FRONT PAGE

PROJECT FINAL REPORT

Grant Agreement number: 607182

Project acronym: LIGHT-TPS

Project title: Light-Weight Thermal Protection System for Space Application

Funding Scheme: Collaborative Project

Period covered: **from** 2015/05/01 **to** 2017/08/31

Name of the scientific representative of the project's co-ordinator[1], Title and Organisation:

Dr.-Ing. María Parco

Fundación Tecnalia Research & Innovation

Tel: +34-946430850; +34-667119601

Fax: +34-946460900

E-mail: maria.parco@tecnalia.com

Project website address: http://www.light-tps.eu/

[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

2. FINAL PUBLISHABLE SUMMARY REPORT

2.1. Executive summary

The future development of near space research and exploration is unthinkable without developing a new generation of reusable space vehicles. All countries active in space have extensively invested in R&D programmes aimed at creating reusable spacecrafts (e.g. X-38 Crew Return Vehicle (USA), SHEFEX (DLR, Germany), Foton (Russia), USV (Italy), etc.), which would overcome the limitations of former reusable space systems (RSS), such as: high weight and size leading to extremely high costs of a mission; high maintenance costs and insufficient reliability.

The basic underlining idea of the project was to combine principle advantages of new metallic and ceramic materials in a single thermal protection system by combining metallic TPS with non-metallic materials (e.g. C/SiC and C/C) and construction elements made of UHTC and heat resistant alloys, coated by composites on the basis of UHTC. In order to gain the highest possible TRL within the project time frame, a decision was done to guide the developments according to two different application scenarios:

A. Light-TPS systems based on new metal frame and NiCr- or Nb- alloys, supposed to be used in flat surfaces where the operating temperatures do not exceed 1100°C and with a specific weight < $10Kg/m^2$.
B. Light-TPS systems based on non-metallic structures, addressed to sharp components, where the operating temperatures overpass 1600°C. For this purpose, highly refractory ceramics and coatings on its basis for the thermal protection of elements made of C/SiC and C/C shall be developed. Additionally, the possibility to apply a graded metal-UHTC layer on Nb base substrates for oxidation/erosion protection shall be explored.

Scenario A: With focus on scenario A, basic requirements to reusable spacecrafts (RSC) have been collected for orbiter vehicles like Space Shuttle (USA), Buran (USSR), Hopper, Hermes (ESA), as well as for multiple TPS.

Main achieved results in scenario A: In first place, new heat resistant oxide dispersion-strengthened powdered and sintered alloys on the basis of NiCr and Nb with densities down to 7.450 and 5.558 g/cm^3, respectively, have been developed. Relevant thermo-mechanical properties have been characterized within the temperature range of 20 -1200 °C. Developed materials have been hot/cold rolled to foils with thicknesses down to 0.06 mm. Based on experimental data and design activities, a new TPS design in size of 300x300 mm was developed that consists of four single tiles of 150x150 mm each. The external panel is a three-layer honeycomb manufactured in the developed Ni-Cr-Al alloy. The same consists of top shell, honeycomb core with hexagonal cell and bottom shell. The single tiles junction is achieved with U- shaped profiles. The stands are made as a unit bracket with four supports. The single tile structure is strengthened at the corners by 4 angles, which are designed for load transfer from the tile external shell to supporting node stand. Two TPS mock-ups have been manufactured using the developed NiCr alloy and corresponding structural elements: 1) 1st mock-up in size of 310 x 150 mm, consisting of two tiles of 150 x 150 mm each; 2) 2nd mock-up in size of 165 x 165 mm, consisting of four tiles of 75 x 75 mm each. The 1st mock-up was tested under complex mechanical loading conditions imitating the expected operational loads, while the 2nd mock-up was aimed to determine the thermo-mechanical strength of TPS structure. The developed TPS structure has been qualified in TRL4.

Scenario B: In order to stablish reference service parameters for demonstration of the UHTCs to be developed in the frame of the project, the heating distribution environment and pressure in the nose cap of the re-entry vehicle X-38 have been analysed in addition to the requirements collected for scenario A. The trajectory of X 38 is similar to those of Space Shuttle, Buran, Hopper and Hermes.

Main achieved results in scenario B: Alternative atmospheric thermal spray depositions processes were investigated in the frame of LIGHT-TPS, leading to homogeneous and dense UHTC coatings on the basis of ZrB_2-SiC-WC, ZrB_2-$MoSi_2$ and ZrB_2-20SiC-10AlN. Accelerated oxidation tests, performed under hypersonic combustions flames and with a Plasma Wind Tunnel facility, have shown the potential of these UHTC coatings for the oxidation protection of non-oxide CMC substrates (C/C and C/SiC composites). Single UHTC on the basis of ZrB_2-3SiC-5WC and ZrB_2-20SiC-10AlN have been deposited on C/C and tested in Plasma Wind Tunnel test facility at probe stagnation pressures around ~23-25 mbar, surface temperatures between ~ 1800-2000°C and an exposure time between 5-6 min. The composition ZrB_2-20SiC-10AlN showed a higher stability under selected test conditions and preserved its integrity even though a clear oxidation layer is present.

2.2. Summary description of the project context and the main objectives.

The future development of near space research and exploration is unthinkable without developing a new generation of reusable space vehicles. All countries active in space have extensively invested in R&D programmes aimed at creating reusable spacecrafts (e.g. X-38 Crew Return Vehicle (USA), SHEFEX (DLR, Germany), Foton (Russia), USV (Italy), etc.), which would overcome the limitations of former reusable space systems (RSS), such as, for instance, the Space Shuttle, notably:

- High weight and size leading to extremely high costs of a mission;
- High maintenance costs;
- Insufficient reliability.

Future RSS will require greatly improved Thermal Protection Systems (TPS) to achieve the ambitious goal of reducing the cost of delivering a payload to orbit by an order of magnitude. An improved TPS, suitable for RSS, must not only perform its primary function of maintaining the underlying vehicle structure within acceptable temperature limits, but must also be durable, operable, cost effective, and light. Durability implies resistance to damage from such environmental threats as handling, low-speed impact, hypervelocity impact, and rain impact as well as the ability to tolerate some level of damage without requiring repair. Operability includes ease of removal, replacement and repair, and minimal maintenance between flights (e.g., minimize or eliminate waterproofing). Cost effectiveness considerations include initial development, fabrication and installation costs, and maintenance costs over the life of the vehicle as well as the impact of TPS on the vehicle performance. The mass of the TPS and limitations on all-weather flying capability significantly affect the performance of the vehicle.

