CB
FDHMT

Optimization of electrically cooled complex HPGe Detector

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GSI Helmholzzentrum für Schwerionenforschung GmbH
Planckstraße 1
64291 Darmstadt

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CONTENTS

1. Introduction

The current study presents a novel technique used for design and optimization of a composite HPGe detector with one or three encapsulated Ge-crystals and based on electromechanical cooling engine. In this technique is accentuated on the detailed investigation of the heat transfer processes – each one separately and in complex, and their impact on the detector performance. The dominating heat transfer mechanisms have been identified and appropriate mathematical model has been applied. Temperature distributions within the detector structure are calculated for various environment and cooling conditions and the functional characteristics of the assembly needed to reach the operational temperature range, are determined.

2. Single capsule electrically cooled detector.

2.1. Geometry description

The single and triple capsule detector is based on a standard EB-capsule, Fig.1. The germanium crystal is fixed inside the capsule by an indium pad with a thickness of 0.7 mm. This fixing prevents damaging the implanted surface of the germanium and provides a constant distance to the inner capsules wall. However in this case the cooling of the germanium crystal is predominantly through the indium pad.

The capsule is attached to a special frame, further named Cold frame, which subsequently is attached to the Cold finger. The previous analysis have shown that the length of the Cold finger, even made out of highly thermoconducting cooper, and number of the thermal junctions are of paramount importance for the good cooling of the capsule. In order to minimize the number of the sections, the Cold finger is made out of only two sections – one with cold flex and small vacuum getter container and another on which the Cold frame is fixed. Thin indium pads of 0.1 mm are used to improve the junctions' thermal contacts.

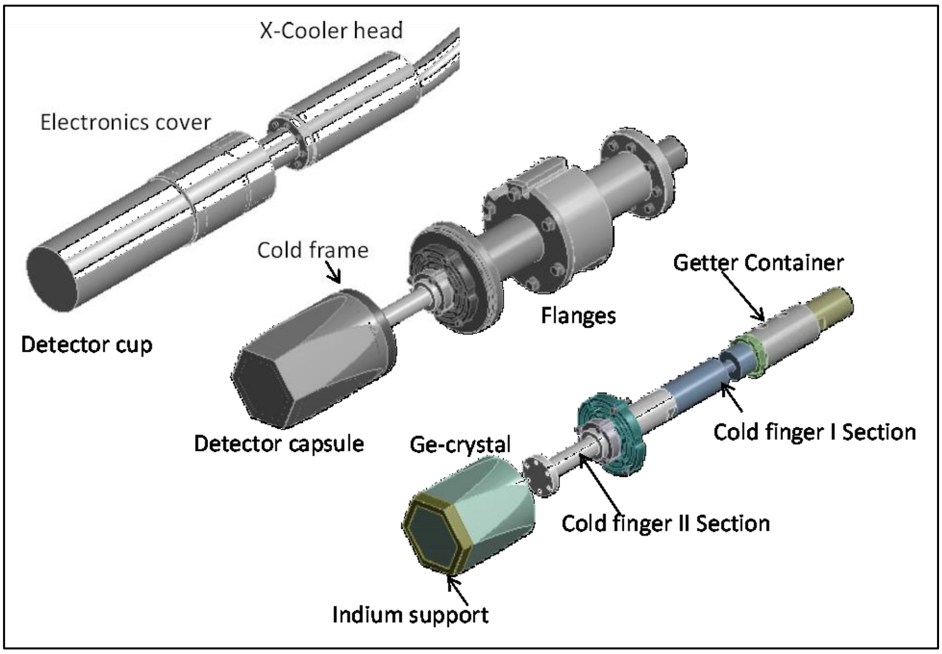

Fig.1. Structure of the single capsule cryostat.

