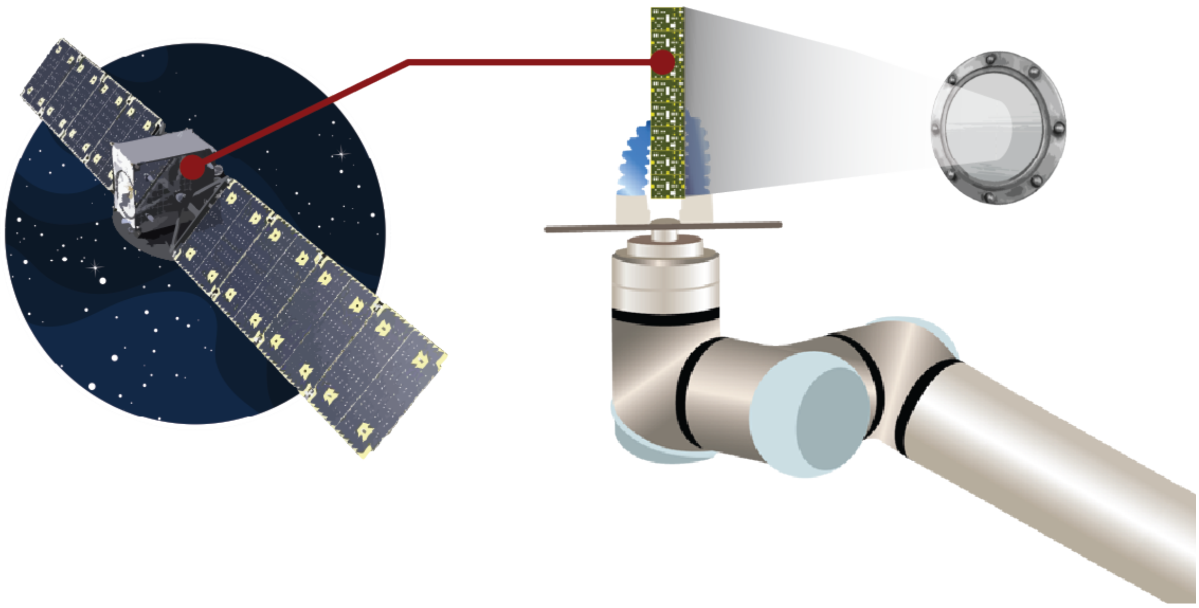
Hi ACTS | Helmholtz Innovation Platform for Accelerator-based Technologies and Solutions

IMPACT STUDY OF THE SOCIO-ECONOMIC BENEFITS FROM THE HI-ACTS USE CASE INITIATIVE

Standardised Station for High-energy Heavy Ion Radiation on Electronics



FINAL REPORT

know.space

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MEETING THE DEMANDS OF SPACE RADIATION ENVIRONMENTS...

Satellites and other space technologies must operate in an environment filled with high-energy heavy ion radiation from sources such as solar flares, cosmic rays, and trapped charged particles in Earth's orbit.[i] This radiation can cause significant damage to onboard electronics, as high-energy ions can pass through a spacecraft's outer shielding and interact with electronic circuit boards. The charged ions can release energy in the circuit boards and lead to short or long-term failures, potentially leading to a complete failure of the electronic component, which can result in mission failures. As these components are critical to spacecraft operations, ranging from navigation and communication to power and data processing, it is essential to understand how radiation affects their performance. To ensure reliable performance and mission success, space hardware must be designed to withstand and quickly recover from disturbances caused by high-energy particles, such as protons or heavy ions, passing through its electronic systems.[i]

Irradiation testing plays a vital role in space technology development by simulating the space environment on Earth, enabling engineers to assess component resilience, predict failure modes, and design systems with sufficient protection or redundancy – the practice of radiation hardening. Without such testing, the reliability and success of space missions would be severely compromised.

Ionising radiation, particularly galactic cosmic rays (GCR) and solar wind, poses a major challenge to the reliability of electronic systems. To test radiation resistance, components have to be exposed on the ground, before the flight, to simulated space conditions to ensure their performance and reliability. Whilst tests on custom-made electronic chips are traditionally performed at low-energy particle accelerators, the recent widespread use of Components-Off-The-Shelf (COTS) requires very high-energy and charged ions to test radiation hardness.