The wide range of temperatures and conditions to which the thermal protection is exposed on the different positions of a RSS impose high demands on the materials for its production. For areas with surface temperatures around 1100-1200°C, a metallic TPS based on honeycomb constructions is the preferred solution. Currently, the most promising high temperature alloys are those based on either nickel (PM-1000 and domestic H80X20 nichrome) or iron (PM-2000), with the heat resistance of PM-2000 being somewhat lower than that of PM-1000 at almost the same refractoriness. However, the main disadvantages of existing TPS based out of such metallic alloys are the significant weight and insufficient lifetime, due to the degradation and corrosion of the metal.

On the other side, thanks to their high strength, high hardness, superior fracture toughness, good thermal shock resistance and low density at elevated temperature, carbon-based Ceramic Matrix Composites (CMCs) are the standard choice for service temperatures in the range of 1260-1650 °C. In this temperature range, TPSs on the basis of carbon-carbon composites (C/C) reliably operate by the principle of "radiation cooling." The disadvantage of this materials class is the low resistance to high temperature oxidation. All oxidation protections for C/Cs basically include three components to protect against oxidation attack over long - term applications, i.e. inner bulk protection, outer multilayer CVD - coating, and finally a glass sealing layer serving as a surface coating. For high temperature applications, bulk treatments are often performed with silicon to form SiC, which possesses superior oxidation protection behavior compared to salt impregnations. Low surface temperatures and high oxygen partial pressures promote the formation of a glassy SiO_2 layer over the surface of these materials. This situation is often referred to as passive oxidation and often corresponds to a net mass increase. Nevertheless, higher temperatures and lower pressures can lead, instead, to the volatilization of silicon oxide products into the gas phase, hence a net mass loss. This scenario, referred to as active oxidation, can become a harmful condition for the integrity of the TPS. The application of ultra-high-temperature ceramics (UHTCs) coatings might be an effective way to reach the goal of improving the in-service performance of CMC structures at temperatures of above 1600°C. This class of materials possesses a unique combination of physic-chemical properties such as the highest melting points of any groups of materials, low creeping rate, good chemical stability in aggressive environment and high thermal conductivity that makes them specifically suited for application in the aerospace sector.

In this sense, new materials and construction technologies are needed in order to overcome the limitations of state-of-the-art TPSs, in particular:

- Lighter alloys with higher thermal, corrosion and oxidation resistance at temperatures around 1100-1200 °C (basis for metallic TPS);
- New UTHC materials with superior oxidation and erosion resistances at temperatures close to 2000 °C and coating technologies for depositing the same on metallic and non-metallic materials;
- Better construction technologies (e.g. new welding technologies for the production of honeycomb sandwich panels) enabling the implementation of new high temperature metallic alloys.

The LIGHT-TPS project aimed at developing innovative materials and manufacturing technologies for the fabrication of a new generation thermal protection systems for future reusable space systems. The main challenge of the project was to develop a super-light, corrosion and oxidation resistant TPS by combining the advantages of metallic and ceramic materials in a single system. Particularly, three main research pillars have been envisaged:

1) Development of new high temperature alloys on the basis of Ni/Cr and Nb for the frame of the TPS;
2) Development of reusable light weight multilayer TPS structure out of the developed NiCr- or Nb-base alloys;
3) Investigation of erosion-resistant UHTCs bulk materials in the ZrB_2-SiC and ZrB_2-$MoSi_2$ systems and development of erosion/oxidation protective coatings on either metallic and non-metallic materials with the most suitable UHTC compositions.

The developed TPS shall be significantly lighter than any existing TPS (under 10 kg/m^2) thus reducing the cost of delivering a payload to orbit and volume of emission, guarantee reliable thermal protection in the entire range of working temperatures, possess improved mechanical and durability properties.

In order to attain the overall project goal, the following technical objectives have been pursued:

O1. To study and systemize the system requirements for the TPS development based on at least 2 of the most advanced European projects concerned with the development of reusable spacecrafts and/or other space systems using TPS.

O2. To research the mechanisms of secondary structures formation under high-temperature oxidation conditions on the working surface of traditional nickel-chromium alloys (reference material is the YUIPMS alloy developed by YUZHNOYE) in correlation with the manufacturing technology with the aim of increasing their operational characteristics.

O3. To develop the manufacturing technologies for a new alloy based on Niobium, which shall possess better exploitation characteristics (i.e. specific weight of 5830–6000 kg/m^3 and improved corrosion resistance).

O4. To investigate the respective physical processes and to develop new oxidation/erosion protective coatings out of UHTC composites based on the ZrB_2-SiC systems, suitable for applications at temperatures up to 2000^{o}C. To investigate the processes of the secondary structures development on such surfaces during exploitation.

O5. To develop realistic prototypes of the TPS elements incorporating new materials, technologies and processes. To carry out the system of tests and evaluation in order to estimate to what extent the technical requirements set at the beginning of the project were met.

O6. To make the project outcomes available to the research communities and potential users (developers of future RSS and respective technologies). To ensure a proper identification, documentation and protection of new knowledge and its transfer to the industry.

2.3. Description of the main S & T results/foregrounds.

In the following, main activities performed inside the different work packages (WP) leading with the technical work and the most outstanding results collected in each case are summarized.

➢ WP1. Collection of requirements:

The first step of the project consisted of the collection of user requirements. Based on existing literature and practical data, technical requirements to the materials and elements of the TPS to be developed in the project have been formulated. A list of key technical, economic and operational requirements has been formulated.

Project results shall be validated in two scenarios:

a) Light-TPS with metal frame out new NiCr- or Nb- base alloys (TPS design/construction/ground test in charge of YUZHNOYE). Service temperature shall be limited to 1100°C due to the NiCr- or Nb- alloy.

b) New UHTC materials in form of a bulk and/or coating on non-metallic structures (definition of scenario done by DLR). Service temperature close to 2000°C.