The previous studies have pointed on the impact of the reduction of the residual gas heat transfer between the capsule and the warm components on the overall thermal management. In order to provide high vacuum along the whole cold structure, two stages vacuum conditioning system is used. The first stage is a small getter container in the Cold finger first section, placed very close to the cooling head cold finger and is to deliver a good vacuum at the initial phase of the cooling. The second stage is a special large volume main getter container, Fig.2, and is placed directly under the Cold frame thus ensuring high vacuum around the capsule. This system also enables easy start up the cooling process even with a low thermal power of the cooling engine.

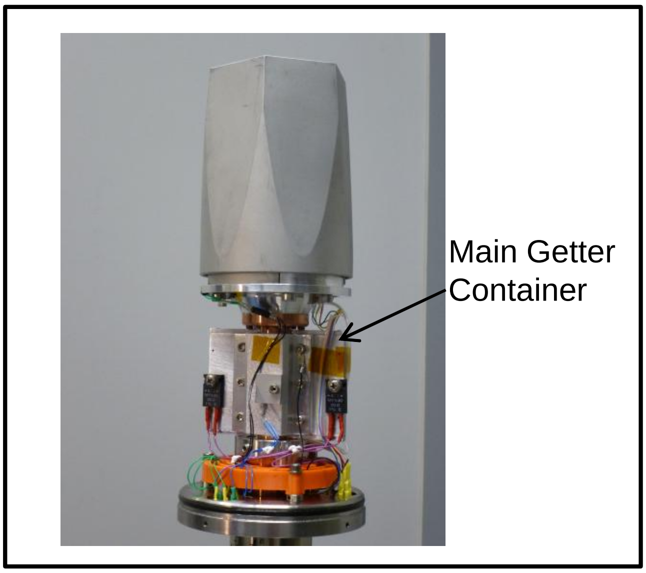

Fig.2. Main getter Container position.

The fixing structures are optimized in order to have as low as possible thermal conduction between the cold and warm sections. In fact only two holders are foreseen – the main holder fixes the capsule along Z, φ and θ (in cylindrical coordinates) and another small centering ring which is to absorb any production tolerances and thermal stress based distortions along θ, Fig.3.

The electric connections are made out of very thin Teflon insulated cooper wires with a length of approx. 15 cm which essentially do not contribute substantially to the overall thermal dynamics. The cold stage of the preamplifier DC rate delivers only 50 mW power. Three Pt100 sensors are used to monitor the temperature – one at the Cold Frame, one at the main getter container and one at the cooling head Cold finger.

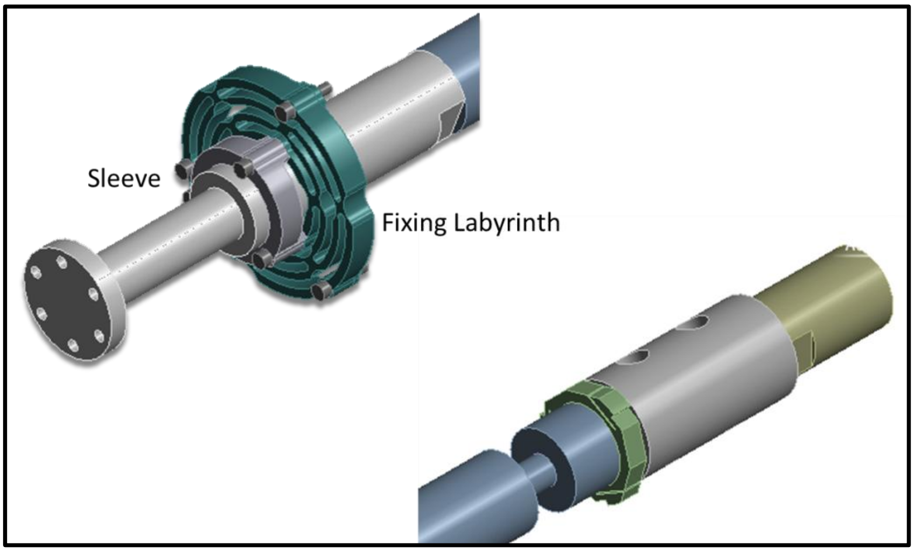

Fig.3. Cold structure mechanical support

2.2. Mathematical model

Temperature field simulations have been performed for the complete detector assembly: germanium crystal within the detector capsule being into the contact through an indium support, the composite cold finger altogether the zeolite container, the composite flange, as well as the fixing parts and the cryostat and the electronics cover.

