# Degradation of Thermal Conductivity of Epoxy Resin-Diamond Filler Composites Under Radiation

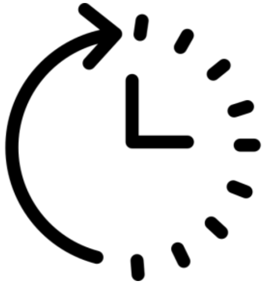
Presenter: Tuyana Ligdenova

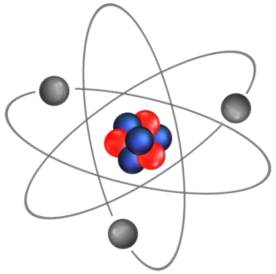
# What are radiation-resistant thermal adhesive?

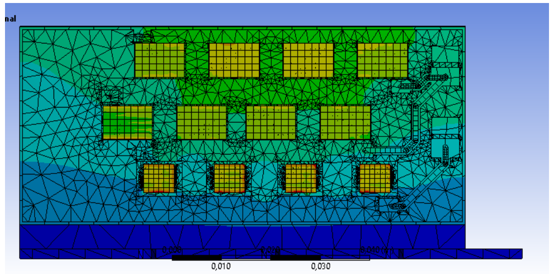
Designed for high-radiation environments (e.g., nuclear power plants, space technology, readout electronics).

Key requirements for the electronics of the accelerator:

- High thermal conductivity (Crucial for efficient heat removal in electronics)
- High electrical resistance
- Durability (Most of the analogs are pastes that cannot be used for several years)
- Radiation-resistant (Cracks in the adhesive during radiation)





***or***

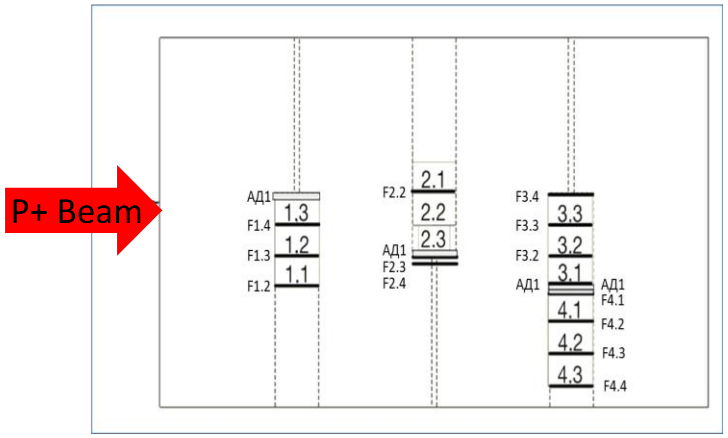
# Comparison of resins for thermal glue

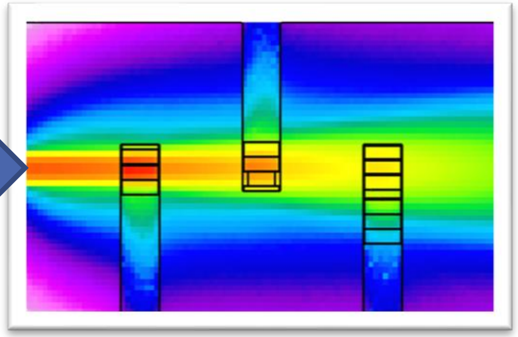
| Adhesives | Thermal Cond. (W/m.K) | Oper. Temp. (°C) | Viscosity (Pa.s) | Elec. Resistivity (Om.cm) | Curing | Rad. Hard, Mrad | shear strength (MPa) |
|---|---|---|---|---|---|---|---|
| HT2 | N/A | N/A | 0,330±100 low Viscosity | N/A | 24 h 23°C+ 10h 50°C | N/A | N/A |
| ED-20 | 0,3-0,6 | 55-170 | 13-20 middle Viscosity | $10^{14}$ | 20 h 25°C | 200-300 | >25 |

## Filler used

| Filler | Thermal conductivity | Dialectical strength |
|---|---|---|
| *C (diamond)* | 900 - 2000 W/(m·K) | $20\times10^{6}$ V/мм |