Based on the analysis of the external influences at maximum levels, it was shown that the trajectories of orbital vehicles like the Space Shuttle (USA), Buran (USSR), Hopper or Hermes (ESA) are identical and any of them can be used as a model to calculate temperature changes and pressure in timing. A conventional trajectory and set of influence levels has been defined for the development of the metallic TPS. In the same way, the volume of ground tests has been defined for the metallic TPS.

➢ WP2. Development of powder alloys:

<u>Task 2.1 - Development of alloys on the basis of NiCr:</u>

Two materials on the basis of nichrome with the following compositions have been developed by IPMS:

- Ni - the base, Cr - 20 %, Al- 5.7 %, Yttrium, oxide - 1 %;
- Ni - the base, Cr - 20 %, Al- 5.95 %, Ti – 1%, Yttrium, oxide - 1 %.

The technology for manufacturing preforms with a relative density of more than 92 % has been developed. Theoretical density of first alloy is equal 7.5 g/cm^3, while the corresponding value for the second composition amounts to 7.44 g/cm^3.

Ingots out of the developed NiCr alloys have been rolled to sheets with thickness between 0.5 mm till 0.05 mm following hot and cold-rolling procedures developed by IPMS. The physical-mechanical and functional properties of rolled foils have been characterized. Measured properties meet the technical requirements for the bulk samples. It was shown that a moderate porosity is found in the microstructure of Ni-Cr alloy foil, which is concentrated predominantly in the material subsurface layers. On the other side, the Ni-20Cr-6Al alloy in as-delivered condition has significant work-hardening as result of rolling process. Average microhardness values amount to H = 2.946 GPa, with a ductility factor of K = 0.660.

Additionally, following simulation activities have been performed by SRI:

1. An analysis and optimization of the TPS temperature fields during the diffusion welding process have been conducted.
2. 3-dimensional heat transfer problems were modeled with the continuous state space equation through mode reduction technique. After deriving a solution in a frequency-domain, an observer was designed with the Butterworth low pass filter. And then, an adaptation algorithm was applied so as to estimate the time-variant parameter in actual thermal process.

3. A methodology for localizing fastener failure in a TPS was developed, utilizing an experimentally validated finite element model.
4. The inverse optimization problem implemented in the first level of experimental validation demonstrated excellent agreement between the finite element model and the experimental results.
5. An analysis of the kinetics of densification process occurring in powder alloys based on the detailed population balance approach has been conducted. It has been shown that the densification kinetics is described approximately by a root dependence on the sintering time, except the final stage of the densification process.
6. The algorithm for finding the distribution of temperature fields inside the TPS has been developed. It has been shown that the heat inside the TPS is transferred mainly along the metallic frames. The estimated time of balancing the temperature and the thermal flow in the TPS is 10-100s.

<u>Task 2.2 - Development of alloys on the basis of Nb:</u>

A new heat resistant dispersion-strengthened alloy on the basis of niobium with reduced density (5.5 -5.7 g/cm^3) was developed by IPMS. Composition of developed Nb-based alloy: Ti - 45±1%, Al, - 6±0.5%, Y_2O_3 - 1±0.5%, the rest is Nb, possible introduction of Zr – 1.5±0.5% and Cr – 1±0.25%.

Technology for reaction sintering of this material was implemented. The heat resistance of the alloy was studied. It was shown that the material fulfils the requirements linked to the expected service conditions at 1200 ºC, thus withstanding 100 cycles of heating and cooling to room temperature. Tests have shown that material loss is equal 1 % of its mass under the cyclic heat loadings. The developed material has characteristics corresponding to niobium alloys and can operate continuously at a temperature of 1200 °C, which exceeds analogues materials. In the initial condition, the niobium alloy has an average hardness value of Hm = 5.388 GPa with a ductility factor of K = 0.814.

<u>Task 2.3 - High temperature tests of the samples of Ni-Cr and Nb alloys under the conditions of oven, convection and radiation heating:</u>

Heat resistance of the alloys was studied under the effect of oven, radiation and convective heating (most outstanding results have been already commented above). It was shown that annealing of Ni-20Cr-6Al alloy does not lead to any significant changes of its structure or chemical composition. On the other side, annealing of the alloy at T = 1200 ºC for 20 minutes in vacuum leads to a significant increase of the alloy microhardness from H = 2.946 GPa up to H = 5.109 GPa. By the results of micromechanical testing, as light decrease of average values of niobium alloy microhardness from Hm = 5.388 GPa to Hm = 5.263 GPa and a slight increase of its ductility factor from K = 0.814 to K = 0.819 are noted after annealing.

The implementation of Ni intermediated layers (deposited by EB-PVD) on the joint surface of Ni-Cr alloy foils, was to found to be a suitable solution for obtaining well-structured diffusion welding joints. A subsequent annealing in air at a temperature of 700 ºC for 50 hours, led to joints with chemical element distributions similar to those found in base metal.

- **WP3. Development of super-light multilayer TPS:**

<u>Task 3.1 - Development of the construction and manufacturing technology for TPS:</u>

The initially developed TPS design is a panel of 300 x 300 mm in size that consists of four single tiles of 150 x 150 mm each (see **Figure 1**). The external panel is a three-layer honeycomb structure. The same consists of top shell, honeycomb core with hexagonal cells and bottom shell. The single tiles junction is achieved with U- shaped profiles. The stands are made as a unit bracket with four supports. The unit tile hardeners are 4 angles, which are designed for load transfer from the tile external shell to supporting node stand that has led to weight indexes increase.

