HEAVY ION ACCELERATORS

Space Irradiation Beamline

User Guide

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NCRIS
National Research Infrastructure for Australia
An Australian Government Initiative

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About us

The Heavy Ion Accelerator Facility's Space Irradiation Testing Beamline (HIAF-SIBL) has been developed with the support of the Australian Space Agency at the Australian National University, Canberra. It provides charged particle radiation testing for equipment sent to space, including materials, solar cells and electronic boards and devices.

The HIAF-SIBL offers the highest-energy heavy ion space radiation testing facility in Australia. It provides Total Ionising Dose (TID) and Single Event Effect (SEE) testing for decapped electronics at the component level. This will provide quantitative assurances to the emerging Australian space sector for mission design and planning, especially regarding the use of commercial-off-the-shelf (COTS) components with no space heritage.

Our competitive pricing scheme (see *page 13*) is designed to make this testing accessible to companies of all sizes, ensuring our facility compares favourably both locally and internationally.

With HIAF-SIBL, we can emulate the space radiation environment to test your equipment under the conditions expected in orbit. Such testing presents the opportunity to reduce the risk of project failure as well as lowering the cost and complexity of space missions.

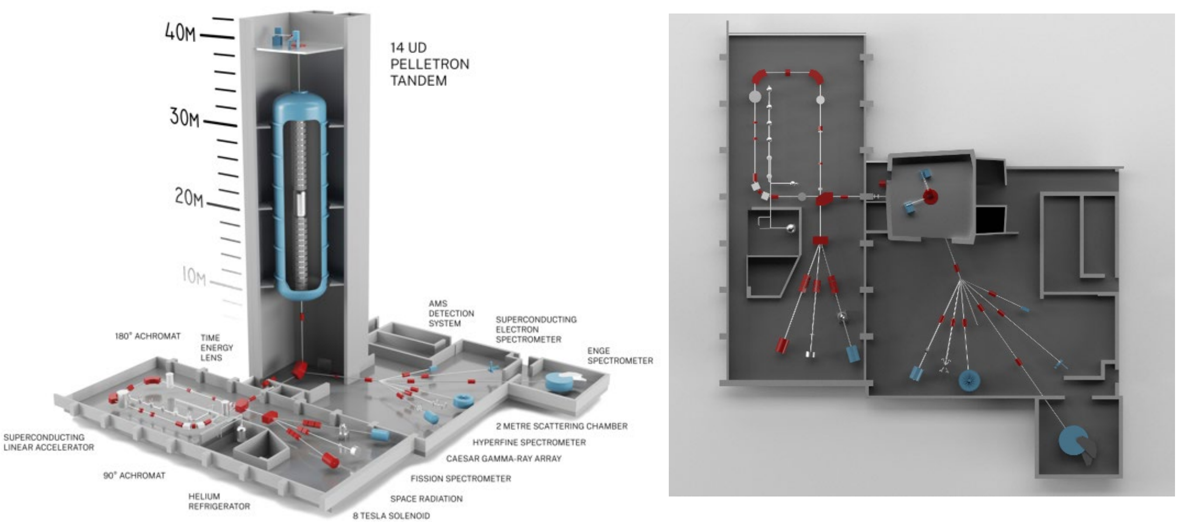


Figure 1: Schematic representation of HIAF

It is important to note that HIAF-SIBL does not provide a formal radiation certification. We provide a quantitative testing environment and work with you to test your components, but it is up to you to decide whether your equipment meets your mission requirements.

Background information

What is ionising radiation?

One of the characteristics of space is ionising radiation, which is radiation with sufficiently high energy to remove electrons from atoms (ionisation). These interactions can cause a range of upsets in your component or device, potentially leading to degradation of device performance or catastrophic device failure.

