JINR HEAVY ION ACCELERATORS APPLICATION FOR SEE TESTING IN ISDE

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ISDE and The Test Laboratory for Hardness to Radiation Effects

ISDE is a focal point of Roscosmos for the development and introduction of new radiation hardness estimation and assurance methodologies of electronics to space radiation environment, including:

1. A parent organization of Interdepartment Radiation Laboratory on the part of Roscosmos.
2. The Test Laboratory accredited to the Russian primary Certification Systems for all types of radiation tests (performs tests of more than 500 parts per year, including more than 400 to SEE), and comprises:
   - Creation of Test Facilities with heavy ion (SEE), proton (SEE, DD), neutron (SEE, DD), gamma (TID), and laser (SEE) sources in collaboration with Russian science institutes and organizations
   - More than 30 Self-designed Roscosmos standards, guidelines and test software
   - Space radiation modeling software (OSOT, DSG)
   - Database of electronic component radiation test results
   - Elements of Space Radiation Environment Monitoring System (40 devices with flight experience)
3. Organizer and co-organizer of scientific and technical conferences in the fields of space radiation

The official websites are www.tlisde.org, www.kosrad.ru

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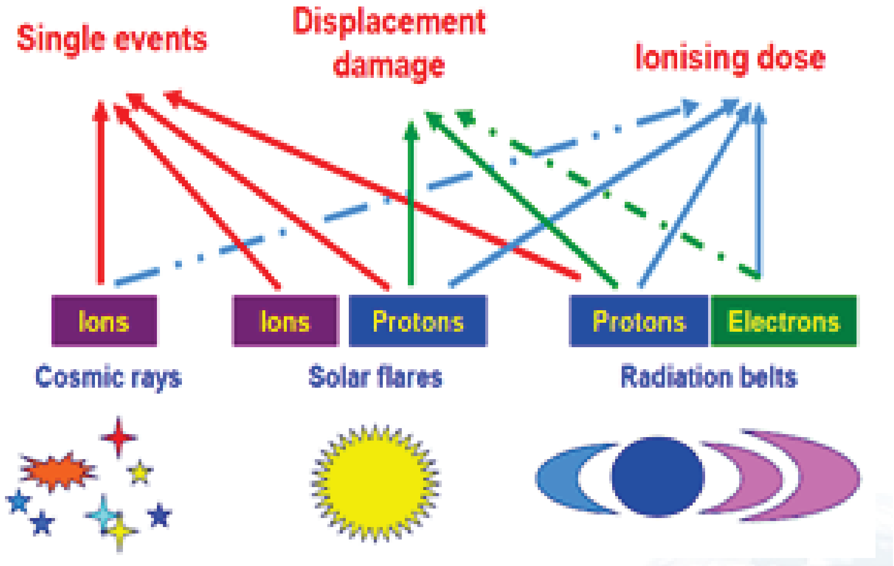
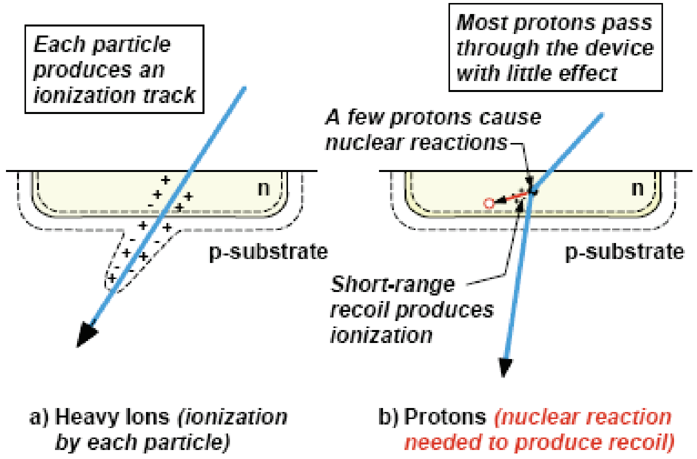
Space radiation environment and Single event effects (SEE)