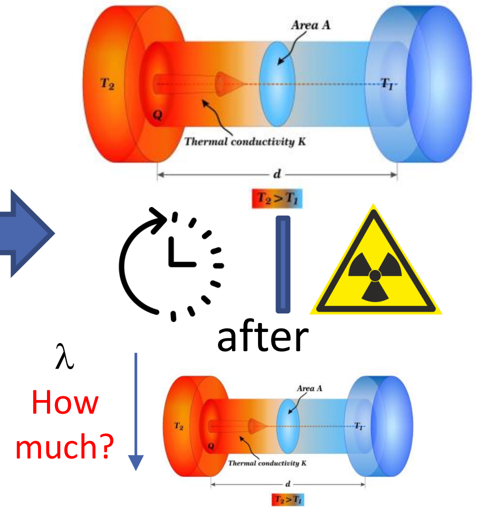
# Experimental methodology



*and*


Thermal conductivity λ
before



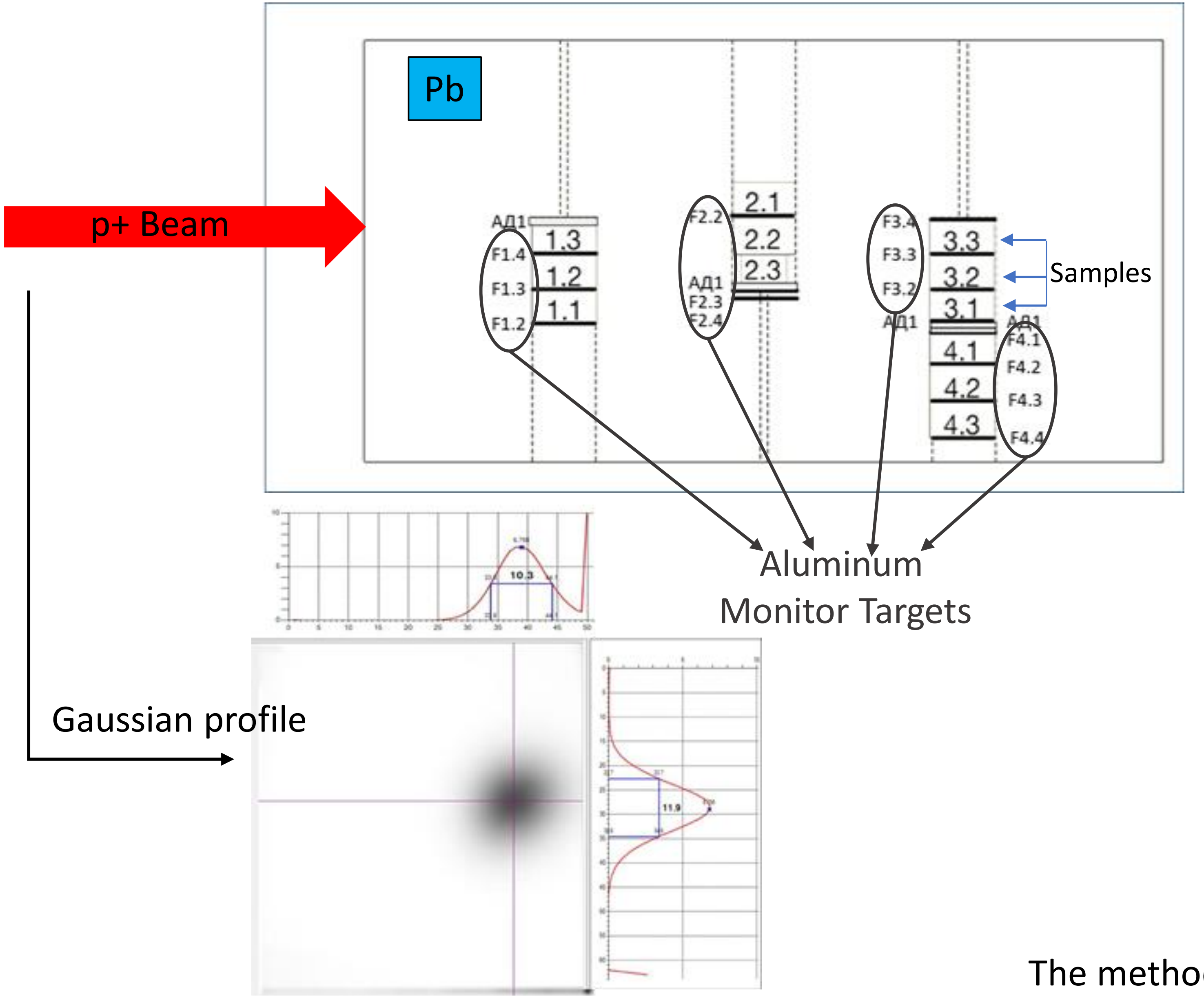

Irradiation of samples

Analysis

- Modeling using FLUKA and MNCPX