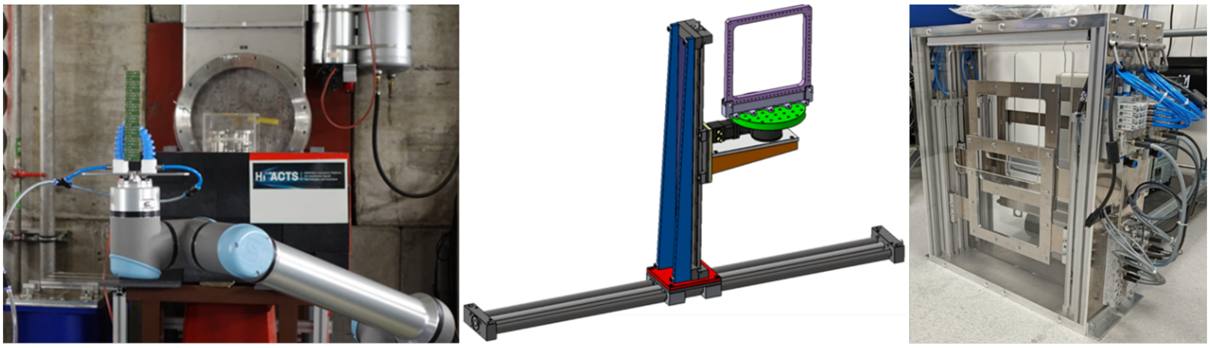
Testing electrical equipment against very high-energy heavy ion radiation demands highly specialised facilities, which are rare worldwide. The GSI Helmholtzzentrum für Schwerionenforschung GmbH, based in Darmstadt (Germany), addresses this challenge with its powerful heavy ion accelerator, originally developed for advanced scientific research. GSI has historically focused on fundamental nuclear and atomic physics research, while also pursuing applied studies in materials science, plasma physics, biophysics, and nuclear medicine.[ii] GSI's accelerator uses electric fields to speed up ions and magnets to steer and focus them through its beamline, accelerating the ions to nearly 90% of the speed of light (about 270,000 km/s).[iii]

...WITH UCI-SUPPORTED ENHANCEMENTS FOR ACCELERATOR-BASED ELECTRONICS TESTING

GSI has one of the few high-energy heavy ion accelerator facilities in the world, and one of only two in Europe, which can mimic the level of irradiation relevant for the space environment. Hi-Acts provided €68,000 to the institution to enhance this facility over 8 months by developing a standardised station for testing space electronics for radiation hardness. An ion-accelerator can precisely target and bombard equipment with high-energy particles, simulating the radiation conditions that spacecraft electronics must endure in orbit (and beyond). While GSI already had the beamline capability, the project was instrumental in developing a standardised station to facilitate industry use.

As part of the station, GSI installed a robotic arm, linear axes with a standardised frame (also used at CERN, UCL and others, where it is known as the European Space Agency (ESA) frame), modular target exchangers, and alignment lasers and cameras in the irradiation facility, Cave A of the heavy ion synchrotron SIS-18. By bringing together the various equipment (see **Error! Reference source not found.**), the station will be able to support a variety of applications without the need for customisation. For example, the robotic arm can hold non-standard size electronics, while the standardised frame on the linear axes will allow users familiar with other electronics testing facilities to mount their samples with increased ease and speed. Meanwhile, the modular target exchangers allow for additional beam manipulation options for more diverse applications, which adds flexibility, efficiency and user-friendly handling, as more complicated structures can also be mounted to them (including modulators).

Figure 1: Three of the new elements added to the standardised station funded under UCI



Robotic arm | Linear axes with standardised frame | Module range shifters

Source: GSI

Alongside the Hi-Acts UCI activity, GSI is also involved in other projects that support industry access to the facility, including the High-Energy Accelerators for Radiation Testing and Shielding (HEARTS) project[1] and the RADiation facility Network for the EXploration of effects for indusTry and research (RADNEXT).[2] Both projects aim to enhance industrial access to heavy ion irradiation facilities, such as GSI and CERN, by providing available beam time for industry use and improving the facility further.[iv, v]

CAPABILITY ENHANCEMENT FOR COMMERCIAL ACCESS

By developing a standardised station for irradiating electronics, the project supports a user-friendly testing facility ready for industry access.