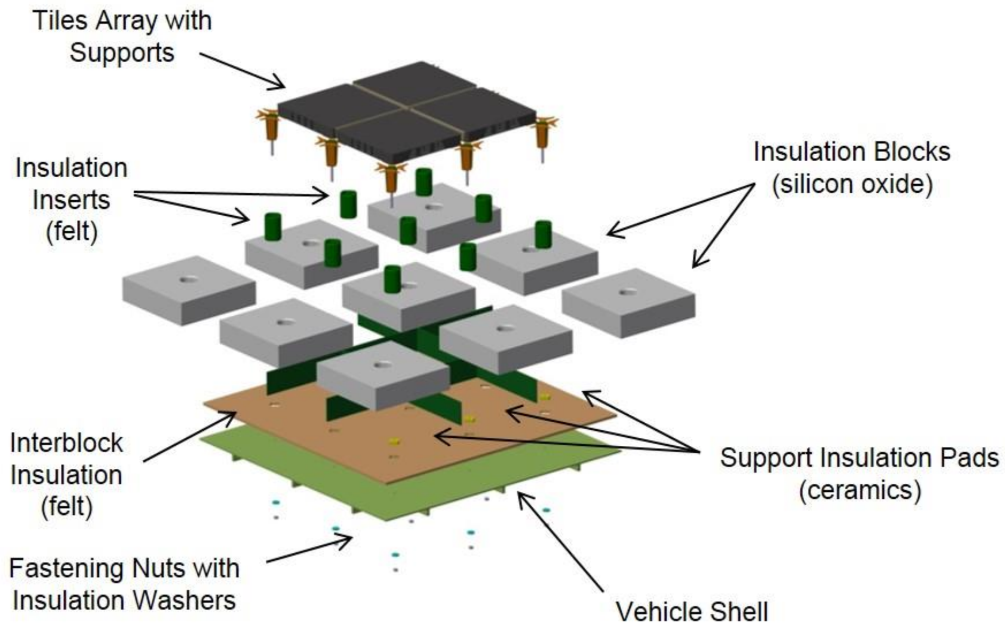


Figure 1: General view of the metallic TPS structure designed in LIGHT-TPS.

In a following step, based on collected experimental data and simulation activities, YUZHNOYE optimized the design of the different TPS elements. In first place, the design of the honeycomb structure has been modified to fulfil the expected specific mass requirement, i.e. an area specific mass below 10 kg/m^2. In the optimized configuration, the hexagonal cells are formed by ribs having a length equal to 15 mm and a thickness equal to 0.1 mm. On the other side, the four individual tiles are connected by linear double U-shaped connecting elements. The junctions of the four tiles (central part) are not connected to each other. Sealing is ensured by a freely embedded crossing between the double U-shaped connecting elements, that eliminates the rigid bond with the outer casing (see **Figure 2**).

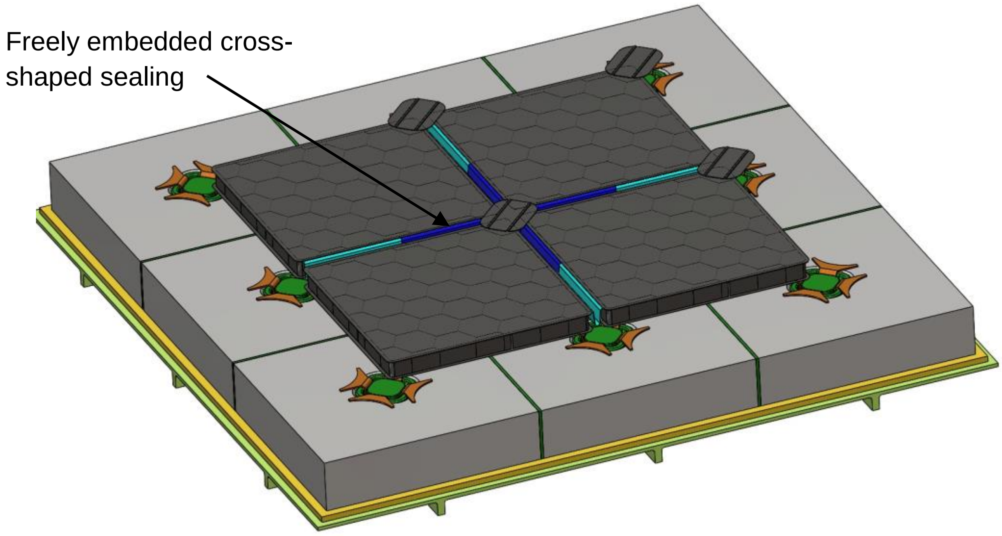


Figure 2: Optimized design of the metallic TPS.

To prevent the cross-shaped sealing from falling out and the hot gases to flow into the central part of the structure, a special lining is being applied. Related strength calculations demonstrated the efficiency of the designed double U-shaped sealing as well as the suitability of the freely embedded cross-shaped plug which provides free movement of tiles under the temperature loads.

In relation to the development of the welding methods, following activities were performed by IEW:

1. The feasibility of using interlayers of different chemical composition for construction of diffusion welding joints was investigated, showing that application of Al/Ni and Cu/Ti multilayers by the EB-PVD technology promotes the formation of joint diffusion zones with higher level of microhardness. Application of interlayers based on porous foils from nickel, copper and cobalt, allows establishing physical contact of the joining surfaces, thus facilitating the diffusion processes and weld joint formation. Those joints produced using interlayers based on nickel and copper have a defect-free structure.
2. The diffusion welding of the Nb-30Ti-6Al niobium alloy was investigated. It was shown that welding at a temperature of 900 ºC in combination with a pressure of 20 MPa provides the dissolution of the oxide film and the formation of common grains in the butt joint. Moreover, the application of a 20 μm thick interlayer from VT1 low alloy, promotes the formation of a defect free joint with several diffusion zones along the butt joint.
3. The manufacturing procedure of three-layer honeycomb panels was developed, which consists of: Cleaning of foil strips, shaping (profile formation), spot welding of the honeycomb block, grinding of end surfaces, application of intermediate layers and diffusion welding of shells with the honeycomb filler.
4. A special holder was designed and constructed to achieve a diffusion welding treatment of three-layer honeycomb panels under homogenous temperature and pressure conditions.
5. The behaviour of the three-layer panel under the heating conditions imposed by the vacuum diffusion welding treatment was investigated. It was shown that the behaviour of the panel is essentially influenced by a number of geometrical factors, namely imposed by the rectangular shape of three-layer panel, cylindrical shape of heaters, small panel height and its considerable surface area. In addition to the homogenization of temperature fields over the entire panel surface, it was demonstrated that shielding of all panel sides is a suitable way to prevent an excessive deformation of the panel during the welding process.
6. Three-layer honeycomb panels in size of 150 x 150 mm and 72 x 72 mm, out of the developed Ni-20Cr-6Al and Nb-30Ti-6Al alloys, were manufactured by diffusion welding at IEW and delivered to YUZHNOYE for TPS demonstrators assembly and ground testing.

