

Superconducting RF Cavity Performance Degradation after Quenching in Static Magnetic Field

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Introduction: Fringe magnetic field of focusing elements in cryomodules of superconducting RF linear accelerators can be much higher than it was realized earlier. Modeling quench propagation in walls of superconducting RF cavities followed by calculation of the magnetic field trapped in the walls after quenching was used as a tool for verification of a trapped flux criterion introduced to predict performance degradation of superconducting RF cavities after quenching. The validity of the approach was tested by measurements using SSR1 cavities of PXIE linac.

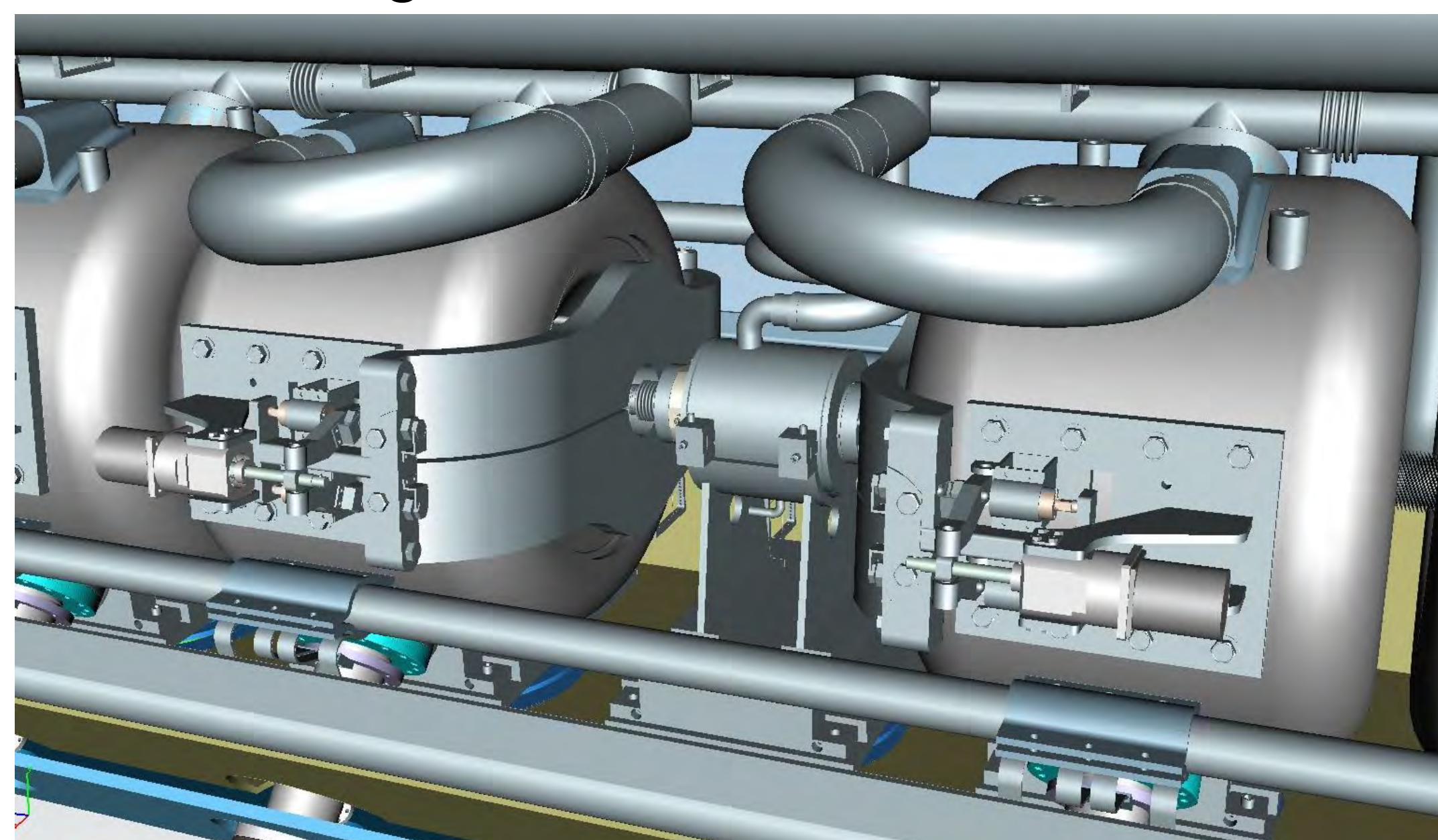


Figure 1. Linac beam line elements in the SSR1 cryomodule

Modeling quench propagation was made by solving time-dependent heat transfer problem in COMSOL environment. As during quenching the cavity surface temperature can grow from ~2K to the room temperature level and higher, relevant material properties can change by orders of magnitude, making the problem extremely nonlinear.