Specific issue was to verify if the temperature along the germanium crystal is within the operating temperature range.

The temperature distribution has been calculated using the time dependent heat transfer equation

(1) $\nabla\cdot(\lambda\nabla T)=\rho c\partial T/\partial t$,

where the symbols have the following meaning

T [K]	temperature
λ[W/m²K]	thermal conductivity
c[J/kg.K]	specific heat
ρ[kg/m³]	mass density
t[s]	time.

The heat transfer within the interior domain of the assembly is being carried out under a broad temperature interval typically ranging from 77 K up to 300 K. The thermal conductivity displays a temperature dependent behavior in such a wide-stretched domain and its values at room temperature may not be a good base for calculations.

The temperature dependent behavior of the thermal conductivity has been also accounted.

The boundary condition at the interface between the cooling engine and the detectors assembly is defined as follows

(2) $T=T_{cf}$

Here T_{cf} is the temperature of the cold finger.

The outer part of the detector assembly is supposed to be equal to the room temperature T_{am} so that

(3) $T=T_{am}$.

Perfect thermal contact conductance between parts means that no temperature drop occurs at the interface. But numerous conditions can contribute to less than perfect contact conductance: surface flatness, surface finish, oxides, contact pressure and etc. Then the amount of heat flow across a contact interface is proportional to the temperature of the both sides of the contact. The thermal conductance is a measure of the ability of a material to transfer heat per unit time, given one unit area of the material and a temperature gradient through the thickness of the material. It is measured in watts per meter per degree Kelvin. Within the study an imperfect contacts between the assembly components have been considered.

Thermal Radiation heat flow rate from surface *i* to surface *j* is based on Stefan-Boltzmann law and given by

(4) $q=\varepsilon\sigma A_{ij}F_{ij}(T_i^4-T_j^4)$

with

σ[W/m²K4]=5.6704•10-8	Stefan-Boltzmann constant
ε	surface emissivity
A_i	area of surface i
F_{ij}	form factor from surface *i* to surface *j*
T_i	absolute temperature of surface *i* and
T_j	absolute temperature of surface *j*.

Finally the model has been completed by taking into account the irradiation between the capsules surfaces and the cryostats. The irradiation between the Ge-crystals and the capsule walls has been neglected due to the minor temperature difference there.

Remark: A support of the germanium crystal has been chosen to be manufactured from indium. Up to now the thermal conductivity of that material has not been discussed. That is why take the thermal conductivity of indium as a function of temperature is presented in Fig.4.