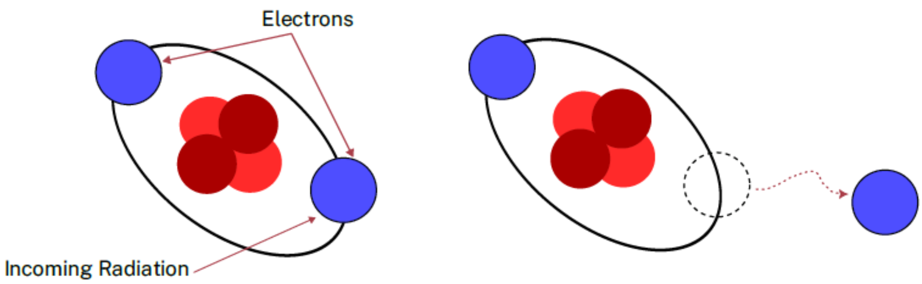


Figure 2. The process of ionisation

There are three different types of radiation: charged particles (ions), beta-particles (electrons), and gamma radiation (photons). While all these types of radiation have ionising effects, charged particle radiation can cause the most damage due to the larger mass and charge. At HIAF-SIBL, we test your component's sensitivity to the most damaging radiation it will be exposed to in space: charged particle radiation.

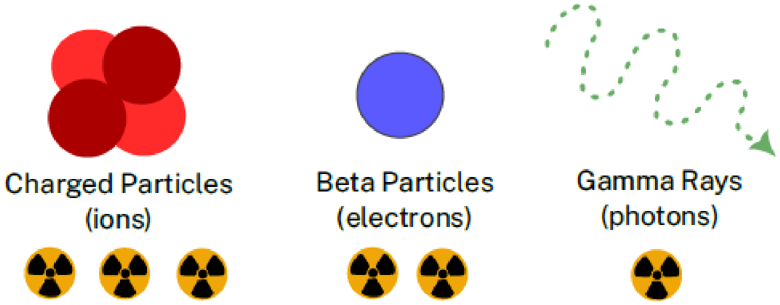


Figure 3. The different types of radiation in space

Where does radiation come from?

Charged particle radiation in space has three sources:

- Galactic Cosmic Rays (GCRs)
- Solar radiation from solar flares and coronal mass ejections (CMEs)
- Charged particles trapped in the earth's magnetic field (known as radiation belts).

Therefore, it is necessary to test your components under simulated space conditions to understand and quantify the risks posed by ionising radiation to your space mission.

How we use our facility for space emulation

Radiation testing at HIAF-SIBL is conducted under vacuum and allows users to analyse the two dominant orbital radiation effects: Total Ionising Dose (TID) and Single Event Effects (SEEs). These tests are conducted very differently so it is important to understand which is best for your needs. We are more than happy to discuss this with you.

Total Ionising Dose (TID)

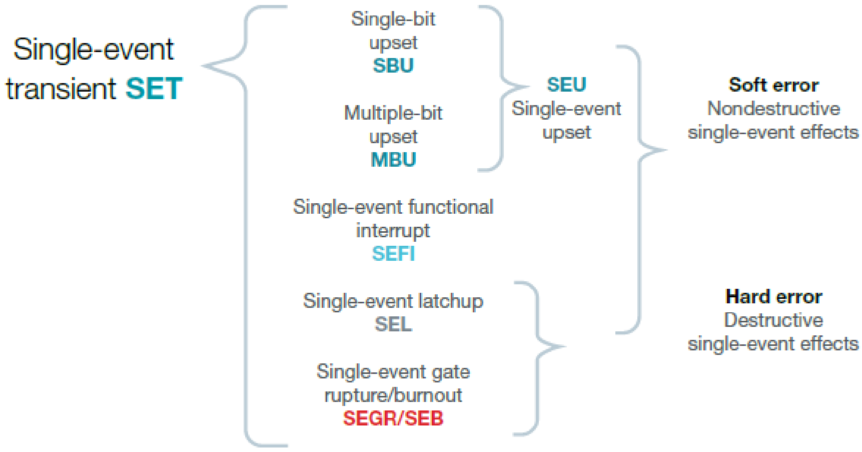
Total Ionising Dose testing at HIAF-SIBL is a process that involves irradiating the component with a certain radiation dose and comparing its performance before and after irradiation. TID testing is primarily associated with materials and solar cell testing, but electronic components can also be tested for the effects of TID. Material and solar cell testing can also include measuring energy losses in components by detection of the energies of the radiation that pass through the material.

If your component does not withstand beta or gamma radiation testing, it is unlikely it will withstand charged particle radiation testing. Presently there are no facilities in Australia to test your components for beta/electron radiation. Therefore, we recommend that you conduct TID testing of your component with gamma radiation before advancing to testing with charged particle radiation at HIAF-SIBL.

Single Event Effects (SEEs)

Single Event Effects (SEEs) arise from single highly energetic particles impacting your component and causing significant damage in very short periods of time. They are most necessary to consider for electronic components, as materials and solar cells are less likely to exhibit catastrophic damage from a single highly energetic particle.