Task 3.2 - Manufacturing of TPS prototypes for the system of pre-flight ground testing:

In order to integrate the different elements into a single mockup (following the initial design of 300 x 300 mm in size), various welding methods were investigated, including laser welding, micro-plasma welding, electron-beam welding and argon-arc welding. All these methods showed a number of disadvantages and didn´t provide good quality joints. Satisfactory results were obtained in a following stage with the use of diffusion welding. Nevertheless, since the diffusion welding facility available in the consortium was limited to laboratory prototypes with maximal dimensions of 150 x 150 mm, a decision was done to scale down the design of the final TPS prototype.

Theoretical computational analysis of the strain-stress state in the initial TPS design (300 x 300 mm) showed that the most loaded areas correspond to the welding points on either U-shaped sealings or the welding points of bearing supports. Based on these calculations, a central fraction of 150 x 150 mm from the initial design (see **Figure 3**) shall already contain all critical structural elements without changing their dimensions. Consequently, operational life tests conducted on such a down scaled mockup, which fully technologically and structurally conform to the most loaded part of 300 x 300 mm mockup, shall fairly represent the service performance of the initial “full scaled” TPS design.

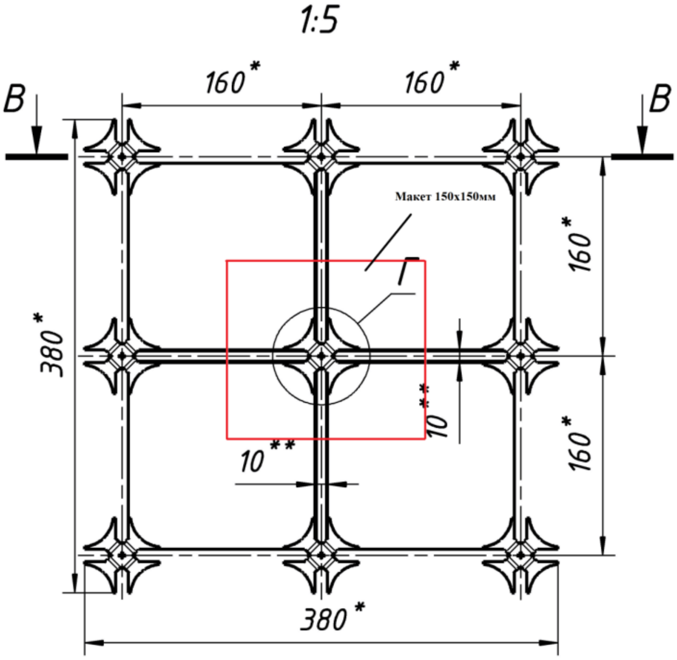


Figure 3: Full-scale mockup with highlighted small mockup zone.

Optimized process parameters for diffusion welding were stablished accordingly for the down-sized TPS elements. A technology to integrate separate elements into a single structure was developed. The technologies of manufacturing the individual structural elements using stamping and hydro-jet cutting were also developed.

Two TPS mock-ups have been manufactured out of the developed NiCr alloy and corresponding structural elements: 1st mock-up in size of 310 x 150 mm, consisting of two tiles of 150 x 150 mm each; 2nd mock-up in size of 165 x 165 mm, consisting of four tiles of 75 x 75 mm each.

Figure 4: Overview of NiCr-base honeycomb panel prototype (single tile).

<u>Task 3.3 - Ground tests of TPS:</u>

A complex ground experimental test campaign was carried out according to the test program developed at an initial stage of the project.

In first place, the properties of the heat-resistant alloy on the basis of Ni-Cr-Al were investigated up to a temperature of 1200 ºC. The results of the alloy tests performed in air do not defer from those obtained in vacuum, thus indicating the high heat resistance of the alloys, which excludes the impact of the medium onto the test results. For the same temperature range, the properties and endurance of the high-temperature thermal insulation material was investigated. The implemented thermal insulation blocks have been developed by YUZHNOYE and are composed of silicon oxide fibres (80-85%) with 2-3 microns in diameter and a silica gel binder. With a density of 100 kg/m^3 and a thermal conductivity around 0.212 W/(m·K) at 1100°C, this material is lighter and features over better weight specific insulation properties than existing space-qualified thermal insulation materials used in reference space programmes like Buran (i.e. ТЗМК-10 and ТЗМК-25). This material features also over a very low thermal expansion coefficient, $\alpha = 0.5 \times 10^{-6}$ 1/K. It is estimated that a thickness of 33-37 mm will be sufficient to prevent overheating of the spacecraft. When the temperature of the heated surface reaches the 1100 °C, the temperature of the bottom surface does not exceed 250°C. Nevertheless, the homogeneity of the implemented insulation material should be further improved in order to achieve the mechanical strength and stability of the thermal properties required for spacecraft applications.

On the other side, the strength of the soldered joints within the different metal structural elements was evaluated. As stated above, it was determined that for the purposes of integrating the shells (covering skin of the panel) and the honeycomb filler into a three-layer panel, it is expedient to use the diffusion welding technique. For this purpose, the implementation of EB-PVD deposited copper or nickel porous intermediate layers was found to be a good approach to obtain homogenous and well-structured weld joints. Studies were carried out in order to assess the applicability and efficiency of the U-shaped joint within an operating temperature range from 20 to 1100 ºC. The U-shaped joint retained its integrity and operability without visible defects during 50 thermal cycles. It was also experimentally proven that at the maximum operating temperature of 1100 ºC, the U-shaped joint is almost completely closed; during the tests the gap did not exceed 0.5 mm.