From Ecoffet R, RADECS – CNES CCT Workshop on Radiation Design Margins, 2015

Mechanisms for Heavy Ion and Proton SEU Effects



From Space Radiation effects on microelectronics, JPL

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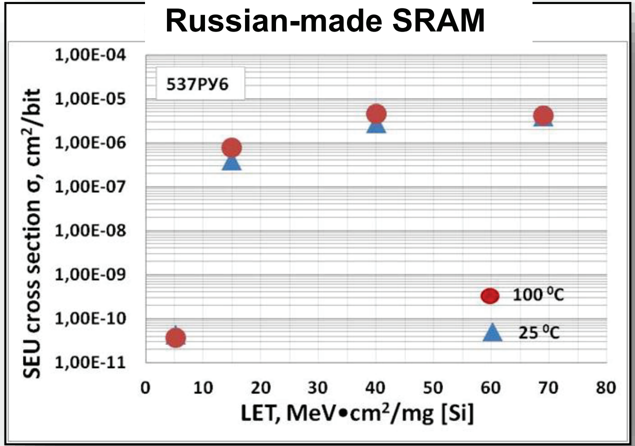
SEE testing foundations

The principle of equivalence thresholds LET for space heavy charged particles and monoenergetic ions, in which the electronic components having SEE : equality thresholds LET under the influence of space heavy charged particles, containing ions of different chemical elements with different spectral and energetic characteristics and any monoenergetic ion having a given value of LET, under the influence of which in electronic components appears SEE

Main SEE hardness characteristics:
•Threshold LET
•Effect cross-section (saturation)
•Dependence of effect cross-section from ions LET



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Variables of SEE Testing

- **SEE testing is carried out with**:
  - Ion accelerator (dominating)
  - Proton accelerator
  - Laser simulator (result calibration on the ion or proton accelerators is necessary!)

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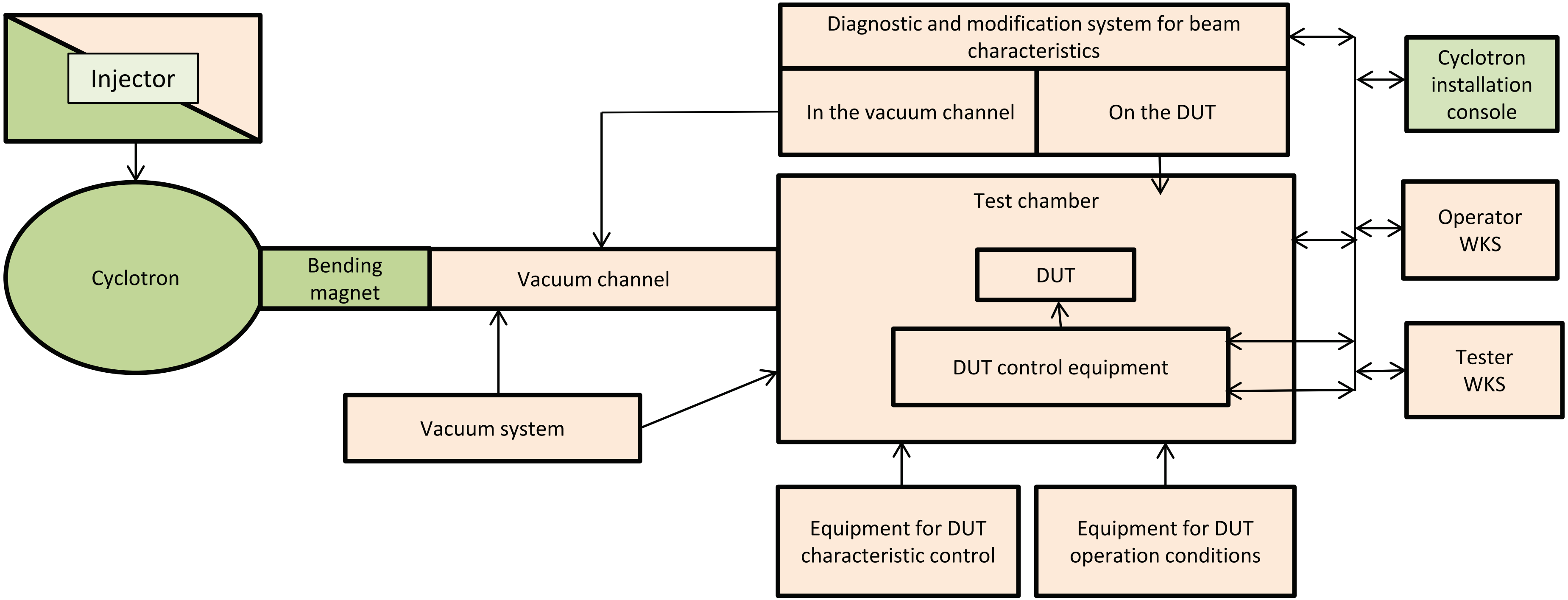
General Structure of the SEE Test Facilities Based on Ion Sources