SEEs can be categorised into nondestructive and destructive types. Nondestructive SEEs induce observable events or data corruption without harming the circuit component. Nondestructive SEEs encompass various types including Single Event Transients (SETs), Upsets (SEUs), Functional Interrupts (SEFIs), and some latch-ups (SELs), avoiding permanent damage. Destructive SEEs, however, irreparably damage circuit components, exemplified by Single Event Gate Rupture (SEGR) and Single Event Burnout (SEB) in power electronics due to higher currents and voltages.



Texas Instruments. (2019). *Radiation Handbook for Electronics*. Dallas, Texas, USA.

Figure 4. Different types of SEEs

Single Event Effect testing at HIAF-SIBL determines how single energetic particles contribute to upsets in your device. It commonly involves communicating with your device during irradiation to understand how it reacts to highly energetic particles. We have a range of vacuum signal feedthrough cable configurations (detailed on *page 12*) to enable communication with your device while under irradiation, enabling live testing of your component's performance in space-like conditions.

Arranging a test

It is important that we understand the purpose of your testing and what you hope to achieve, so that we can help you make the most of your time at HIAF. This guide will supply you with all the information you need to design a test with us.

Capabilities of HIAF-SIBL

The capabilities of HIAF-SIBL are as follows:

- Particle beams from protons up to 28 MeV in energy, to gold ions up to 350 MeV, with a comprehensive range of beam types and energies in between to provide desired Linear Energy Transfer (LET) values
- Beam intensities can range from 10 ions/cm^2/s up to 10^{12} ions/cm^2/s over a user-defined area
- An irradiation vacuum chamber that allows the testing of large components or several test boards within a maximum size of 250 x 200 mm
- Standard vacuum feedthroughs, including BNC, SMA, USB-A, RJ45 and DB 25, to allow communication with your device while it is undergoing testing
- A silicon ΔE-E telescope (i.e. two stacked silicon surface-barrier detectors) available for use with materials or solar cell testing to measure the number and energy of high energy ions.

Please note that tests are conducted under vacuum and thus components must be vacuum compatible.

We are here to help you design a test best suited to your mission requirements. To complete a test with us, please complete an Expression of Interest (EOI) form, which is available on our website at: https://accelerators.org.au/capabilities/space-irradiation-beamline-testing-components-for-space/.

More information on booking a test can be found on *page 13*.

Testing requirements

To complete the EOI form and start the process of designing your test, you will need to provide the following information:

- A description of your test identifying whether you require TID or SEE testing
- The desired beam species and energy (e.g. protons at 10 MeV)
- The desired total fluence (e.g. cumulative number in particles/cm^2 over what area)
- The desired beam flux, if necessary (e.g. 10^4 particles/cm^2/s over what area)
- The number of samples/components to test
- The dimensions of the sample/component
- The elemental composition of samples/components

  Any hazards associated with the samples/components
- The connection, if any, that will be required for communication with the device during testing
- Whether the components are vacuum compatible.

Please note that any materials that contain iron, such as stainless steel, are unable to be irradiated due to the long radioactive decay time if the iron is activated by the particle beam.

The following guide will help you acquire all the relevant information needed to answer these questions.

Technical data

Testing conditions at HIAF-SIBL are described by Linear Energy Transfers (LETs), flux and fluence. It is important to understand these values to determine the beam characteristics being irradiated onto your test component.

Linear Energy Transfer (LET)

LET is defined as the amount of energy that an ionising particle transfers to the material as it moves through it, measured per unit of distance. Energy is transferred by these particles largely through ionisation. While it is not necessary to provide us with a desired LET value, it is important to understand the concept, as it is a major factor in choosing the particle beam species and beam energy for testing. It can also help you understand how the radiation in space will affect your electronics.