To support GSI's broader efforts to attract industrial users and facilitate the transition from a facility predominately used by scientific researchers, GSI needed to enhance its infrastructure. A central element was the creation of a standardised station, designed for ease of use and minimal customisation. This included a robotic arm for handling non-standard electronics and a standardised frame on new linear axes, ensuring compatibility with testing setups that users are familiar with at other facilities.

With this setup, GSI conducted a pilot run (outside of the Hi-Acts project) involving companies from the USA, UK, and Germany. Participants successfully irradiated their electronics, supporting validation efforts toward space qualification. The pilot also served to trial new access models for commercial users, who may have different expectations and workflows than scientific users, demonstrating the viability of industry engagement.

This initiative marks a strategic shift for GSI, introducing a new capability focused on industrial space applications testing. While the facility has historically centred on biomedical and fundamental science

[1] The HEARTS project is funded by the European Union through the Space Work Programme of the European Commission.

[2] The RADNEXT project is funded through the European Union's Horizon 2020 research and innovation programme.

research, it can now tap into a new application area and potential revenue stream. However, access models for industry use are still under development. The pricing structure for the coming years will be based on corresponding operating costs. As demonstrated in the pilot runs, it can be assumed that GSI will be able to offer competitive prices compared to international alternatives. As informed by stakeholders, alternatives are currently priced between around €3,400 - €4,700 per hour of use.[3] [vi]

It is not yet possible to make concrete revenue forecasts for the coming years, as the availability of industrial beam time is still to be determined – a limiting factor. Furthermore, GSI is currently commissioning its new FAIR accelerator, which will connect to the GSI facility in future. This will lead to longer shutdown phases without user operation until 2028.

INCREASING EFFICENCY

In developing a standardised station, the facility can help save on personnel time and maximise beam-time, leading to cost savings and increased revenue opportunities.

To safely irradiate electronic components, it is essential that the tested device is securely mounted and precisely positioned throughout the exposure. The heavy ion beam must be delivered with high accuracy to ensure controlled and consistent results. Any instability can lead to uneven exposure, compromised data, or potential damage to both the sample and the beamline. A stable setup is therefore critical for both safety and experimental integrity.

Creating custom setups for each experiment is time-intensive, requiring careful design, alignment, and validation to ensure compatibility with the beamline. This process can delay testing and place a significant burden on GSI's engineering resources. The Hi-Acts project enabled GSI to develop a standardised station, providing a reliable, ready-to-use setup for a wide range of users. This reduces the labour and preparation time needed for GSI, improving facility efficiency and lowering the barrier for industry access, where speed and predictability are especially important.

The GSI team estimates the standardised setup can save GSI around 3 to 4 workdays per experiment, or more for complex cases, by removing the need for custom design and validation. In the first half of 2025 alone, a GSI stakeholder noted that over 10 users have already used the station, resulting in a collective saving of at least 30 to 40 workdays.

This efficiency has made it possible to support industry access without placing a heavy demand on scientific staff time. Importantly, moving to standardisation also helps to conserve beam-time, which is both costly and limited. Automated positioning can expedite sample alignment, while the modular design enables quick transitions between experiments with minimal reconfiguration.

With these improvements, the facility can support more experiments or samples in the same timeframe. GSI stakeholders roughly estimate an overall efficiency gain of 10% to 15% for GSI operations, enabling additional test campaigns / scientific experiments, many of which might not have been possible under the previous setup.

BRIDGING SCIENCE AND INDUSTRY

Expanding GSI's user reach to industry has increased commercial understanding for GSI staff, and has the potential to support two-way knowledge transfers in the future.

[3] This access fee range of €3,400 - €4,700 was estimated for the NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory, alongside an access fee of around €3,800 estimated for CERN.