Basic Technical Features of the SEE Test Facilities Based on Ion Sources

Technical features	IS OE PP (LE)	IS OE VE-M (HE)	IS OI 400-N (LE)
Ion source	Cyclotron U-400M FLNR JINR	Cyclotron U-400M FLNR JINR	Cyclotron U-400 FLNR JINR
Energy, MeV/nucleon	3 .. 6	15 .. 40 (60 for light ions)	3 .. 9
Flux density, particle/(cm²×s)	10 .. 10^5	10 .. 10^5 (10^4 for Bi)	10 .. 10^5
Nonuniformity, %	± 15	± 10	± 10
Suit of ions	C, O, Ne, Ar, Fe, Kr, Xe, Bi	Ne, Ar, Kr, Xe (C, O, Fe, Bi)	C, O, Ne, Ar, Fe, Kr, Xe, Bi
LET (Si), MeV × cm^2/mg	1 .. 100	1 .. 98(with using degraders)	1 .. 100
Range in Si, µm	> 30	130 .. 2000	> 30
Irradiation area, mm	200 x 200	Ø 60 (Ø 40 for Bi)	150 x 200
Operational pressure, Pa	2,2 x 10^{-3}	Forevacuum/atmosphere	2,2 x 10^{-3}
Vacuum pumping time, min	6	5/0	8
Temperature range, °C	+25 .. +125	-40 .. +125	-40 .. +125

Retrospect of the Test Facilities Annual Load

	2010	2018
Number of Test Facilities (TF)	1 (LE)	3(LE/HE)
TF max. output, hr	1000	3500 - 4000
Number of test sessions per year	2	9
Number of tested electronic components, part types	~150	800-1000

Total tested electronic components > 4170 part types

LE – low energy; HE – high energy

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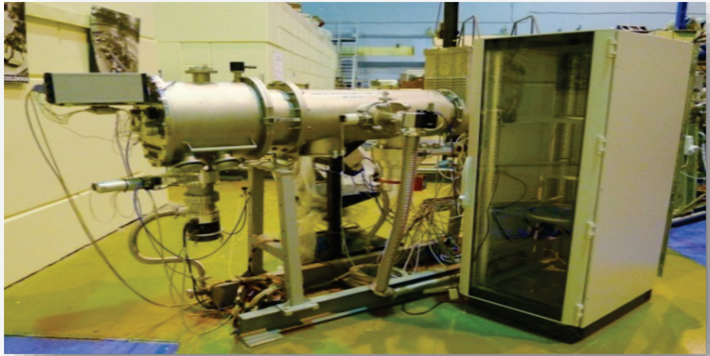
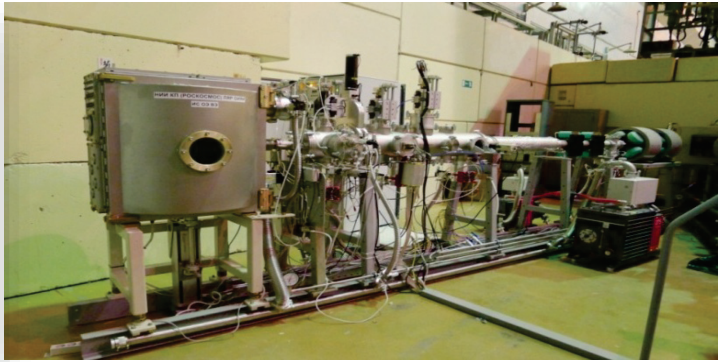
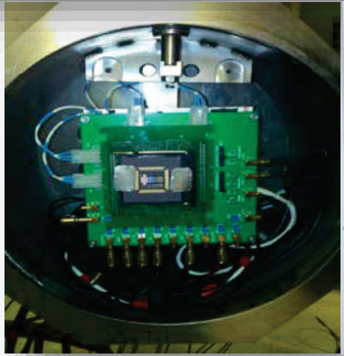
Heavy Ion SEE Test Facilities







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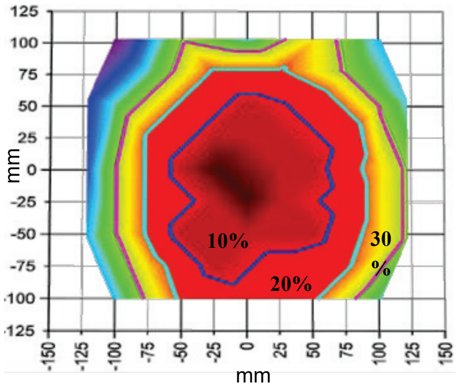
Beam Transfer Channel Layout

The test facility comprises a large number of diagnostic tools for ion characteristics high-precision determination.