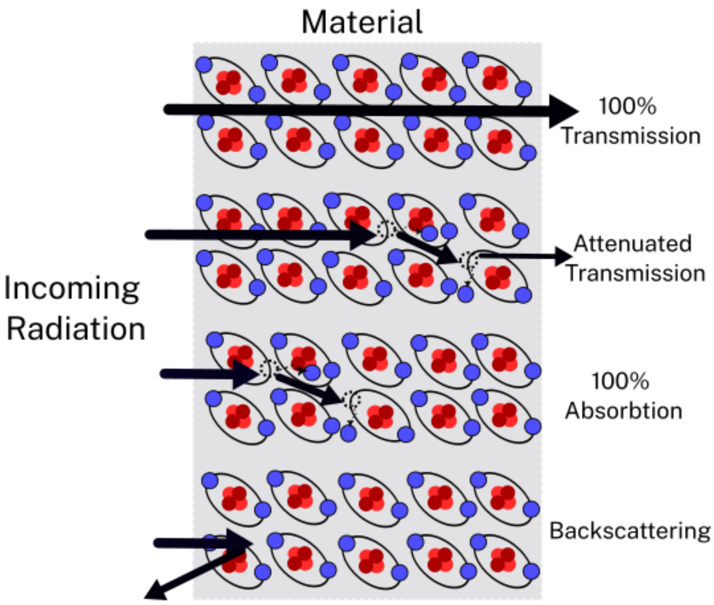


Figure 5. Radiation interacting with matter in different ways

The LET can provide information on:

- The stopping power, defined as how quickly the particle loses energy through a material. Higher LET values indicate that the particle loses energy faster while traversing the material resulting in a shorter distance travelled.
- How likely a particle is to ionise atoms in the material. Higher LET particles cause more radiation damage due to their higher ionisation potential and localised energy deposition.

When charged particle radiation interacts with matter, the particle initially loses energy slowly, and then more rapidly as its energy falls, when it approaches the end of its range. This behaviour is seen in the Bragg curve of the particle in question, which shows the LET as a function of the depth into the material. It indicates that the LET increases as it moves through the material, so unless a shield is thick enough to stop a particle completely, it will increase the LET and potentially cause more damage to the component. An example of the Bragg peak curve of a carbon particle is given below.

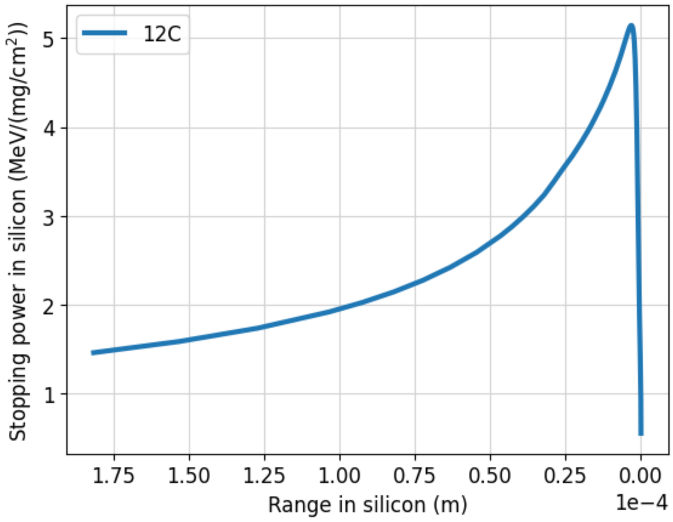


Figure 6. Bragg curve of carbon particle in silicon

LET technical data

The following table contains the details of the maximum energy beams available for a selection of species produced by the accelerator. The surface LET and range in silicon have been calculated for these beams using SRIM[1].

Table 1: Stopping and range of select ions available at HIAF-SIBL

Species	Max E (MeV)	Max E/A (MeV/amu)	Surface LET in Si (MeV/(mg/cm²))	Range in Si (um)
^{1}H	28.15	28.15	0.02	4372.00
^{12}C	98.15	8.18	1.48	175.58
^{16}O	126.15	7.88	2.64	134.32
^{24}Mg	172.63	7.19	5.76	92.62
^{40}Ca	228.35	5.71	15.59	53.87
^{58}Ni	279.60	4.82	27.67	46.03
^{63}Cu	279.60	4.44	30.08	42.42
^{93}Nb	311.80	3.35	26.74	51.13
^{197}Au	349.89	1.78	85.49	29.85

1.Ziegler, J. F., Ziegler, M., & Biersack, J. (2010). SRIM – The stopping and range of ions in matter (2010). *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 268*(11–12), 1818–1823. https://doi.org/10.1016/j.nimb.2010.02.091

Figure 7 shows the characteristic LET as a function of the range in silicon for a selection of beam species which can be produced with the accelerator. The LET and range were calculated with SRIM and cover the range of energies which can be produced by the accelerator.