Through the development and delivery of this project, the GSI team has gained insight into industry practices and expectations. Working directly with industrial partners during the pilot phase - including Astranis, a US-based company which builds geostationary communications satellites, and RadTest Ltd, a UK-based radiation testing and support company, has helped shift the team's perspective toward a more commercial customer-focused mindset. This shift was directly enabled through Hi-Acts funded activities, and can support the successful commercialisation of this new radiation testing service for industry users in the future. It also builds internal capabilities for more effective engagement with non-academic users in future projects.

While initiatives like RADNEXT and HEARTS have played a significant role in raising the profile of GSI and increasing industry awareness through various workshops, these reputational increases are partly enabled through the UCI-funded development of the standardised station.

Exposure to industry requirements has also allowed for reflection and further iteration on internal processes / the commercial access model, which will allow GSI staff to adapt their approaches to better align with the needs of commercial partners. This organisational cultural shift is a crucial step toward establishing the facility as a trusted and reliable partner for applied research and commercial irradiation services.

Looking ahead, there is also potential for two-way industry-research organisation knowledge transfers. As industrial users become more involved, their willingness to share challenges, methods, or feedback could lead to deeper collaborations and mutual learning. Such engagement may unlock new opportunities for scientific research informed by real-world application needs, while offering industry users access to cutting-edge expertise and infrastructure. This convergence of scientific and industrial perspectives could strengthen both communities and support the long-term sustainability and relevance of the facility.

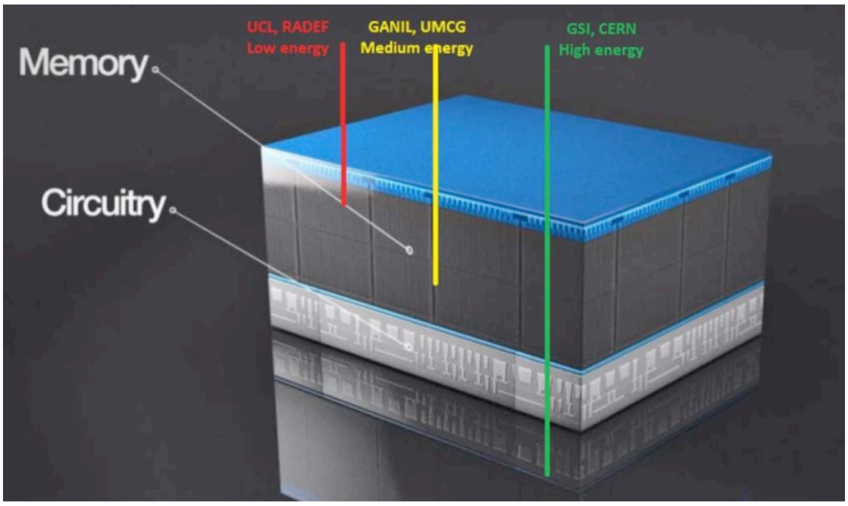
LOWERING BARRIERS TO ACCESS FOR INDUSTRY

By providing access to very heavy ion radiation for industry, GSI has increased the international capacity of this specialised testing, enabling faster innovation for the space sector.

Globally, there are only a handful of facilities offering similar capabilities, such as the NASA Space Radiation Laboratory (NSRL) at the Brookhaven National Laboratory in the USA and the CERN Highly-Accelerated Mixed Field Facility (CHARM) at CERN in Switzerland. Both of these facilities experience high demand. Through GSI providing an alternative test facility, availability of beam time for industrial users significantly increases. This can help drive product development, supporting the acceleration and growth of innovation in the European space sector.

GSI's irradiation testing also helps reduce cost and technical risk. Many companies aim to use commercial off-the-shelf radiation-hardened chips, but without access to a facility capable of penetrating deep into electronic packages, they would need to physically de-lid or thin the chip, which carries a significant risk of damaging or destroying these high-value parts. A pilot-user noted that they can cost anywhere from €8,500 (US$10,000) to €42,000 (US$50,000) each. The ability of GSI's facility to perform precise deep-penetrating irradiation without the need for such destructive preparation eliminates that concern (see **Error! Reference source not found.** for a comparison of various European facilities and their penetration capabilities). Testing can be conducted on fully assembled boards, preserving the integrity of the components and removing a major financial and technical barrier.