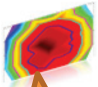
Time of Flight (TOF) detectors (energy determination)

1– slide gate
2– bending magnet
3– diaphragm
4– X-axis magnetic scanner
5– Y-axis magnetic scanner
6– degraders
7– luminophore
8– Faraday cup
9– slide gate
10– target node
11– beam monitoring system

Example: Ion Ar



Beam monitoring system (fluence determination)



Beam preparation system (focusing, spreading, deceleration)

Ion beam profile in the plane of DUT location

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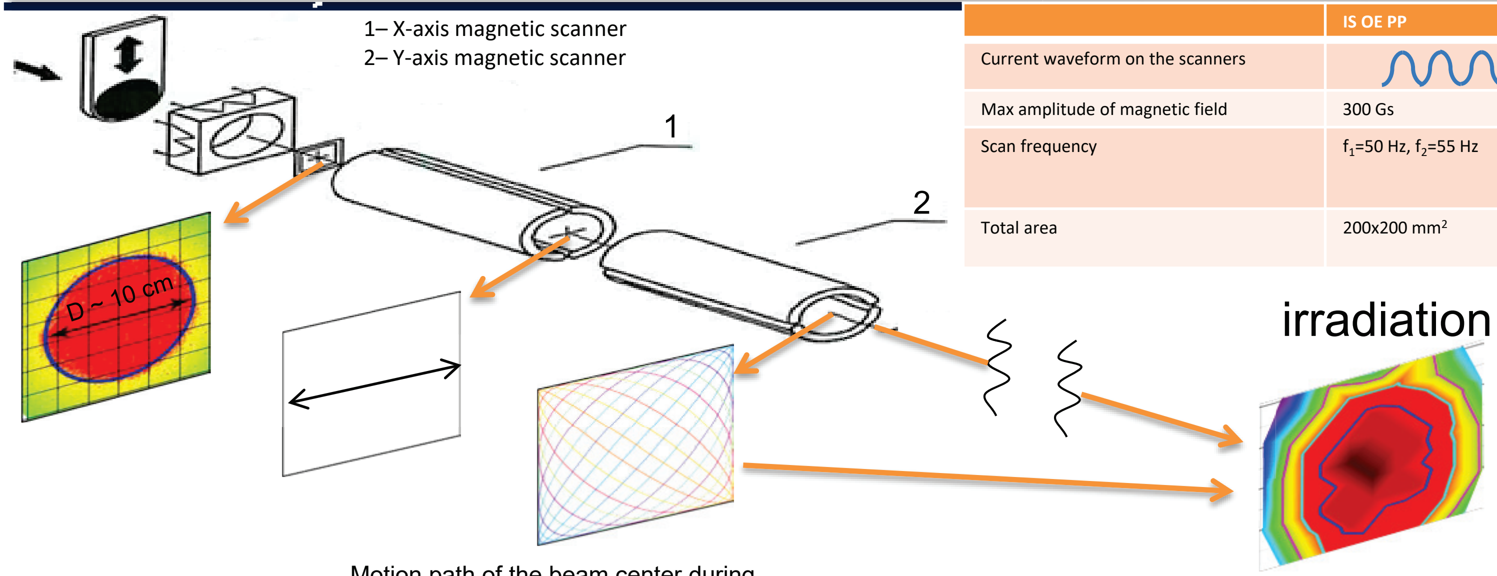
Beam Modification System



Motion path of the beam center during scanning

	IS OE PP	IS OU 400-N
Current waveform on the scanners	
Max amplitude of magnetic field	300 Gs	350 Gs
Scan frequency	f_1=50 Hz, f_2=55 Hz	f=50-100 Hz (Step of 1 Hz)
Total area	200x200 mm^2	150x200 mm^2

The scanning system provides an increase of irradiation area from 4÷10 cm to 11.5÷20 cm with min. nonuniformity