[1]Ziegler, J. F., Ziegler, M., & Biersack, J. (2010). SRIM – The stopping and range of ions in matter (2010). *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 268*(11–12), 1818–1823. https://doi.org/10.1016/j.nimb.2010.02.091

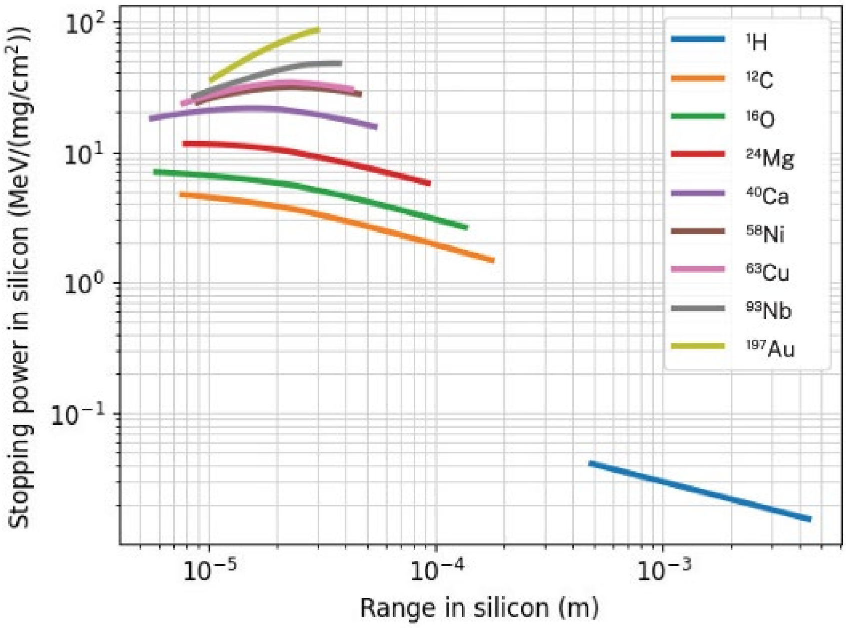


Figure 7. Partial Bragg curve for ions listed in Table 1

Fluence and flux

Fluence and flux are important terms to describe the intensity and dose of particle radiation your component may encounter in space.

In the context of HIAF-SIBL, flux refers to the number of particles incident on the sample area per unit of time. It represents the intensity of the particle radiation and indicates how quickly particles impact the component. A higher flux corresponds to a higher particle impact rate. Flux is measured in particles/cm2/s.

By extension, the fluence is equal to the flux multiplied by time and refers to the total number of charged particles from the selected beam species incident on the sample area. Fluence indicates the particle density in the space environment and is necessary to understand for testing. Fluence is measured in particles/cm2.

Similar to the LET information requirements, the fluence and flux required for testing will depend on your component's mission requirements.

Fluence and flux capabilities at HIAF-SIBL

The range of available flux values is from 10 ions/cm^2/s to 10^{12} ions/cm^2/s. This can vary slightly depending on the selected beam energy to remain within the safe radiation limits of the facility.

At HIAF-SIBL, there is no limit on total fluence you can test for. However, higher fluences require longer irradiation time and will extend the time needed for the test.

Decapping

We suggest testing decapped chips when you test with us. While it may be possible for our higher-energy proton beams to penetrate the sensitive silicon volume of the component, even with the epoxy capping, the reliability of this cannot be guaranteed. You will need to perform your own sophisticated modelling to account for the energy lost due to the additional material.

AMD Zen 2 EPYC 7702 server processor, before delidding

AMD EPYC 7702 after delidding, with remains of solder thermal interface material (TIM).

Decapping. (2024, June 6). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Decapping

Figure 8. Diagram of decapped electronics

Operations

Dimensions for testing

In addition to technical data requirements, the component must be compatible with our mounting design. If it is incompatible, you may need to design a mounting system to integrate your component with our setup.

The irradiation chamber allows the testing of large components or several test boards up to a maximum size of 250 x 200 mm. Positioning will be done with a translatable stage, which features three types of motion. It has remote control for horizontal and vertical linear motion and can rotate to tilt the sample board, changing the beam's incidence angle.

The irradiation area of the beam spot can range between 1 x 1 mm and 40 x 40 mm. With the moving test stage, the total possible irradiation area is 220 x 200 mm in 40 x 40mm increments.