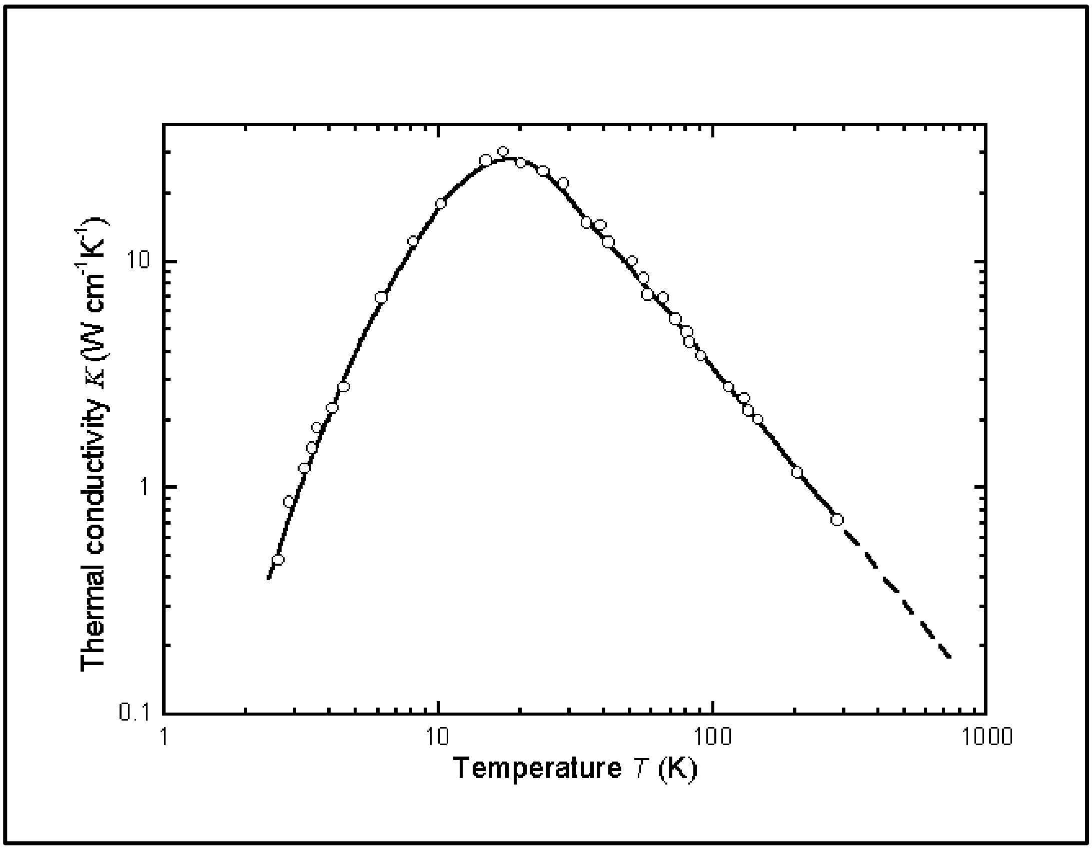

Fig.4. Indium thermal conductivity as a function of temperature (after Aliev et. al. 1965).

2.3. Thermal simulations

The simulations have been carried out at temperature of the cooling part 80 K and the ambient temperature of 290 K. The emissivity of the Ge-capsule is taken to be 0.2 when the emissivity of the processed inner surface of the cryostat is 0.1.

Thermal conductivity of Vespel, used for the mechanical supports, varies strongly with its type. That is why two different scenarios have been investigated: first when fixing parts are manufactured from Vespel with thermal conductivity of 0.35 W/m.K and then when they are manufactured from Vespel with thermal conductivity is 0.5 W/m.K.

The fixing parts are supposed to possess a weak contact to the other metal parts of the assembly. Within the simulation the thermal conductance there is supposed to be 1000 W/m^2.K.

In contrast, special cares have been taken to assure a good contact between the composite cold finger components. Though in the second progress report it has been revealed that the thermal conductance significantly influence the temperature deviation along the Cold finger and consequently the operating temperature. To learn more about the thermal contact quality an experimental verification has been suggested and presented in the third progress report.

