tokyo-based firm **Orbital** Lasers is set to tackle the growing issue of space debris with its laser-based technology, targeting development by fiscal 2025 and actual debris removal services by fiscal 2029. In collaboration with **SKY Perfect JSAT** and **RIKEN**, they have designed a payload using laser ablation to actively eliminate space debris. The approach involves vaporizing/ionizing the debris' surface, causing it to detumble and burn up upon reentry. Orbital Lasers plans to demonstrate a prototype for in-orbit debris removal in 2027, highlighting safety, cost-effectiveness and environmental benefits. Additionally, the company aims to offer Earth observation services using LiDAR laser technology for applications such as assessing vegetation density and supporting infrastructure design.

Meetings & Events

European Hydrogen Energy Conference
March 6-8
Bilbao, Spain
https://ehec.info

23rd International Cryocooler Conference
June 3-6
Madison, Wisconsin
https://cryocooler.org

CSA's Foundations of Cryocoolers Short Course
June 3
Madison, Wisconsin
www.cryogenicsociety.org/foundations-of-cryocoolers-short-course-2024

Cryogenic Operations 2024
July 17-19
Grenoble
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

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