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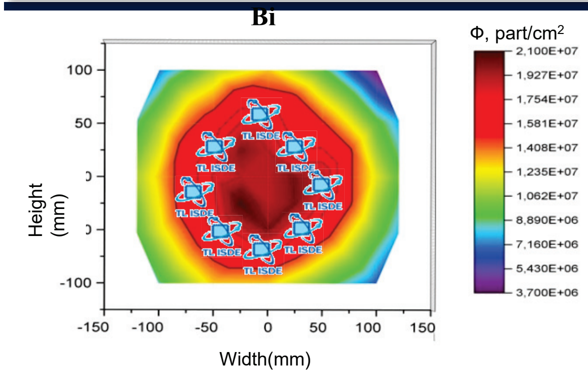
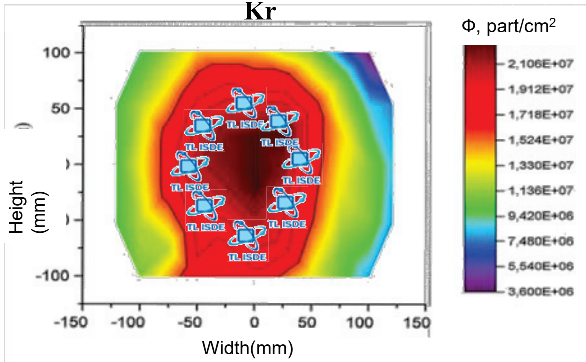
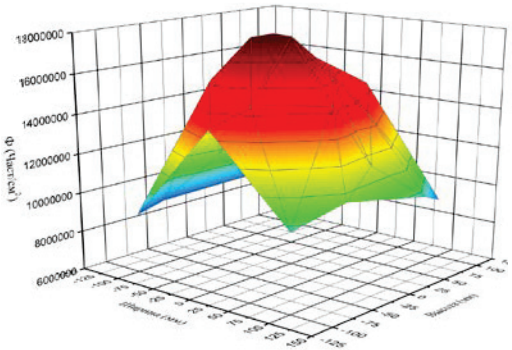
Typical Shapes of Ion Beam Profile & Best location of DUTs

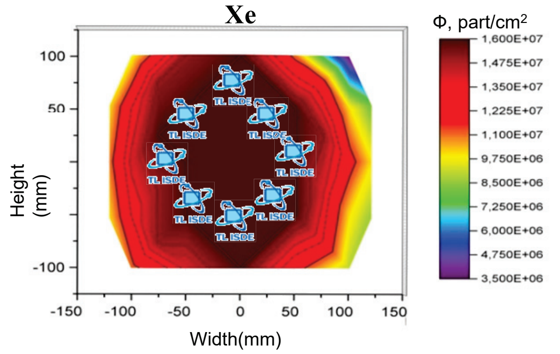


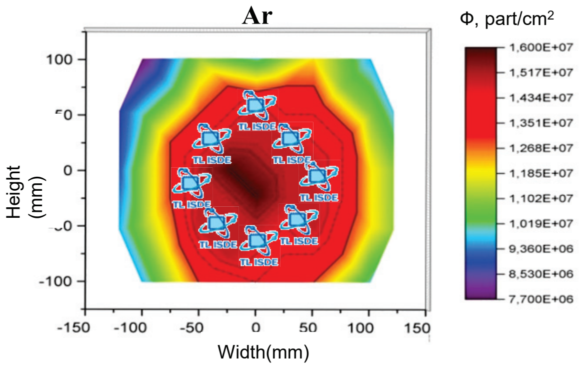


Provides the DUTs best location determination with respect to on-line detectors with minimum error.



TL ISDE Best point of DUTs





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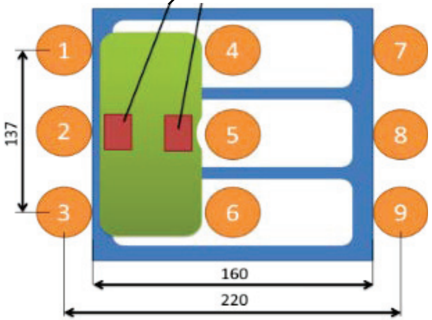
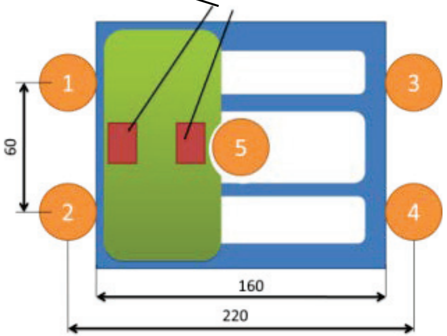
Heavy-Ion Fluence Determination - Procedures

1. The fluence evaluation method is quasi-on-line (on-line - scintillators, off-line – track detectors) and yet it shows excellent accuracy.
2. On-line detectors are used to determine the moment for stopping the irradiation after the fluence reaches $>10^7$ ($3x10^5$ for Power MOSFETs).
3. To obtain a precise value, the track detectors placed close to the DUTs are used.