Tests simulating the operational conditions (during transportation, launch and flight within the injection segment) were conducted on the delivered mock-ups, which showed that the developed TPS structure is able to maintain its efficiency under the expected service conditions. The 1st mock-up in size of 310 x 150 mm (composed of two tiles of 150 x 150 mm each) was tested under complex mechanical loading conditions. The 2nd mock-up in size of 165 x 165 mm (composed of four tiles of 75 x 75 mm each) was aimed at determining the thermo-mechanical strength of TPS structure. The developed TPS has been qualified in TRL4.

- **WP4. Development of UHTC and gradient coatings on its basis:**

Task 4.1 – Production and characterization of UHTCs:

At the beginning of the project, 12 different compositions from the ZrB_2-SiC and ZrB_2-MoSi2 systems were selected for synthesis and base-line characterization. The activities performed by CNR and IPMS revealed that the most promising sintering additives are WC or WSi_2, B_4C, $MoSi_2$ and CrB_2. They enabled to obtain bulks possessing room temperature strength in the order of 500-730 MPa and the lowest specific weight gain upon exposure to oxidation at 1500°C. In addition, it was concluded that little amount of SiO_2-former, introduced as SiC or transition metal silicide, is beneficial to enable densification, to limit grains growth and to protect from oxidation. However, the amount of such SiO_2-former has to be carefully controlled to limit the gas evolution in the subsurface scales and bubbles formation upon oxidation above 1600°C.

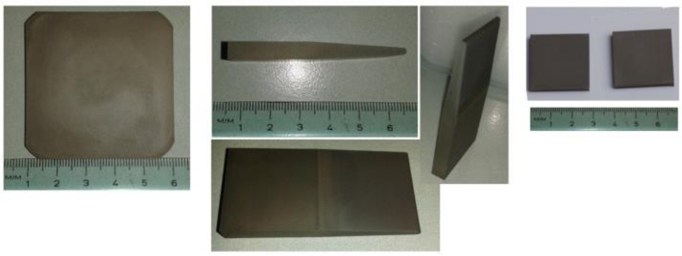


Figure 5: Bulk UHTC (ZrB_2-WC-SiC) manufactured by Hot Pressing at CNR.

Further activities have been focused on the advanced thermo - mechanical characterization and oxidation resistance testing of selected UHTC composites in form of bulks (see **Figure 5**). Following ceramic composites have been selected thanks to their outstanding refractoriness and oxidation performances:

Z-WS: ZrB_2 + 15 vol% WSi_2

ZS-WC(3): ZrB_2 + 3 vol% SiC + 5 vol% WC

ZS-BC: ZrB_2 + 15 vol% SiC + 5 vol% B_4C

Z-MS: ZrB_2 + 15 vol% $MoSi_2$

ZS-CB: ZrB_2 + 15 vol% SiC + 5 vol% CrB_2

ZM-CB: ZrB_2 + 15 vol% $MoSi_2$ + 5 vol% CrB_2

Tests were focused on the characterization of the flexural strength at high temperature in air, creep behaviour, coefficient of thermal expansion up to 1300°C and the thermal conductivity up to 2000°C. In addition, advanced oxidation tests have been carried out in a bottom-loading furnace at 1650°C for 15 minutes and repeated for 1-3 times. Most outstanding results collected are as following:

1. **Bending strength** of the samples was measured at 1400-1500°C. It remains almost constant compared to that at room temperature, one materials containing WC developed at CNR even enabled to keep a strength over 700 MPa when tested at 1500°C in air.
2. **The creep of developed** UHTCs was studied by indentation in the temperature range of 1200-2100 °C by compression at a pressure of 48 MPa. The creep of ZrB_2 + 15 vol% SiC ceramics up to 2100 °C is under the conditions of super plasticity without material destruction up to 65% of deformation. Additives like tungsten silicide/carbide, boron carbide and chromium boride notably slow down the creep rate. For the developed materials, the creep starting temperature ranges 1760 - 1930 °C and is max for B_4C and WC additions (1910 - 1930 °C). The activation energy of the creep process is in the range of 4.3-11.7 Ev. depending on the type of sintering additives.
3. **Thermal cycling** of developed ZrB_2-$MoSi_2$ composites in the flow of combustion products at T = 1400°C is accompanied by strength increasing in the range of 0-6000N due to the healing of surface defects in the stream and it is not accompanied by degradation of strength, which indicates a ceramics high thermal strength and thermal resistance.
4. **Oxidation tests** performed on samples produced at IPMS in non-isothermal conditions with heating rate of 3-4°C/min at **1250 and 1500°C** for 30 minutes revealed that additive of $MoSi_2$, CrB_2 and SiC increase the oxidation resistance through the formation of a protective film of high-temperature phases. Ceramics obtained by vacuum hot pressing showed higher resistance to oxidation compared to ceramics obtained by hot pressing.
5. **Oxidation tests, performed at CNR in a bottom-loading furnace** at **1650°C** for 15 minutes and repeated 3 times, revealed that ceramics obtained by vacuum hot pressing showed higher resistance to oxidation compared to the other ceramics obtained by hot pressing, $MoSi_2$ enable to retain the pristine ZrB_2 under a thin outermost SiO_2 glassy layer. Among the investigated materials, none showed oxide spallation and the best results were achieved when ZrB_2 was sintered with solely $MoSi_2$ or simultaneous addition of $MoSi_2$ and CrB_2.
6. Selected ceramics have been subjected to **thermal-erosion testing in a supersonic oxygen-fuel single phase flow**. The composition ZrB_2 - 15%$MoSi_2$ - 5%CrB_2 revealed the best stability. It was subjected to 7 heating cycles at a total duration of 1000 s and a temperature of 1671°C showing a mass loss of 201 mg/cm^2, which corresponds to an average linear loss rate of 0.33 µm/s at a density of 6.1 g/cm^3.
7. **Thermal-erosion tests on UHTCs wedge shaped** samples have been carried out within the supersonic flow of chemically neutral combustion products of a stoichiometric fuel-air mixture. The surface temperature reached 1650 - 1850 °C on the blade tips. The sample of ZrB_2-$MoSi_2$ composition was tested at the leading-edge temperatures between 1715°C and 1845°C in four heating cycles with a total duration of 3,236 seconds at a stagnation pressure of 0.38 MPa. The average temperature for the entire test period was 1800 ± 40 °C, the weight loss of the sample during the test was around 80.45 mg and the linear drift was about 0.2 mm. At the end of the tests, the ZrB_2-$MoSi_2$ sample has fully retained its operability. In comparison to the rest of the tested ceramic samples, this material configuration showed the highest resistance.
8. **Thermal-erosion testing in two-phase flow** has been done at flow angle of 30° and distance to the nozzle of 80 mm. At these conditions, the specimen (plates of 50 x 50 x 5 mm) surface temperature was around 1250 °C and 1350 °C. Alumina particles with a size distribution between

63 and 80 mm have been used as abrasive media (particles velocity was around 480 m/s). The coefficient of mass loss was around 2.8×10^{-4}-3.8×10^{-4} kg/cm^2.