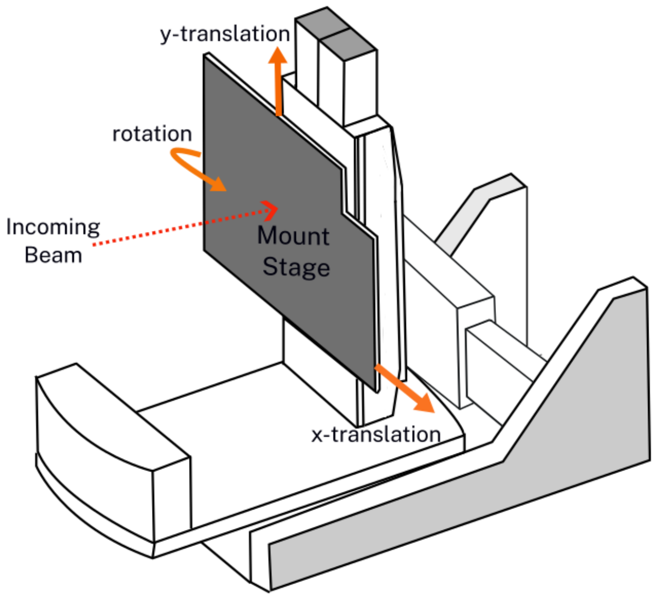


Figure 9. Moving stage in the irradiation chamber

Mounting information

At HIAF-SIBL, we have two existing mounting setups for use: a 20 x 20 mm sample plate designed for materials and solar cell samples, and a pinboard plate designed for electronic components.

Materials and solar cells

Our mounting structure for materials and solar cells consists of a mounting plate designed to fit fifteen 20 x 20 mm samples attached to the chamber stage. The attachment has a gap between the moving stage and the mount to allow room for the detectors.

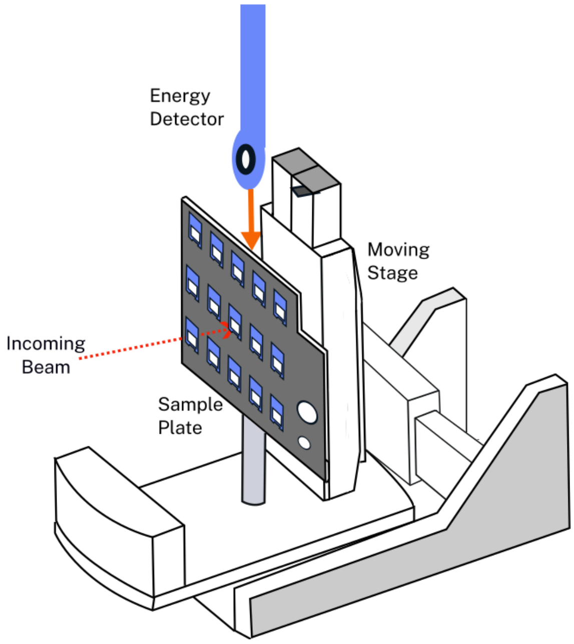


Figure 10. Material/solar cell plate mounted in the chamber with energy detectors

If your samples are smaller than 20 x 20 mm, the samples may not be able to be clamped down or could fall out of the through-holes. To avoid this, samples smaller than 20 x 20 mm should be mounted on a larger backing sheet/substrate. A detailed diagram of the mounting pattern can be made available upon request.

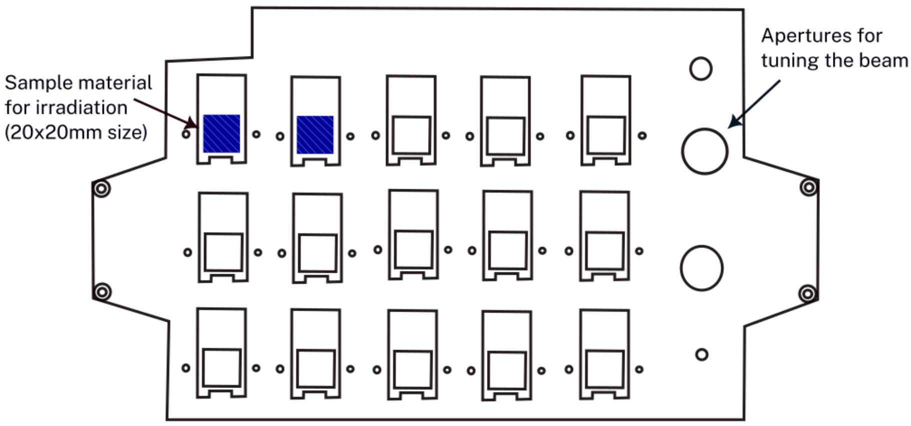


Figure 11. Mounting plate for material samples

If larger samples are required for testing, customers could construct their mount in consultation with the team at HIAF-SIBL. This may incur an extra cost.