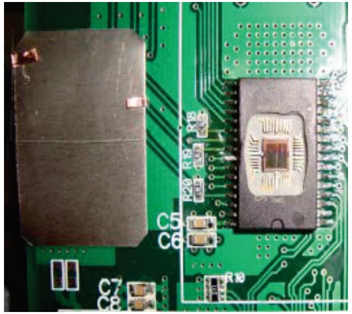
Track detectors (TD) mounting → TD irradiation → Holes calculation

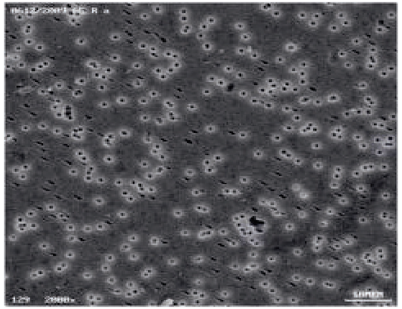


IS OI 400-N



IS OE PP





Determination of the true fluence value in the DUT location or all over the beam profile, and nonuniformity determination

For operational evaluation of ion fluence in the DUTs location the K coefficient is determined. K interrelates fluence according to track detectors ($\Phi_{track\ detectors}$) and dimensionless quantity characterizing ion fluence according to data from on-line monitoring counters (Φ_{count}).

$$\Phi_{track\ detectors} = K^* \Phi_{count}$$

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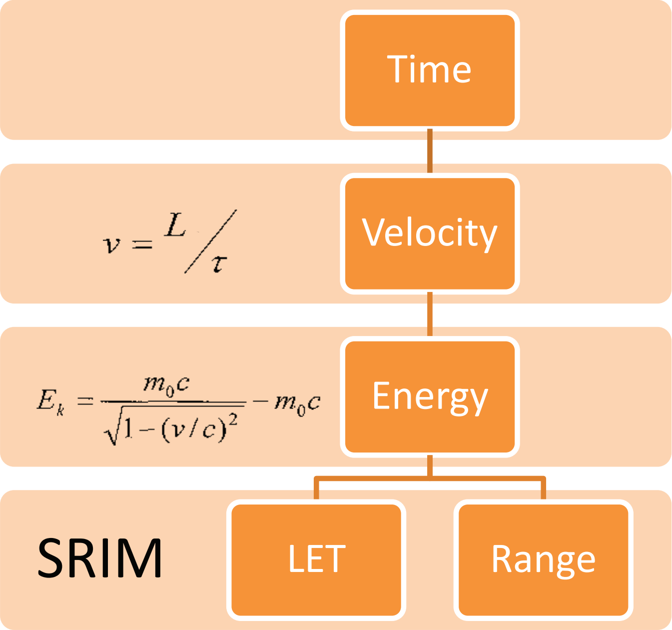
Ion Beam Characteristics Determination



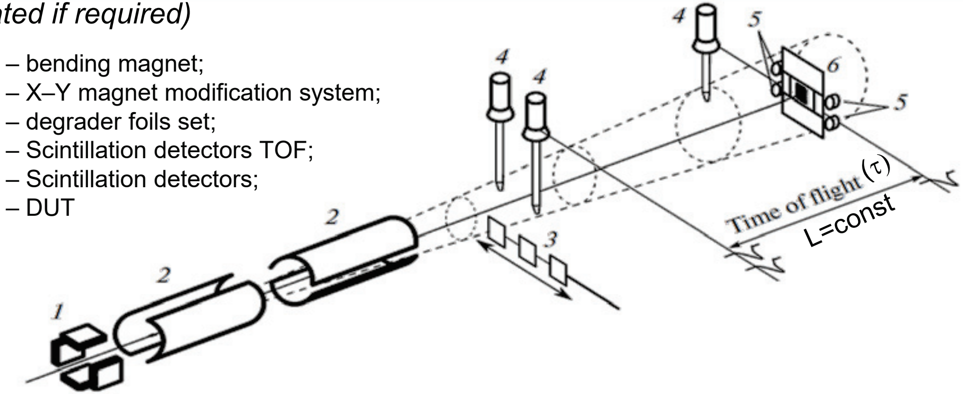
m_0 – Ion rest mass
c – electromagnetic constant

Time of Flight Technique

The energy measurement method based on one-to-one correspondence between the kinetic energy E_k and the particle velocity *v.*

Energy measurements are performed once after ion ejection (may be repeated if required)

1 – bending magnet;
2 – X–Y magnet modification system;
3 – degrader foils set;
4 – Scintillation detectors TOF;
5 – Scintillation detectors;
6 – DUT



