The main idea of the project consists in linking three distinct theories: the plastic flow of metals, the continuum damage mechanics and the fracture mechanics, into one complex approach dealing with fracture at extremely low temperatures. The expected result consists in building physically based, multiscale model of macrocrack propagating in the material, including thermomechanical coupling resulting from the specific heat tending to zero with temperature. Thermomechanical coupling consists in the plastic strain induced temperature oscillations, that determine the excitation of lattice and the dislocations mobility. The macrocrack propagation occurs under the conditions of smooth or discontinuous plastic flow, and is followed by the evolution of microdamage accompanied by production of the secondary phase, resulting from the diffusionless fcc-bcc phase transformation.

The main aim of the project consists in the following question: how the evolution of microdamage and the plastic strain induced phase transformation, occurring in the vicinity of the crack tip, affect the propagation rate of macrocrack at extremely low temperatures (including proximity of absolute zero)? Do the microdamage fields accelerate propagation of the macrocrack? Does the plastic strain induced phase transformation decelerate the evolution of the macrocrack? The first being critical, and the latter being beneficial to the lifetime of the material, which one of them prevails and under which conditions? Thus, the main aim of the project consists in verifying to what extent can the phase transformation compensate for the critical effect of the evolution of microdamage at the crack tip. An additional objective is related to the question, whether the discontinuous plastic flow, consisting in the macroscopic slip resulting from breaking the lattice barriers by dislocation pile-ups, can induce discontinuous mode of macrocrack propagation. The experiments seem to confirm this hypothesis. Thus, the evolution of the macrocrack may have discontinuous character, correlated with the stress oscillations as a function of strain in the course of discontinuous plastic flow.

The research covers the experiments carried out at extremely low temperatures, by means of liquid nitrogen 77K, liquid helium 4.2K, and superfluid helium 1.9K, and under complex loads consisting in simultaneous traction and torsion. The experiments are unique, and the set-up follows an original idea by the project team. According to the present knowledge, such a set-up does not exist elsewhere. This unique and brand new research set-up, comprising dedicated cryostat and suitable equipment for monotonic and cyclic multiaxial loads, is capable of performing the proportional and the nonproportional loading paths. The experiments based on superfluid helium (Bose-Einstein condensate, 1.9K), will be carried out in cooperation with European Organization for Nuclear Research, CERN, in Geneva.

In the next part of the project, a mathematical description of macrocrack will be developed, including the coupled fields in the vicinity of the crack tip: the plastic strain field, the microdamage field, and the stress field resulting from the plastic strain induced diffusionless fcc-bcc phase transformation. In order to describe the above phenomena, a multiscale, physically based, multiaxial constitutive model of metastable elastic-plastic material with nonlinear kinematic and isotropic hardening will be used. The model will be used to describe the coupled phenomena occurring in direct proximity of the crack tip, for a macrocrack propagating through the metastable material at extremely low temperatures.

Mathematical description of fracture (onset and evolution of the macrocrack) in the context of coupled dissipative phenomena, that occur at very low temperatures, extends the limits of contemporary knowledge, and has fundamental meaning for the design of structures operating in extreme conditions: the space shuttles, the space probes and orbiters, research and diagnostics instruments, the superconducting particle accelerators, the nuclear magnetic resonance (NMR) magnets, the cryogenic transfer lines, etc. The analysis of fracture of materials in cryogenic conditions will allow to extend the application range of the materials currently used, and will enhance safety level of the instruments/devices operating at extremely low temperatures.