Besides the total energy stored in the cavity before quenching, efficiency of cooling of the cavity surface by liquid He defines the maximum size of a normally conducting opening in superconducting wall of the cavity.

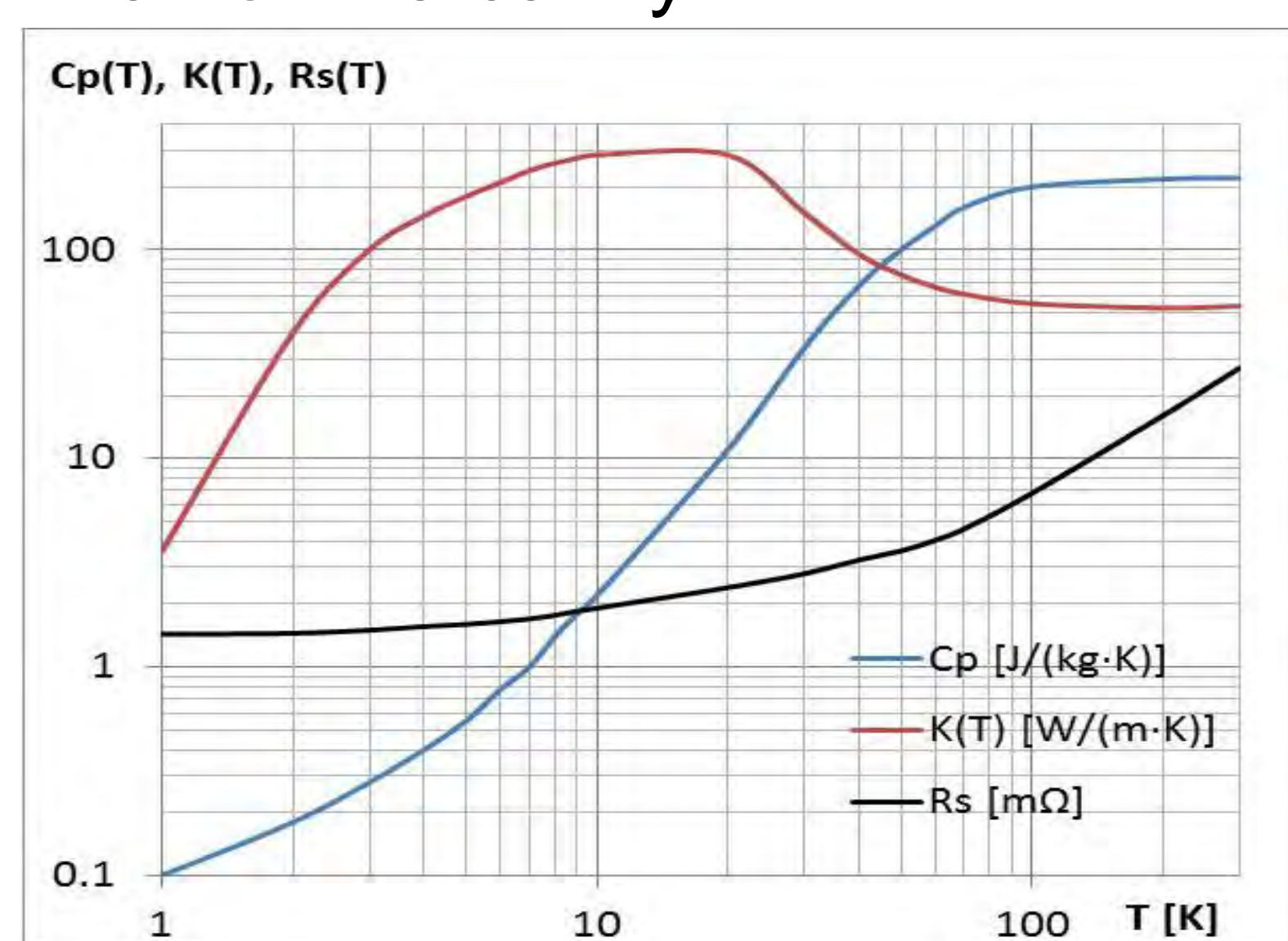


Figure 2. Material properties

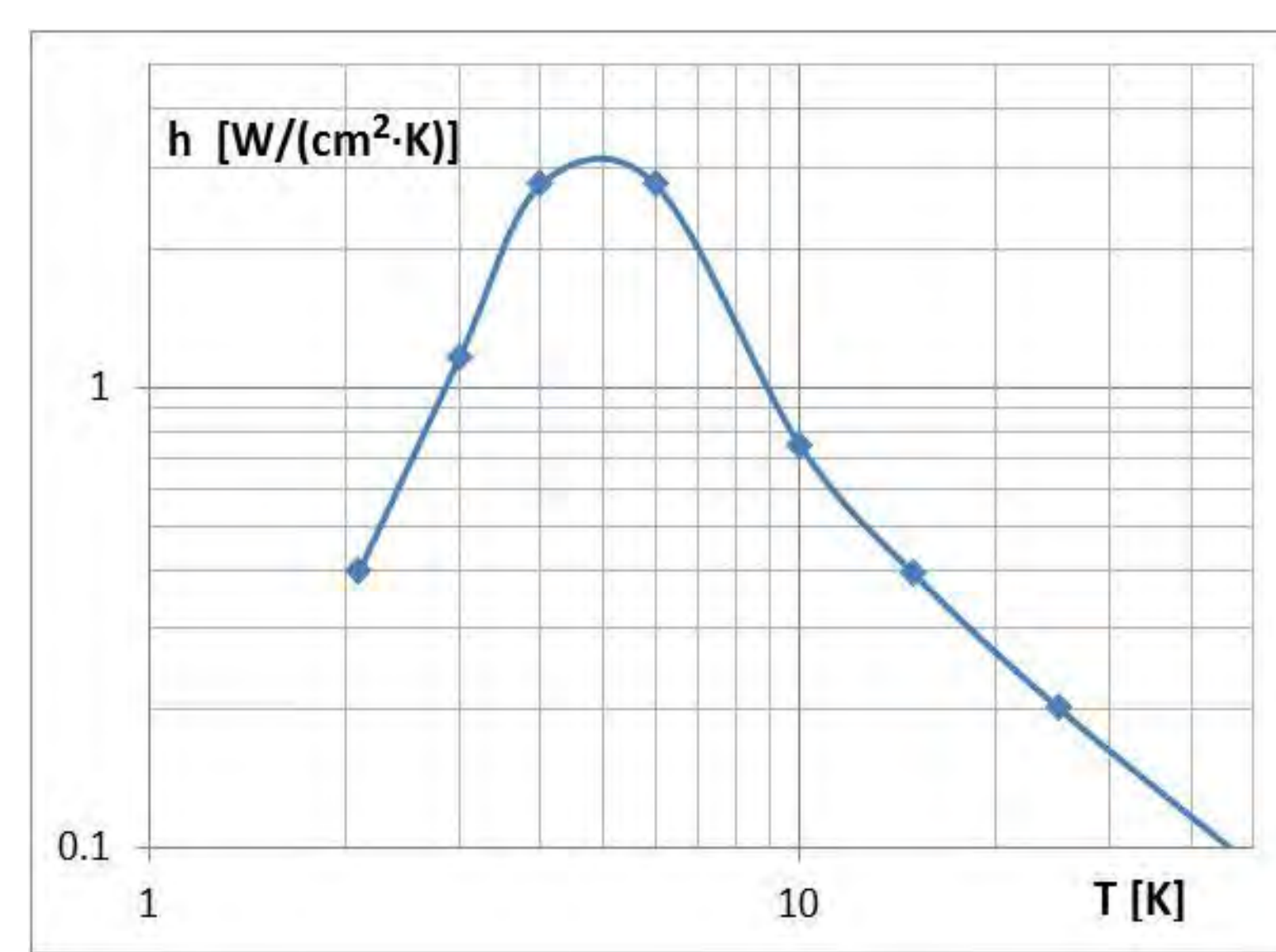


Figure 3. Heat transfer in 2K LHe

The heat transfer equation is solved simultaneously with the equation for the energy W stored in the cavity:

$dW/dt = -2N(\mu_0 \cdot V) \cdot [W \cdot R_s \cdot dS]$, where $\Lambda = \mu_0 \cdot H_t^2 \cdot V / (2 \cdot W_0)$, and the integral is taken over the normally conducting ($R_s > 0$) areas of the cavity surface.