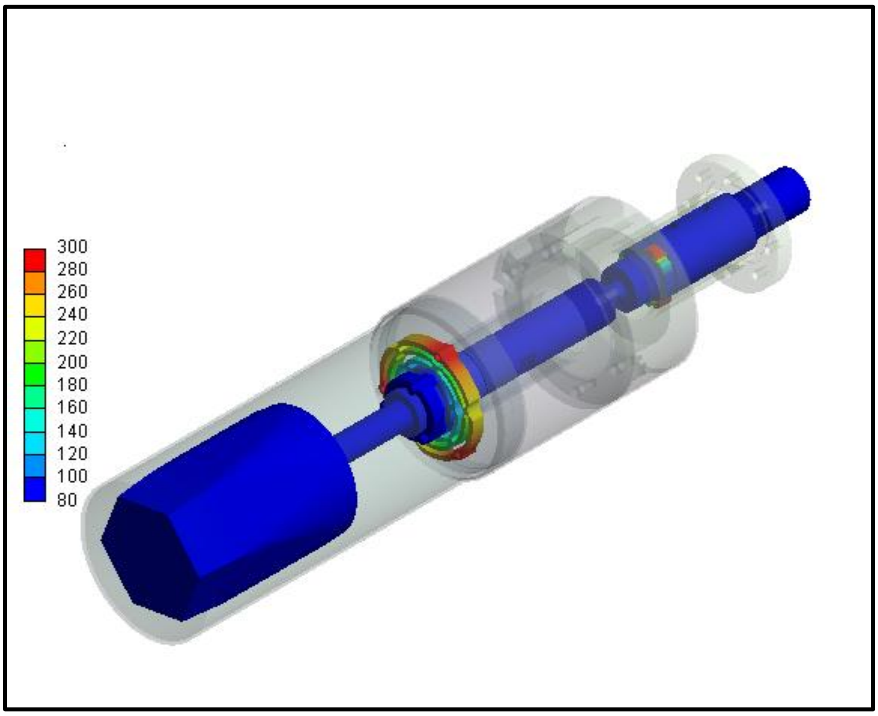

Fig.5. Temperature distribution along the detectors capsule, the composite cold finger, the fixing labyrinth and the cold finger support when the temperature of the cooling part is 80 K and the ambient temperature is 290 K. The emissivity of the detectors capsule is 0.2 when the emissivity of the processed inner surface of the cryostat is 0.1. Thermal conductance between composition parts of the cold finger is 2000 W/m^2.K. Thermal conductance between the other parts is considered to be 1000 W/m^2.K.

Now to learn how the thermal conductance influences the operating temperature of the Germanium detectors two scenarios have been investigated. Initially the calculations have been performed with the thermal conductance of 2000 W/m^2.K and then with 2500 W/m^2.K.

Clearly to identify the temperature distribution for the different construction parts the temperature range has been chosen appropriately and the plots are given separately in Fig.5-8.

It is to mention that starting from 80 K at the end of the cooling part, the temperature rise up to 85.2 K at the sleeve and then reaches 91.4 K at the germanium crystal.

The resulting heat flux is 1.53 W when the fixing parts are manufactured from Vespel with thermal conductivity of 0.35 W/m.K and increases to 1.72 W for the fixing parts manufactured from Vespel with thermal conductivity of 0.5 W/m.K.