Scintillation Detectors Position Relative to Ion Beam

This method provides energy determination with up to 2% accuracy

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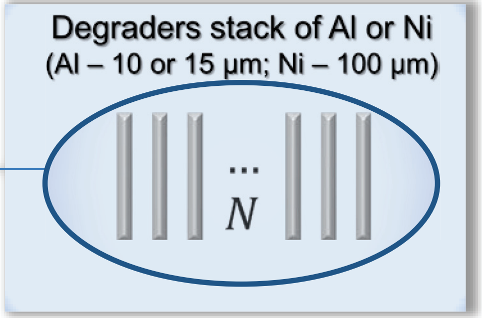
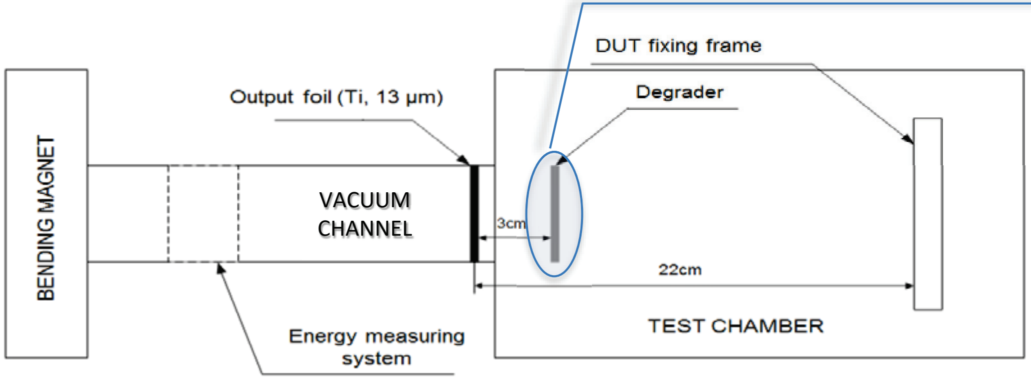
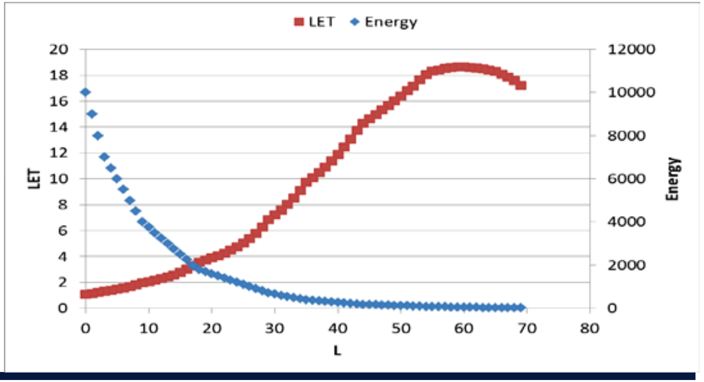
Special Features of Beam Parameters Determination for the High-Energy Test Facilities

The use of degraders allows to obtain almost any LET with the required range (See next slide)