Figure 2: Penetration capabilities of ions with various energies at European facilities in the context of a 176-layer FLASH memory



Source: GSI and EETimes [vii,viii]

By making these testing services more affordable and more accessible, GSI is helping to open space electronics development to companies of all sizes. In particular, increased access to satellite validation and component testing supports shorter development cycles and reduces time-to-market. For companies working within limited funding windows, this kind of efficiency can mean the difference between staying on track or missing key market opportunities. Ultimately, by filling a critical infrastructure gap, GSI is helping accelerate innovation in the space sector and possibly enabling broader participation in space missions. Satellites that undergo irradiation testing can serve various purposes, from communication to Earth observation. These applications offer significant benefits for the planet, such as climate monitoring and support for global banking systems.

ENHANCING EUROPEAN COMPETITIVENESS

By enabling industry access to very heavy ion beam time, UCI funding has enabled GSI to position itself as key infrastructure in Europe, supporting German and European industry and contributing to European innovation goals.

This project has positioned GSI as a leader in advanced space environment testing, significantly enhancing its competitive edge and reputation within the European research and innovation landscape. Notably, GSI is now one of the first facilities in Europe to offer testing under simulated Galactic Cosmic Ray (GCR) conditions. GCR represent a continuous, low-dose background radiation environment composed of high-energy particles from outside our solar system. These conditions are particularly relevant for long-duration space missions, such as deep space probes or lunar infrastructure, and replicating them is technically challenging.

Prior to this project, space companies might have been unaware of GSI's potential for radiation hardness testing. One pilot user noted that they had searched in previous years for heavy ion test facilities and had found GSI by chance when searching for alternatives in 2025. The standardised station, combined with the pilot initiative, has increased the visibility of the facilities. While the pilot initiative was not funded through Hi-Acts, pilot users would not have had access to the facility without the standardised station, allowing for a degree of attributability to the UCI funding.[4]

[4] The facility's competitive testing offering has also expanded with the addition of the heavy ion microprobe, developed under a separate UCI project titled *Microprobe 2.0*. This project will enable users to conduct highly targeted fault analysis and material studies, using a finely focused ion beam with spatial resolution down to 500 nanometres. This capability is particularly valuable

GSI noted that the standardised station project lowers the barrier to access for small and medium-sized enterprises (SMEs), which is critical in the German economy, where SMEs make up a significant portion of the industrial ecosystem, accounting for 55% of the country's employed population.[ix] Additionally, offering commercial access to heavy ion testing within Europe could act as a key enabler for European space companies, taking away the need to travel to the USA (see Figure 2 for a comparison of European facilities). By supporting access to cutting-edge testing infrastructure, the facility may directly contribute to national and European innovation goals. It aligns with Horizon Europe's Pillar Two (Cluster 4) by advancing next-generation space technologies and strengthening Europe's competitiveness in space infrastructure.[x] It also contributes to strategic autonomy in space by reducing reliance on non-EU testing facilities and supports the EU Chips Act by reinforcing Europe's capacity to test and validate microelectronics.[xi] Making advanced services available to a broader user base is not only a technology transfer goal but also a strategic effort to support long-term economic growth and security for Europe.

In lowering barriers to access, the project also supports companies looking to spin-in to the space sector, reducing the costs and complexity of testing space electronics. The increased availability of such testing capabilities furthers this support, increasing accessibility which can help bring new players, ideas, and technologies into Europe's space ecosystem.

GSI stakeholders also noted that these achievements are expected to generate political goodwill, strengthening GSI's position for future funding and infrastructure development. With greater visibility, increased service offerings, and demonstrated value to both science and industry, GSI is now better placed to evolve as a national asset supporting space technology development, innovation, and economic resilience.

ATTRIBUTABILITY OF THESE BENEFITS TO HI-ACTS FUNDING

The Hi-Acts UCI funding was highlighted as a key enabler for supporting the direct industrial use of GSI's very heavy ion beam in Cave A. In the absence of funding, GSI stakeholders noted that they would not have developed the standardised station nor the capacity to support direct commercial access. Without the standardised station, the amount of labour required to prepare for each customer would make direct commercial industry access not possible. GSI also noted that the project was important for increasing the facility's visibility and for demonstrating to internal stakeholders the value of attracting commercial users.