- Calculation of absorbed dose

Comparison of thermal conductivity values before and after irradiation

# Experimental setup

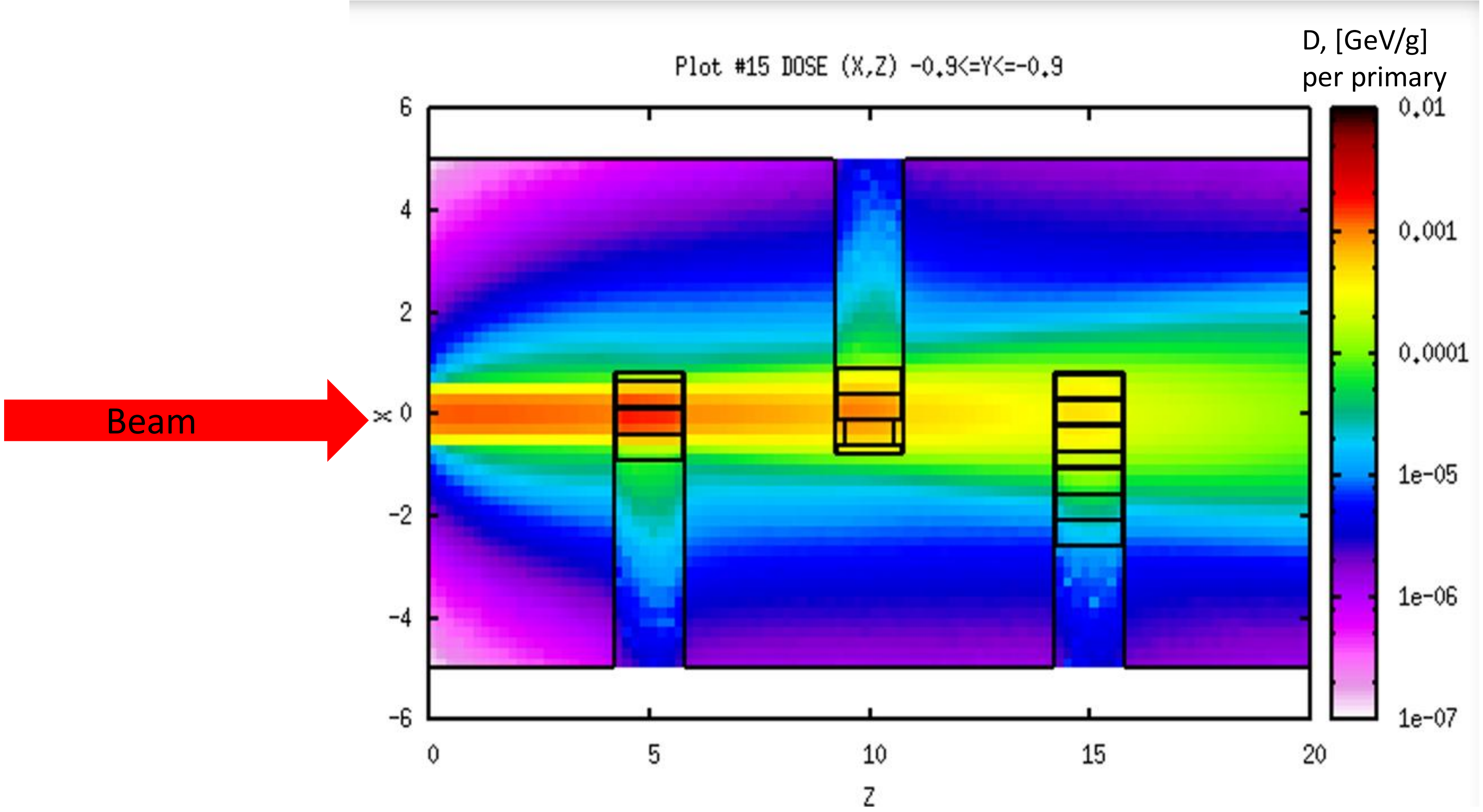



Sample sizes : ∅ 15 mm, d = 5 mm.
Aluminum targets: ∅ 15 mm,
d = 80 microns.