Main results of the quench propagation analysis:

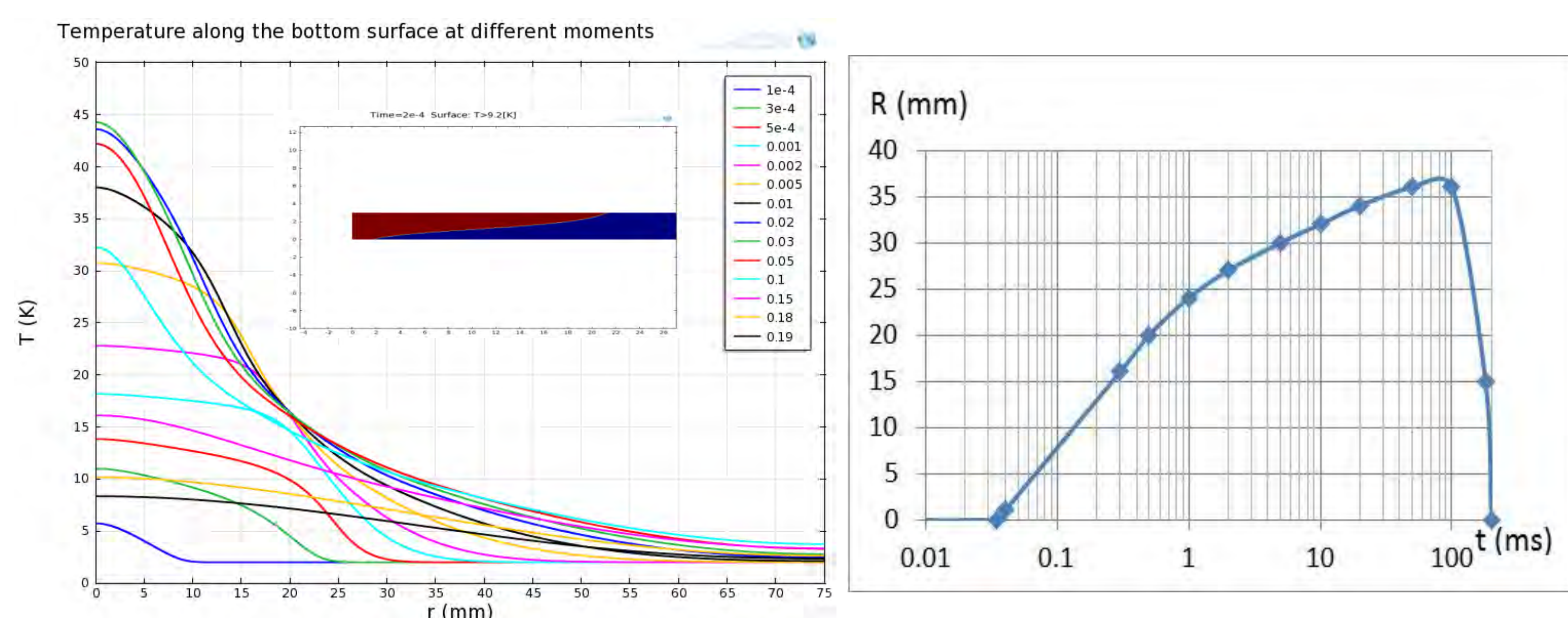


Figure 4. Temperature profiles at the cooled surface;
Radius of the normally conducting area vs time; $W_0 = 14$ J.

Quench propagation analysis resulted in parameterization of the maximum size of the normal conducting opening in superconducting wall at quench. For the SSR1 spoke-type cavity of PXIE linac cryomodule the radius of the opening