Electronics

Our mounting structure for electronics acts like a pinboard with 25 mm grid spacings of M4 threaded holes to attach boards and components for testing. A detailed diagram of the mounting pattern can be made available upon request. This mount is incompatible with the use of energy detectors.

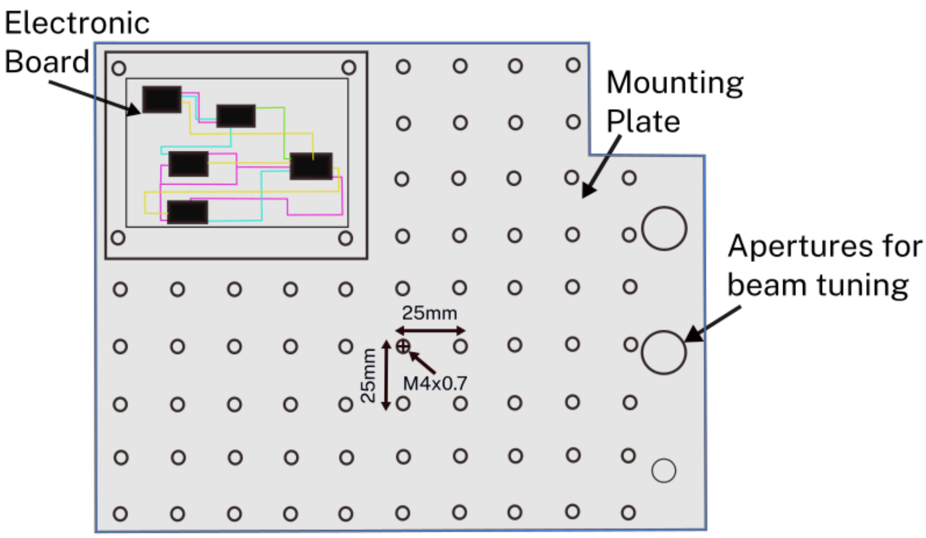


Figure 12. Mounting pate for electronic components

Users can mount their electronics directly onto the board, given that they have the correct spacing and screw hole size. Alternatively, electrical components can be attached to a larger backing that has the required attachment abilities.

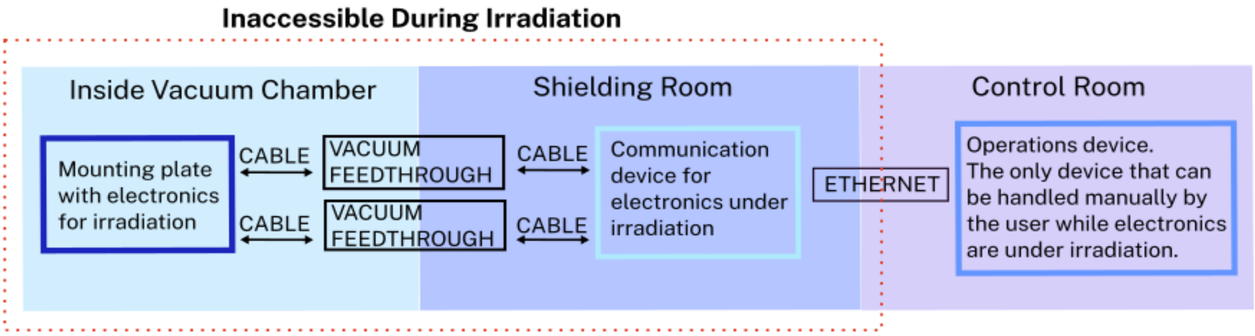


Figure 13. Block diagram of electronic components under test

Energy detectors

Energy detectors are available to be used for material/solar cell testing, as this testing can benefit from knowing the energy lost through the sample. This is less of a consideration in electronics testing as this testing is typically trying to understand how the electronics react to the radiation, not how well they shield the radiation.