The lead target was irradiated with a proton beam from the JINR DLNP phasotron
Beam diameter – **10 mm**
Energy of protons in a beam - **660 MeV**
I = **1 μA**
Irradiation time -**15 min**

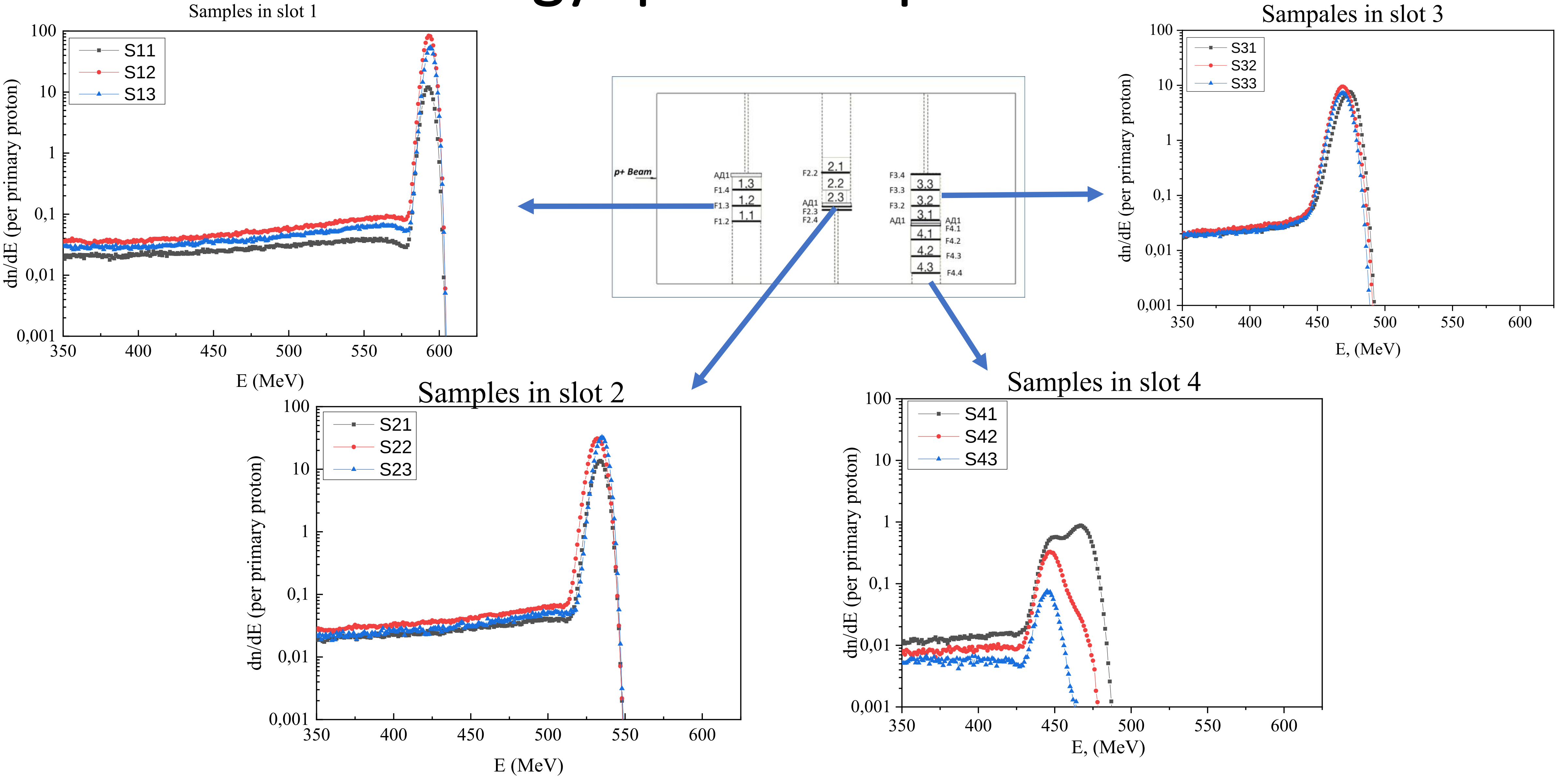
The method was proposed by S.I. Tyutintikov