$$R_m[\text{mm}] = 25.5 + 9.8/\Lambda + 0.8 \cdot W_0[\text{J}]$$

Trapped flux analysis

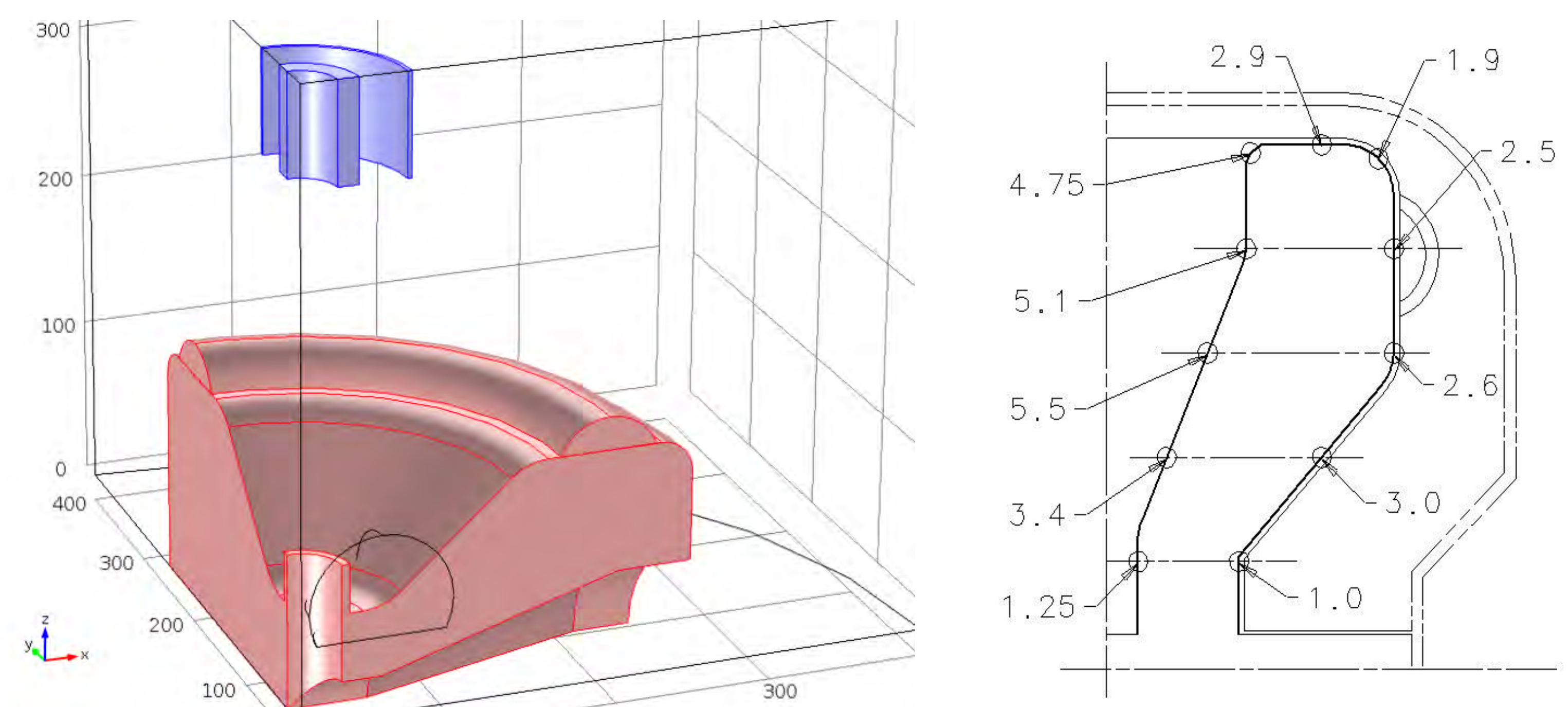


Figure 5. Focusing lens in the vicinity of the SSR1 cavity;
Distribution of the factor Λ on the surface of the cavity

Trapped magnetic flux that reduces the unloaded quality factor of a cavity Q_0 to the level $Q_1 = \eta \cdot Q_0$ ($\eta < 1$) can be calculated as

$$\Phi_{tr} = 2\mu_0 \Phi_0 / (R_s \cdot \xi_0^2) \cdot f \cdot V / (\Lambda \cdot Q_0) \cdot (1 - \eta) / \eta,$$

By calculating the trapped flux, we can find expected degree of degradation of the cavity performance after a quench event: η

Verification. Results of the modeling were verified by measuring performance of cavities after quenching in magnetic field.