Future impacts resulting from industry access to the facility, including potential knowledge transfers between industry and GSI scientists, can be attributed to Hi-Acts funding to a limited extent, as the facility could have potentially secured alternative support for such developments over time. GSI stakeholders noted that no immediate alternative funding sources were available at the time; however, the facility may have pursued other funding routes as they emerged. In the short term, the benefits to industry, such as faster access to irradiation testing and associated time savings, are highly attributable to Hi-Acts.

The facility and the region's reputation increased as a result of the project, though it is important to acknowledge that the Hi-Acts funding is part of a larger initiative to support industry access to advanced scientific facilities. As with HEARTS and RADNEXT,[5] this UCI-funded project is expanding GSI's user community, and developing an access model to include industry alongside scientists and researchers. Nonetheless, the Hi-Acts platform has been an essential enabler to support industry

for identifying the precise origin of faults in microelectronics, which is essential for both failure analysis and component qualification.

[5] Funded under separate European Union initiatives.

access by increasing the efficiency of testing setup, minimising the technical and financial risks of increased testing duration and complexity.

IMPACT SUMMARY

Standardised Station for High-energy Heavy Ion Radiation on Electronics

GSI	Industry	Society
Jobs and Skills: • Increased understanding of industry needs and business know-how for GSI staff • Potential for further cross industry-academia knowledge transfer **Competitiveness and Reputation:** • International standing: leveraged reputation as one of the few facilities internationally to provide access to very-heavy ion radiation testing • Visibility: raised profile of the services available at GSI **Technical:** • New services: Standardisation station facilitates industrial access which was not previously available • New industries addressable: Commercial space sector with international market access already established in the UK and USA, as well as domestic use from Germany • Additional use cases: Scientific applications including biomedical, with over 10 experiments demonstrated in 2025 at GSI **Commercial:** • Increased revenue opportunities • New potential users: Unlocking full operational potential, from no prior industry users to scalable growth	Enables easier access internationally to crucial testing and validation infrastructure for space electronics. Relevant for: • Economy • Knowledge & Technology • German / European Competitiveness, sovereignty & resilience • Improved attractiveness of the local area / Germany / Europe for investment • Regulation & policy-making	Scaling international testing enables faster fault finding, quicker validation, and reduced time to space launch, while supporting EU policy / strategy. Relevant for: • Scientific knowledge • Environment & sustainability • National security & safety • Governance

Granularity of evidence

Attribution to UCI support

[i] Brookhaven National Laboratory (n.d.). *Towards Safer Spaceflight.* Available at: https://www.bnl.gov/nsrl/

[ii] GSI (n.d.). *Research at GSI – An Introduction.* Available at: https://www.gsi.de/en/researchaccelerators/research_an_overview

[iii] GSI (n.d.). *Accelerator.* Available at: https://www.gsi.de/en/researchaccelerators/accelerator_facility

[iv] RADNEXT (n.d.). *About RADNEXT.* Available at: https://radnext.web.cern.ch/#about

[v] HEARTS (n.d.). *High-energy heavy ion testing for space in Europe.* Available from: https://hearts-project.eu/

[vi] HEARTS (n.d.). *HEARTS@CERN 2025 user campaign*. Available from: https://indico.cern.ch/event/1548956/

[vii] This image is courtesy of the Hi-Acts Academy presentation *Radiation Hardness Testing at GSI and HZB – Unique Capabilities to Test Modern Electronics,* which utilises an image courtesy of Micron Technologies (see below)

[viii] EETimes (2020). *Micron Leapfrogs to 176-Layer 3D NAND Flash Memory.* Available at: https://www.eetimes.com/micron-leapfrogs-to-176-layer-3d-nand-flash-memory/

[ix] Statistisches Bundesamt DESTATIS (2024). *Shares of small and medium-sized enterprises in selected characteristics 2022 by size class.* Available at: https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Unternehmen/Kleine-Unternehmen-Mittlere-Unternehmen/Tabellen/wirtschaftsabschnitte-insgesamt.html

[x] Horizon Europe NI (n.d.). *Pillar Two.* Available at: https://www.horizoneuropeni.com/pillar-two

[xi] European Commission (n.d.). *European Chips Act.* Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en