9. The investigation of ascertained **thermal- properties** has been done within the temperature range of 25 - 2000 °C. Thermal conductivity of ZrB_2-SiC ceramics of different compositions ranges 80-100 W/mK at room temperature and is around 42-60 W/mK at 1500°C, and 50-60 W/mK at 2000ºC. Heat capacity of ZrB_2-SiC ceramics of different compositions rises from 0.46-0.51 J/gK at room temperature to about 0.7-0.8 J/gK at 2000ºC.

Task 4.2 – Development of coatings of UHTC and UHTC-based composites:

Based on results collected during the 1st Reporting Period and results arising in Task 4.1, CNR and IPMS further optimized the composition and quality of UHTC composite powders aimed at the production of coatings by thermal spraying. Significant efforts were dedicated by CNR to optimized the powder morphology and particle size distribution of powders out of the selected composition from the ZrB_2-SiC system (i.e. ZrB_2-5WC-3SiC). IPMS' efforts were mainly focused on the development of powders on the basis of ZrB_2-15$MoSi_2$. At a later stage of the project, following alternative compositions with improved oxidations resistance were investigated: ZrB_2-15$MoSi_2$-5CrB_2, ZrB_2-20$MoSi_2$-10AlN, ZrB_2-20SiC-10AlN and ZrB_2-15SiC-5CrB_2. As result of these efforts, n**ew one stage cost-competitive technologies** for obtaining ZrB_2 and composite powders to be applied as protective coatings has been developed by CNR and IPMS. Several batches of powders with the required size (10-40 and 64 -140 µm), compaction level and negligible oxygen content have been delivered to Tecnalia for coating deposition.

In relation to the development of coatings, TECNALIA and IPMS worked actively on the development of UHTC coatings following different approaches and implementing different deposition technologies. TECNALIA was mainly focused on the development of UHTC coatings by means of the Shroud Plasma Spray technique, dedicating some minor efforts to the development of graded and/or composite metallic-UHTC coating by High Velocity Oxy/Air Fuel spraying. IPMS worked mainly on the development of UHTC by detonation, plasma spraying and laser cladding. Some efforts were dedicated to the development graded metallic-UHTC coatings, implementing a High Velocity Air Fuel spraying system in this case. CNR extensively contributed to the microstructural and chemical characterization of as-sprayed coating and tested specimens. Most outstanding results are as following:

1. **Homogenous UHTC coatings with compact structure** based on compositions selected within Task 4.1 (ZrB_2-15-20$MoSi_2$ and ZrB_2-5WC-3SiC) have been obtained by Tecnalia using a Shroud Plasma Spray (SPS) system. Coatings have been deposited on last state-of-the-art non-oxide CMC plates (C/C and C/C-SiC) in size of up to 50 x 50 x 5 mm (**Figure 6**). Even though at the expenses of a lower oxidation resistance, the adhesion strength to the C/C plate can potentially be improved through an infiltration post-treatment with Si. Coating thicknesses in the range of 200 – 400 µm have been investigated.

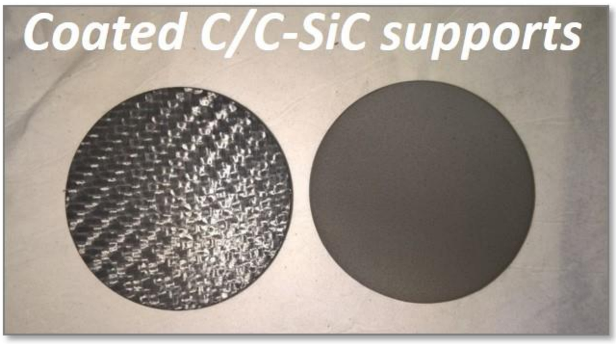


Figure 6: C/C-SiC support, uncoated (left) and with ZrB2-5WC-3SiC coating deposited by Shroud Plasma Spraying (right).

2. **ZrB_2-20SiC-10AlN** was investigated as an alternative composition to reference UHTC appointed above, thus evidencing a better CTE match of the resulting coatings to the C/C-SiC base plate (no coating spallation observed) and a higher high-temperature corrosion resistance at temperatures above 1800ºC. A coating thickness around 200 µm might be sufficient to guarantee the oxidation

protection of the CMC plate under re-entry conditions, if the base material is not exposed to the environment.

3. Under the responsibility of IPMS, **homogenous UHTCs coatings based on ZrB_2 with refractory additives of $MoSi_2$, SiC and AlN** on stainless still and C/C-SiC substrates have been obtained by the methods of HVAF and plasma spraying. The coating thickness amounted to 100-400 µm for coatings deposited by plasma spraying and 70-80 µm for the ones obtained by HVAF. The ZrB_2 - 15$MoSi_2$ coatings microhardness was around 6-18GPa that corresponds to those for bulk ceramics. The coatings have a rather high adhesion to the substrate.
4. The availability of **laser technologies** to obtain two layered UHTCs coatings on C/C substrates has been shown. The advantage of the laser coating deposition technology compared with the widely used thermal spray techniques is a high bond adhesion to the substrate and a high material utilization coefficient, small components oxidation, low ability to pore and fracture formation.