# Spatial distributions of absorbed doses in the assembly




Computer modeling using the FLUKA program was carried out by Elena Litvienko

# Energy spectra of protons at slots




Computer modeling using the FLUKA program was carried out by Elena Litvienko

# Determination of particle fluence at the irradiation time

The initial activity (Ao) of the aluminum monitor (t=0) was calculated from activity measured after 10 months as:

$$\text{No}=\text{Ao}/\lambda \quad \rightarrow \quad \text{Ao} = \frac{S/\tau}{\gamma\ (^{22}\text{Na}) * e^{-\lambda t} * \epsilon}$$

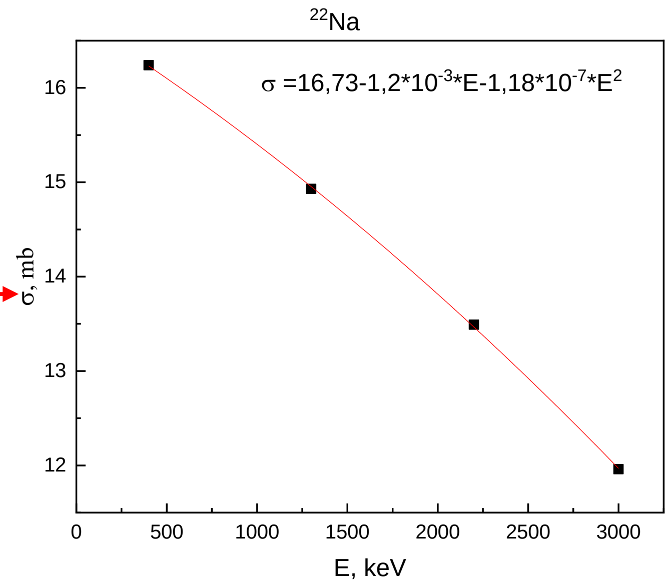
by simple transformations (believe me)

| Nuclide | Half-life time | Main γ-rays energies (keV) | Absolute intensity(%) |
|---|---|---|---|
| $^{7}$Be | 53 days | 477.6 | 10.44 |
| $^{22}$Na | **2.6 years** | 1274.5 | 99.9 |
| $^{24}$Na | 15 hours | 1368.6<br>2745 | 99.99<br>99.86 |

## Fluence

$$F = \frac{\boldsymbol{N} * M}{\boldsymbol{\sigma} * \rho * d * \text{N}_A * S}$$

N - number of $^{22}$Na nuclei,
M - molar mass of aluminum,
$\sigma$ - cross section through $^{22}$Na,
$\rho$ – aluminum density,
d - thickness of the aluminum target,
$\text{N}_A$ – Avogadro's number,
S – Al monitor foil area.




Graph of the dependence of the activation cross-section on the particle energy for the element $^{22}$Na

*H. Matsuda. Iwamoto "Proton-induced activation cross section measurement for aluminum with proton energy range from 0.4 to 3 GeV at J-PARC ", 23 March 2018.

# Determination of absorbed dose

To calculate the irradiation dose of the samples, only proton interaction was taken into account.
The stopping power (s) elements included in the adhesives have been assessed:

$$s * \frac{1}{\rho} = \sum_i \omega_i * \left(\frac{dE}{dx}\right)_{\mathrm{i}}$$