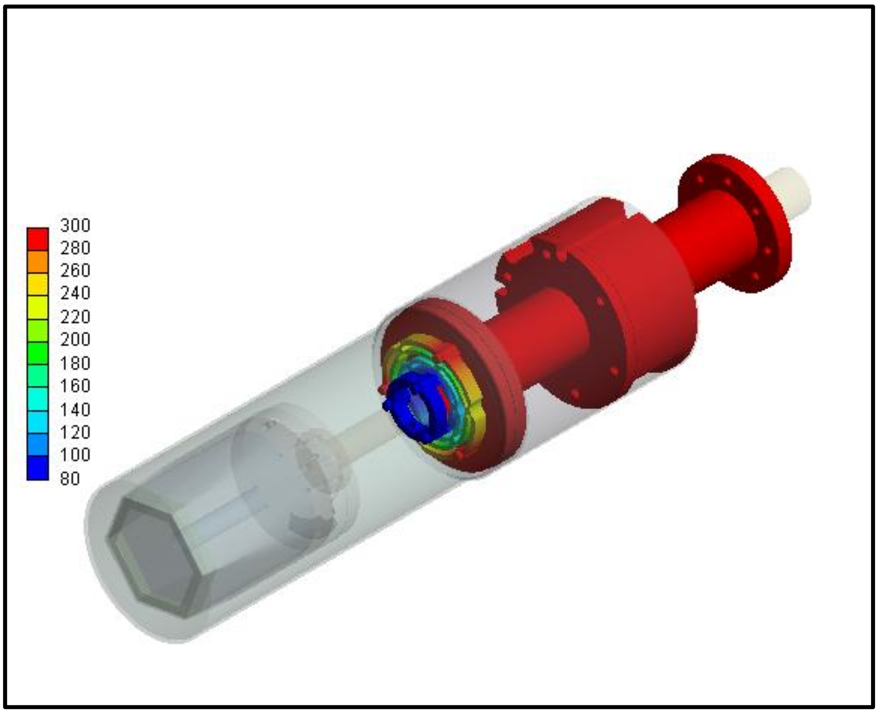

Fig.6. Temperature distribution along the fixing labyrinth and the flanges when the temperature of the cooling part is 80 K and the ambient temperature is 290 K. The emissivity of the detectors capsule is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. Thermal conductance between the cold finger components is 2000 W/m^2.K. Thermal conductance between the other parts is considered to be 1000 W/m^2.K.

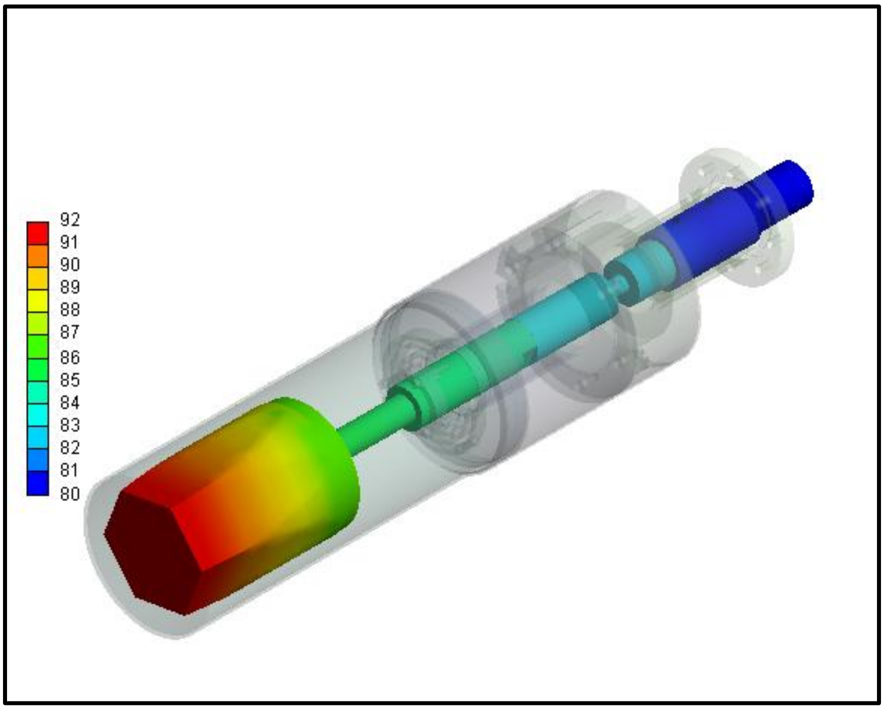

Fig.7. Temperature distribution along the detectors capsule and the composite cold finger when the temperature of the cooling part is 80 K and the ambient temperature is 290 K. The emissivity of the detectors capsule is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. Thermal conductance between different tails of the cold finger is 2000 $W/m^2.K$. Thermal conductance between the other parts is considered to be 1000 $W/m^2.K$.