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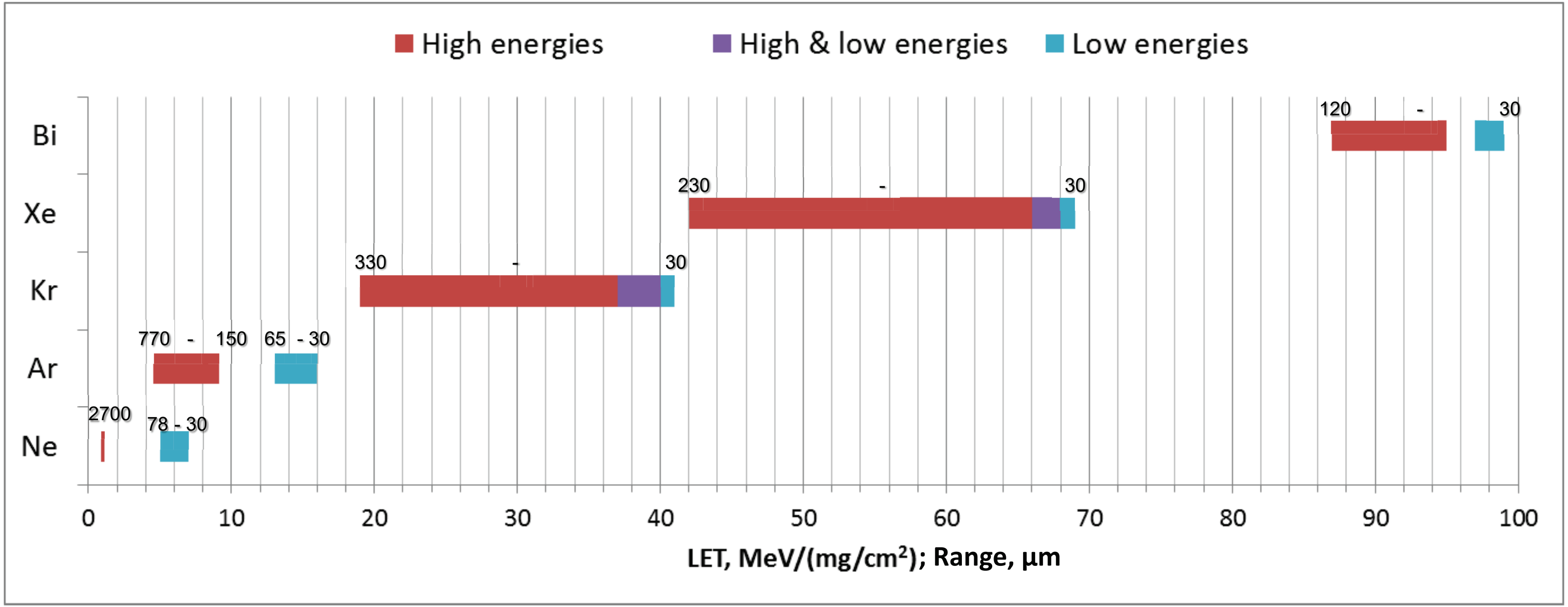
Degraders Advantages – LET / Range



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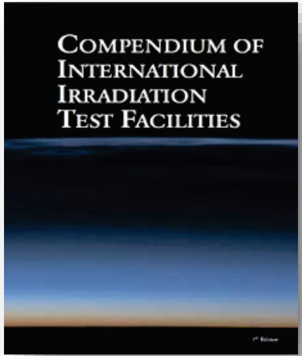
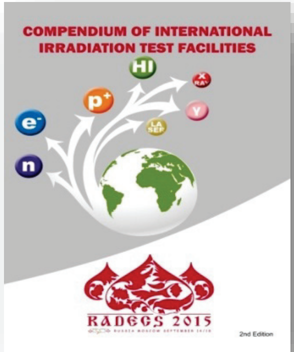
Advantages of SEE Test Facilities

- Large irradiation area**: up to 200 x 200 mm ^{2}**
- High accuracy: **nonuniformity up to ± 10 % (in the DUT location up to ± 5 %)**
- Suit of ions: **C, O, Ne, Ar, Fe, Kr, Xe, Bi**
- Wide LET range: **1…100 MeV x cm^{2}/mg [Si]**
- Wide range of fluxes: **10 .. 10^{5} particles/cm^{2} x sec**
- Irradiation in a wide range of temperature: **- 40... + 125 °C**

Recognition of the Heavy-Ion Test Facilities High Scientific and Technical Level





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Directions for the Development of Test Facilities

1. Improvement the accuracy of technical characteristics
2. Creation of on-line beam monitoring system (energy, nonuniformity, flux, fluence, etc.)
3. Creation of test facilities with milli- and micro- beams for fundamental investigations
4. Creation of technological bench for ensuring de-encapsulation of electronic components
5. Creation of new test facilities based on accelerators that exist or under development in JINR

We invite you to mutually beneficial collaboration on this directions and also creation of semiconductor detectors for on-board radiation monitoring system!

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Conclusion

ISDE in collaboration with JINR operates the modern high-quality SEE Test Facilities, which allow to make the best use of up to 4000 hours of the test time per year and provide tests of electronic components of all functional classes to all types of radiation effects, taking into account the specific technical features.

We invite you to joint research – common application of heavy-ion test facilities for electronic components radiation testing and investigations.

I would like to thank FLNR JINR team for their work

on the development and operation of the test facilities!

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WELCOME to RAD-TEST 2019 - RADECS Association event in Russia

13-16 MAY 2019 in DUBNA CITY (1,5h from Moscow)

Held by ISDE & JINR

The key topic of the workshop is all aspects of radiation tests of semiconductor devices, integrated circuits, microelectronic modular assemblies, units and hardware of spacecraft systems and equipment to all types of radiation effects (TID (ELDRS), DD, SEE (upsets & failures))

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THANK YOU FOR YOUR ATTENTION!