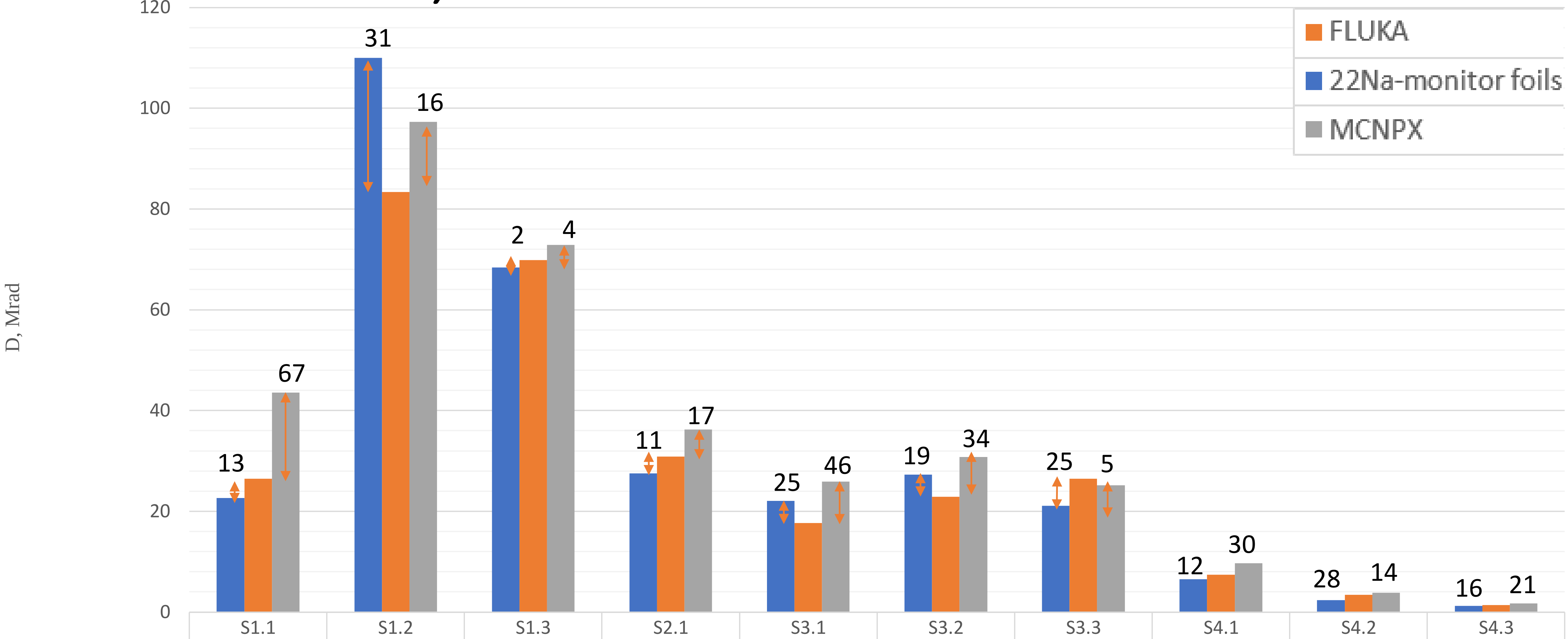
The mean free path (R) for each sample was calculated using the FLUKA program, and since ***d<<R*** is true for our samples, we can find the energy loss after passing through a material of thickness ***d*** using the formula:

$$E = \left(\frac{dE}{dx}\right)_0 * d$$

The total energy is defined as the product of the energy ($E_{total}$) and the number of particles per unit area of the target, located perpendicular to the beam axis ($dN = F \cdot S$). From here we can express the radiation dose $D$:

$$D = \frac{\rho * d * \left(\frac{dE}{dx}\right)_0 * F * S}{m}$$

# Comparison of experimental and theoretical values of absorbed dose, Mrad




| | S1.1 | S1.2 | S1.3 | S2.1 | S3.1 | S3.2 | S3.3 | S4.1 | S4.2 | S4.3 |
|---|---|---|---|---|---|---|---|---|---|---|
| FLUKA | 22,6 | 110 | 68,4 | 27,5 | 22,1 | 27,3 | 21,1 | 6,5 | 2,4 | 1,2 |
| 22Na-monitor foils | 26,5 | 83,4 | 69,9 | 30,9 | 17,7 | 22,9 | 26,5 | 7,4 | 3,4 | 1,4 |
| MCNPX | 43,6 | 97,3 | 72,9 | 36,2 | 25,9 | 30,8 | 25,2 | 9,7 | 3,8 | 1,7 |



Alfredo Ferrari1, Daniela Kiselev2, Tatsumi Koi3, Michael Wohlmuther2 and Jean-Christophe Davide4 //Po-production in lead: A benchmark between Geant4, FLUKA and MCNPX [http://arxiv.org/pdf/1806.03732].