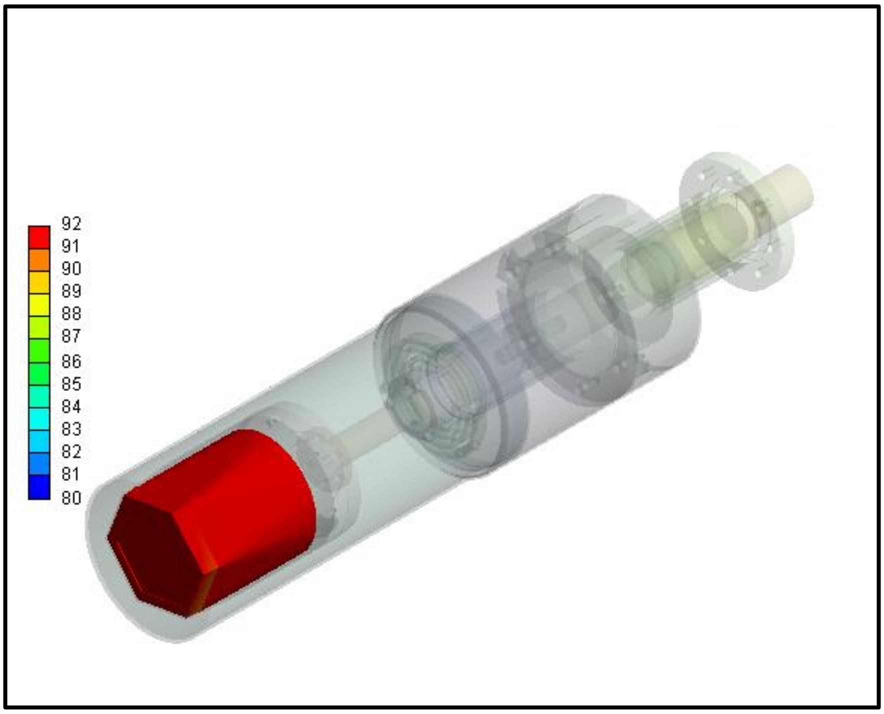

Fig.8. Temperature distribution along the Ge-crystal and the indium support by the temperature of the cooling part is 80 K and the ambient temperature is 290 K. The emissivity of the detectors capsule is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. Thermal conductance between different tails of the cold finger is 2000 $W/m^2.K$. Thermal conductance between the other parts is considered to be 1000 $W/m^2.K$.

Contact between the Cold finger and the Cold frame is of paramount importance for the thermal management of the whole detector assembly and different scenarios have been evaluated in this study.

An increase of the thermal conductance from 2000 W/m^2.K to 2500 W/m^2.K leads to an decrease of the Ge-crystal temperature from 91.4 K to 90.6 K (Fig.8-9)

The contact quality slightly influences the heat losses but has a strong impact on the temperature increase along the crystal surface.