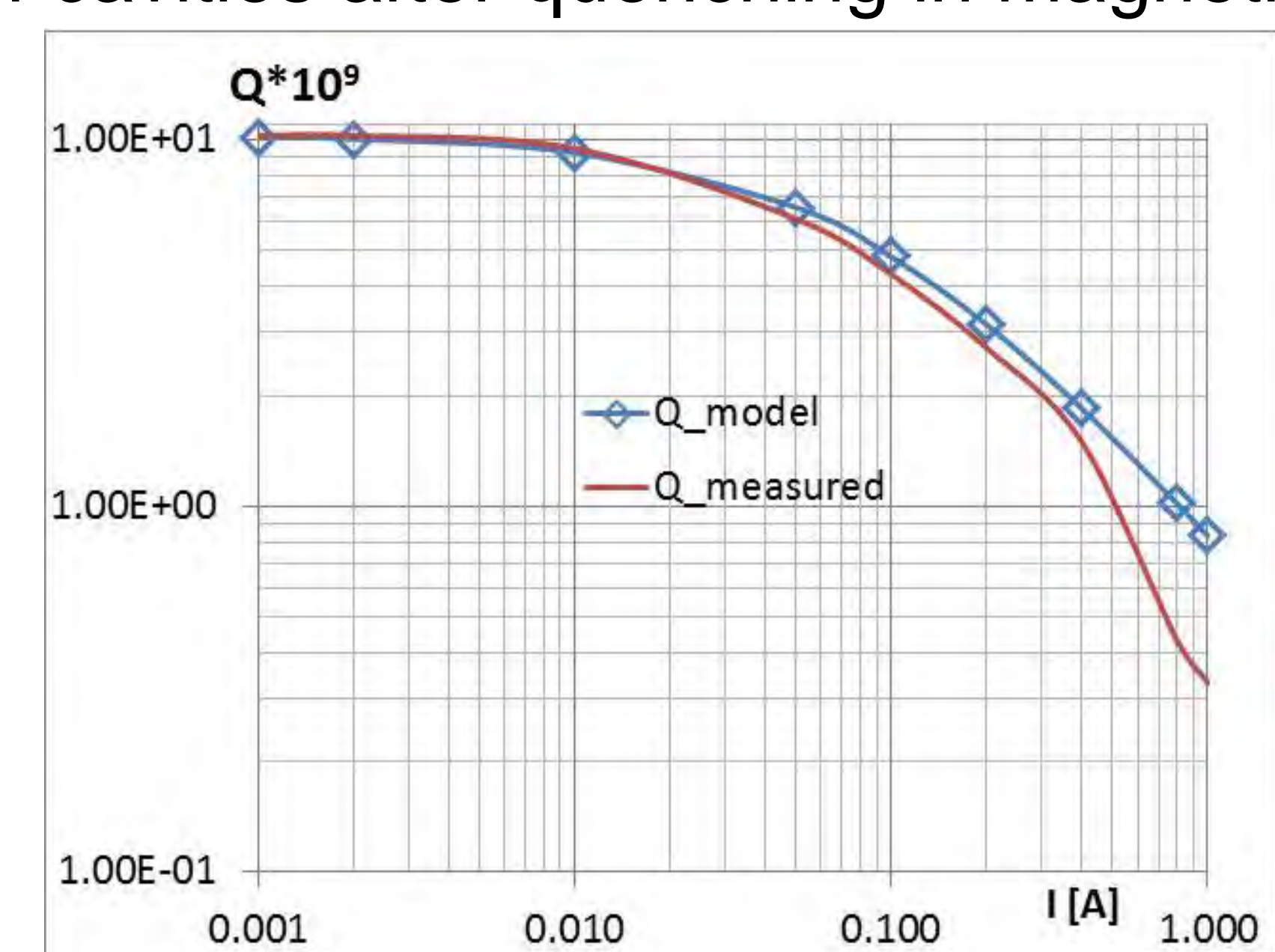


Figure 6. The modeled and measured quality factor after quenching in magnetic field for the SSR1 cavity and $\Lambda = 2.6 \text{E}$

Conclusions: A method was developed and verified for predicting performance degradation of superconducting RF cavities after quenching in magnetic field. Results of the work allow significant relaxation of requirements for the maximum level of magnetic field generated inside cryomodules of linear accelerators. Possible improvements in the modeling technique include using 3D model for quench propagation analysis and calculation of the RF power loss by adding a new (RF) physics in the model.

References:

1. T. Khabiboulline, et al, "Superconducting Cavity Quenching in the Presence of Magnetic Field", FNAL TD note TD-11-020, (2011)E
2. T. Khabiboulline, et al, "Acceptable Level of Magnetic Field on the Surface of a Superconducting RF Cavity", FNAL TD note TD-12-008, (2012)E