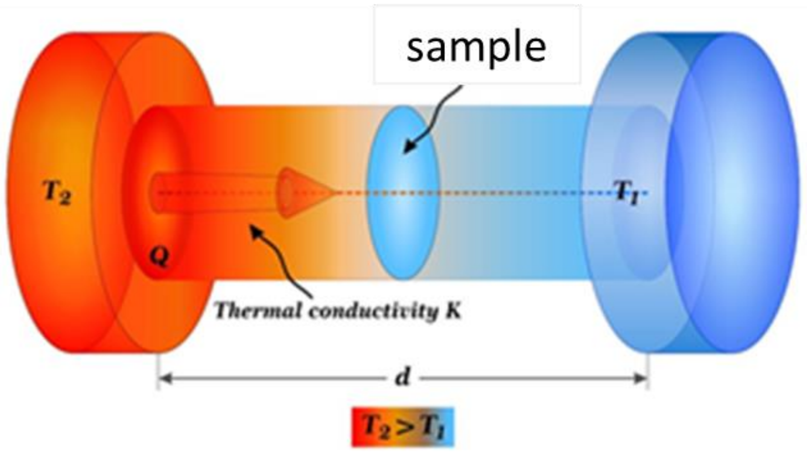
# Thermal conductivity measurement

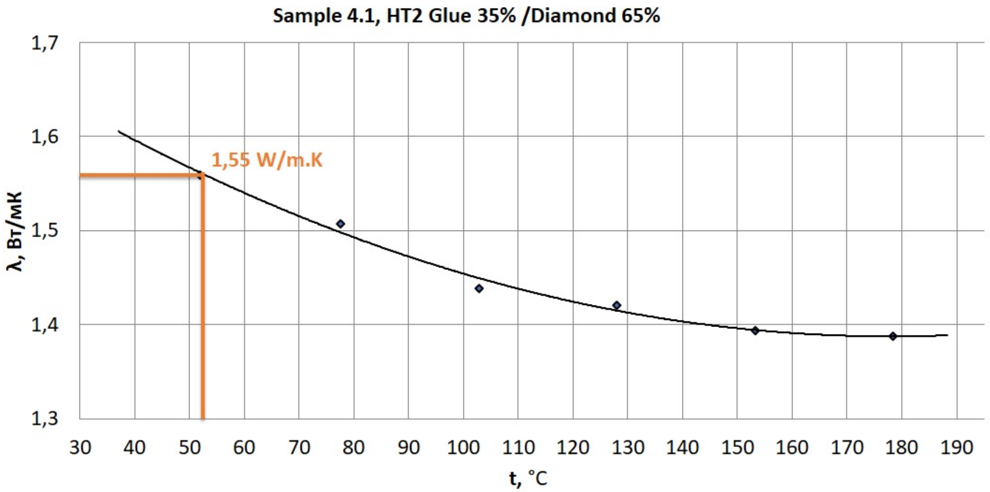
**Sample sizes** : ∅ 15 mm, d = 5 mm.

**With the help of what?** Specialized equipment - **IT-λ-400**

**Duration of measurements** t ≤ 2,5 hours

**Where?** D.I.Mendeleyev Institute for Metrology (VNIIM) in SPb by V.Mekhiev.




:al result of these measurements the thermal conductivity

# Thermal conductivity of the samples before and after irradiation

Measured samples:

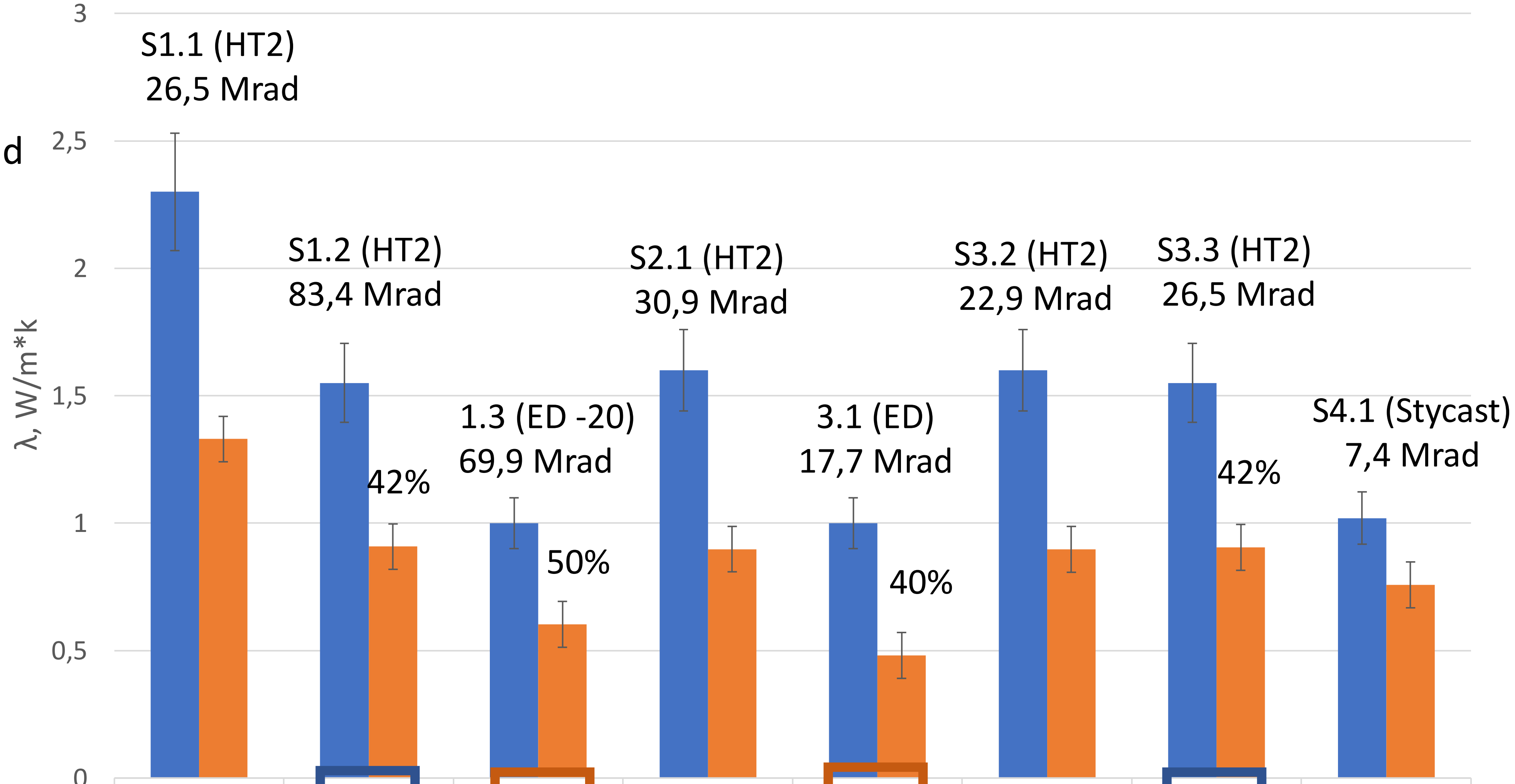
**№1.** Glue HT2 23 %
Diam. powder - 77 %
Two fractions of diamond
D1 – 8.5 µм – 56%
D2 – 50 µм – 21%

**№2.** Glue HT2
Diam. powder - 65%
D2 – 8,5 µм -75%

**№3.** Glue ED -20
Diam. powder - 50%
D1 - 8.5 µм - 37%
D2 – 50 µм – 13%

**№4.** Glue HT2
Diam. powder - 65%
D1 – 8.5 µм- 35%

**№5.** Stycast 2850FT




| | №1 | №2 | №3 | №4 | №3 | №4 | №2 | №5 |
|---|---|---|---|---|---|---|---|---|
| λ, before irradiation | 2,3 | 1,55 | 1 | 1,6 | 1 | 1,6 | 1,55 | 1,02 |
| λ, afret irradiation | 1,33 | 0,908 | 0,603 | 0,898 | 0,481 | 0,897 | 0,905 | 0,758 |

Thermal conductivity of the samples was measured by V.Mekhiev (the D.I. Mendeleev All-Russian Institute for Metrology, SPb)

# Conclusion

- *A rather simple method was established for studying the degradation of the thermal properties of composite dielectric glues (made of epoxy and diamond powder).*
- *The dose absorbed by the irradiated glue samples was determined by the activation analysis of the aluminum monitor foils placed close the samples and combined with theoretical estimations calculated using FLUKA and MCNPX simulations.*
- *The absorb dose accuracy of the method is estimated 25-30%*
- *The thermal conductivity (measured 10% accuracy) of the irradiated samples decreased by 40-50% within the range of doses from about 7 to over 80 Mrad.*
- *The main advantage of the method is the simplicity and ability to obtain data on different dose levels in one irradiation.*

# Future work:

- *Include various dielectric fillers.*
- Increasing the number of irradiated samples to improve the reliability of the results.
- *Simplification of the setup design to minimize its impact on the accuracy of absorbed dose measurements.*
- *Include in the study the degradation of electromechanical properties of samples:*
  - *Dielectric strength*
  - *Mechanical strength*

# Thank you for your attention