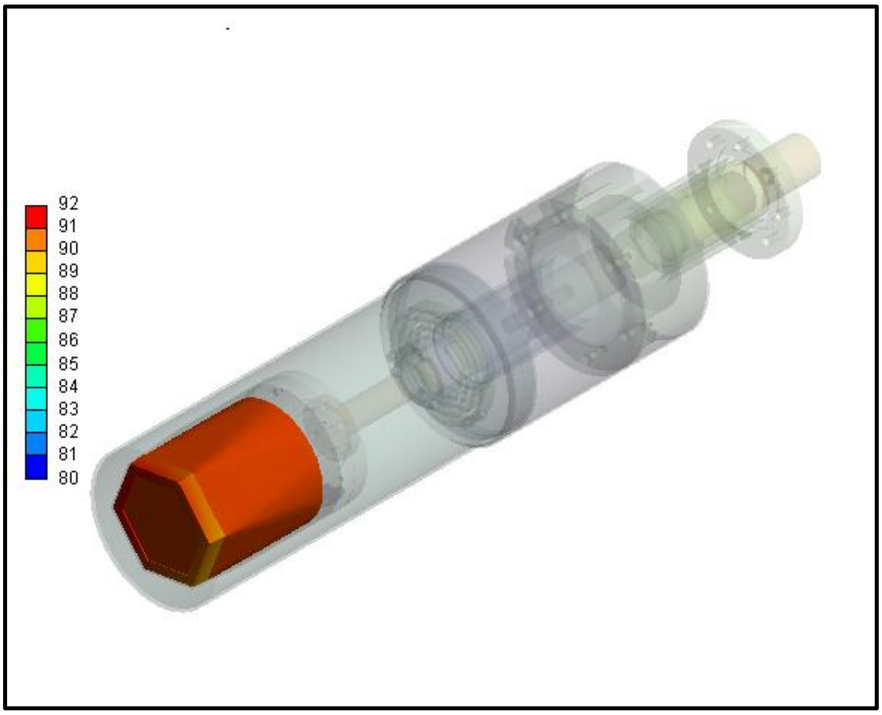

Fig.9. Temperature distribution along the Ge-crystal and the indium support by the temperature of the cooling part is 80 K and the ambient temperature is 290 K. The emissivity of the detectors capsule is 0.2, when the emissivity of the processed inner surface of the cryostat is 0.1. Thermal conductance between different tails of the cold finger is 2500 W/m^2.K. Thermal conductance between the other parts is considered to be 1000 W/m^2.K.

The experiments with cooling the single capsule structure are a good agreement with the predictions. On Fig.10 are shown the temperatures measured at the point shortly after the input of the cold structure of the cryostat, at the main getter container and at the Cold frame. The temperature difference of 4.7 K seems somewhat lower than it is predicted, namely 6.2K. However, the lowest point measured is after the junction between the Cold finger section 1 and the cooling head cold finger, which influences significantly the results. Generally, these results are derived as a function of such parameters as the emissivity, thermal conductivity etc. which are not well known. The emissivity of the capsules varies large from capsule to capsule, the thermal conductivity of the Vespel and other materials is known from the literature and not by producer specifications. The tolerances of these parameters are also unknown. Therefore, conservative values of the parameters have been considered, so that any divergence of the averages would not affect significantly the resulting temperature. From this point of view, these results should be considered as an upper limit for the temperatures.

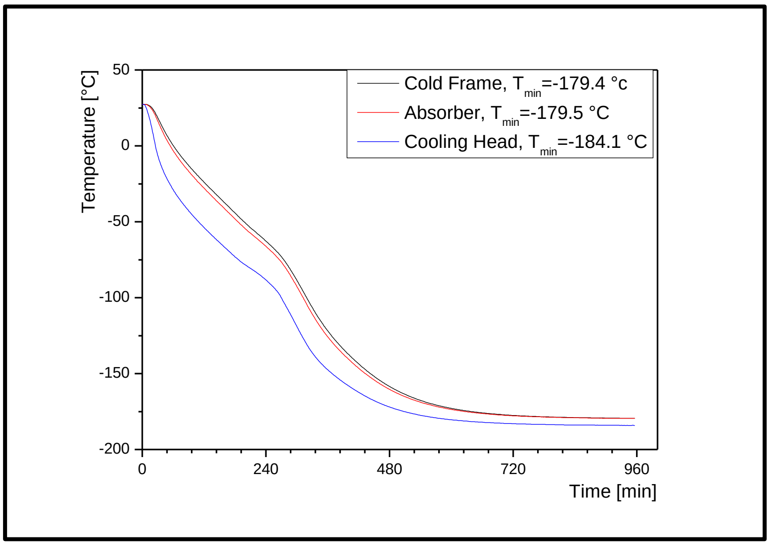

Fig.10. Cooling of the single capsule assembly, capsule HEX 158.

It is also remarkable the kink of the temperature plot around 170-180 K. This cannot be explained only by the temperature dependence of the cooper heat capacity, it is rather smooth in this region. At this temperature the absorbing capacity of the getter in the main getter container grows up considerably causing significant vacuum improvement, so that the effect of the residual gas heating becomes negligible and which ultimately accelerates the cooling.

5. References

Aliev, S. A., A. Ya. Nashelskii, and S. S. Shalyt, *Sov. Phys. Solid State* **7**, (1965) 1287.