Communication to/from device

Interchangeable vacuum feedthrough flanges are installed to provide cabling access between the sample board and the user testing system. This will allow you to communicate and run your device while undergoing radiation testing.

A basic suite of connectors is installed to cover user needs. Depending on cabling needs, there is room for more, and plates can be custom made.

The preinstalled plates include:

- 12 SMA coaxial female/female connectors, rated up to 18 GHz
- 9 DSUB 25-pin male/female reversible connectors
- 2 ethernet interface connector
- 2 USB 3.0 type A female/female connector
- 10 BNC connectors

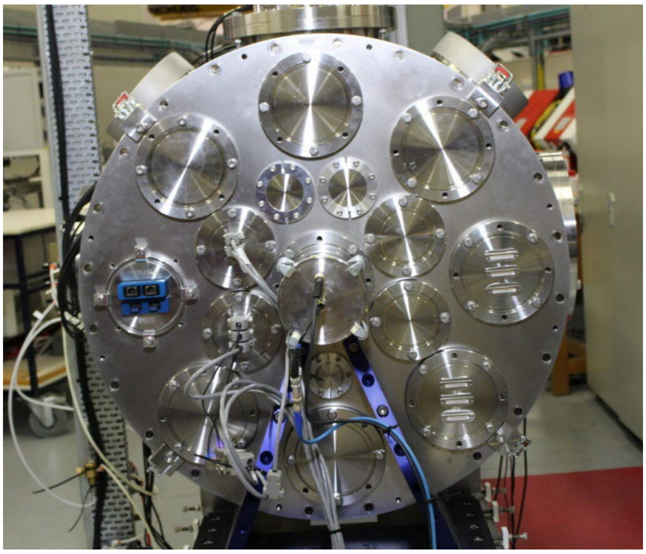


Figure 14. Front of the irradiation chamber with feedthrough flanges

Testing report

After testing, we can provide a report of the testing conditions, containing any of the following information:

- Tested beam species and LET
- Tested beam flux/intensity
- Tested total fluence
- Time of irradiation
- Rastered area of irradiation
- Total area irradiated

If detectors were used to measure the energies passing through the sample material, we can provide the data in a csv file.

As a reminder, it is important to note that this report is not a formal radiation certification.

Booking information

To express interest in testing with us, please fill out our Beam EOI form on our website:
https://accelerators.org.au/capabilities/space-irradiation-beamline-testing-components-for-space/
(refer to Contact Us *Start a new request* section).

Once submitted, a member of our team will contact you to discuss your tests in further detail.

Cost

To maximise access to a broad range of users, our prices represent a significant discount from actual operating costs. All prices in this document are in Australian dollars, are exclusive of GST and are correct at time of publication.

For up-to-date information about the **HIA Access and Pricing Policy**, please visit our website https://accelerators.org.au/reports-documentation

Category	Type of access	Rate*	AUD
Publicly funded research	Unassisted	daily	$3,000
	Assisted	daily	$4,000
Industry funded research *(small-medium enterprises)*	Assisted	daily	$6,000 Plus, one-off $2500 setup and consultation fee
Industry funded research *(large enterprises)*	Assisted	daily	$12,000 Plus, one-off $2500 setup and consultation fee

**'daily' means up to 16 hours per day*

For industry funded users, there are two different costs associated with accessing the space irradiation beamline at HIAF: an initial setup/consultation fee and a daily cost of testing.

The initial setup and consultation fee recognises that almost all new users will require assistance in designing/framing their experiments and the design or manufacture of new mounting, or modification of existing mounting. It is a one off $2500 + GST charge irrespective of the number of days for testing.

The daily cost of testing consists of a daily facility charge and a daily staff charge. This is the baseline cost of accessing the facility and staff required to operate the accelerator. Each day of beam time represents 16 hours of operation and dedicated support from our physicists and technical staff.

It is our strong recommendation to new clients that testing is booked for a minimum of two days as the first day is usually dedicated to setting up your component in the vacuum chamber.

Wait time for beam

Testing dates are usually booked up to three months in advance. Wait time for testing is dependent on demand so booking in advance is preferred. This allows us to prioritise your experiment and give our staff enough time to prepare. For international users that need more notice for travel, please contact us for pre-booking.

Contacts

For inquiries about testing, tours or for more information, contact our User Engagement Team: userengagement.hiaf@anu.edu.au .

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