<u>Task 4.3 – Advanced characterization of coatings:</u>

According to the work plan, advanced characterization tests were performed by IPMS and DLR. Based on results collected in Task 4.1 and 4.2, the most promising UTHC material compositions either in form of bulk or as coatings on CMC base plates were manufactured by CNR, IPMS and TECNALIA for testing. Most outstanding results are as following:

1. Oxidation resistance tests with the Indutherm facility performed by DLR (at T ~ 1800°C and P= 200 mbar):

- An infiltration treatment of single ZrB_2-5WC-3SiC layers deposited by SPS is a good prospective way to improve the adhesive strength of this layers to a C/C substrate, even though at the expenses of a lower oxidation resistance.
- The implementation of a thin intermediate PVD layer on the basis of AlN might be a good prospective way to improve the HT resistance of top ZrB_2-15$MoSi_2$ layer deposited by plasma spraying. A button scale sample prepared by IPMS was successfully tested under the selected conditions, with no evidences of spallation, cracks or defects both in the coating and the substrate, which testifies the high thermal protective properties of this coating. The oxide scale formed on the surface is mainly composed of $ZrO_{2mon.}$). Because of the time constrain limitations, this sample configuration could not be tested within the PWT facility.
- A single ZrB_2-20SiC-10AlN coating might be a good alternative to the initially selected UHTC compositions (ZrB_2-5WC-3SiC and Zr_2-15$MoSi_2$), with superior oxidation and thermo-cycling resistance.
- Regarding the oxidation of bulk UHTCs, the production method in combination with the composition is the decisive factor for a well-functioning system. Bulk samples out of 80% ZrB_2+ 15% $MoSi_2$ + 5% CrB_2 produced by vacuum hot pressing achieves the best results with respect to the stability of the material and stable oxidation layer.

2. **Thermal erosion tests** performed by IPMS in a supersonic flow of combustion products of either a **kerosene (fuel) / air mixture or kerosene (fuel) / oxygen mixture:**

- Single coatings based on reference compositions, namely ZrB_2-15 $MoSi_2$ and the ZrB_2-3SiC-5WC, were tested under similar conditions. Both material compositions were deposited by SPS on C/C-SiC plates. Under heating, a constant cyclic change in the colour of the coatings of both compositions as well as in their radiation coefficients occur, like for the bulk UHTC, which testifies a similarity of the processes taking place on their surfaces. The measured emission coefficient on the ZrB_2-15 $MoSi_2$ coating ranged around $\acute{\varepsilon}$ = 0.61-0.71, while for the ZrB_2-3SiC-5WC composition it was around $\acute{\varepsilon}$ = 0.48-0.69.
- Under the **thermal erosive action** of the **air-kerosene flame** (corresponding to a stagnation temperature of 2100 °C and a stagnation pressure of 0.45 MPa), the endurance of the C/C-SiC

base plate was increased from 5 up to more than 20 minutes when applying a ZrB_2-15$MoSi_2$ coating, and up to 12 minutes in the case of the ZrB_2 -3SiC-5WC coating. When performing the test with an **oxygen-kerosene mixture** (leading to a surface temperature of 1600 °C and partial pressures of molecular and atomic oxygen of $P°O_2$ = 75 kPa and P°O = 6.6 kPa, respectively), the ZrB_2-15 $MoSi_2$ coating protected the CMC plate from destruction for at least 10 minutes, while the ZrB_2-3SiC-5WC coating did it for 6.5 min.

- In addition, high-temperature tests of UHTC coatings out of the composition ZrB_2-20SiC-20AlN (deposited by IPMS with an increased amount of AlN to obtain a stable oxide scale) were performed in the more severe conditions, i.e. using an oxygen-propane-butane torch, leading to a Tmax. ~ 2000 °C for a test duration of 900 seconds. For a functional thickness of 400 µm, this coating has been oxidized to a depth of 300 µm during the test, nevertheless with no spallation, cracks and defects neither in the coating nor in the substrate, which evidences the high temperature stability of the coating.

3. **Plasma Wind Tunnel (PWT):** Coatings on the basis of ZrB_2-3SiC-5WC and ZrB_2-20SiC-10AlN have been deposited on C/C plates and tested in a PWT facility (under subcontract at CIRA) at probe stagnation pressures around ~23-25 mbar and surface temperatures between ~ 1800 – 2000 °C for exposure times of roughly 5-6 min. The composition ZrB_2-20SiC-10AlN showed a higher stability under selected test conditions and preserved its integrity even though a clear oxidation layer is present. Based on these observations, it can be stated that to achieve a sufficient oxidation protection during expected re-entry conditions, the TPS shall then either be coated completely with such an UHTC layer or a more oxidation resistant substrate should be used.

2.4. Description of the potential impact

During an initial stage of the project materials specifications have been defined according to two different application scenarios:

A. Light-TPS systems based on new metal frame and NiCr- or Nb- alloys, supposed to be used in flat surfaces where the operating temperatures do not exceed 1100°C and with an area specific weight of less than $10Kg/m^2$.
B. Light-TPS systems based on non-metallic structures, addressed to sharp components, where the operating temperatures overpass 1600°C. For this purpose, highly refractory ceramics and coatings on its basis for the thermal protection of elements made of C/SiC and C/C shall be developed. Also the possibility to apply a graded metal-UHTC layer on Nb base substrates for oxidation/erosion protection shall be explored.

Scenario A: With focus on scenario A, basic requirements to reusable spacecrafts (RSC) have been collected for orbiter vehicles Space Shuttle (USA), Buran (USSR), Hopper, Hermes (ESA), as well as for multiple TPS, including the following items:

1. Number of re-starts.
2. Requirements to TPS materials.
3. Temperature conditions of casings.
4. External influences at all stages of operation.
5. Requirements to hydrophobic properties and non-hygroscopic (water-resisting).
6. Requirements to design – thermal protective design should be made as individual tiles.
7. Requirements for sealing between the individual panels.
8. Mounting methods for TPS to underlying structures.
9. Resistance requirements against microorganisms, bacteria, products of vital activity of living organisms (birds, mice, insects).
10. TPS verification under real simulation of its operation conditions.
11. Cost effectiveness of TPS.

Innovation brought in scenario A: Based on the analysis of the external influences at maximum levels, it is shown that the trajectories of orbital vehicles Space Shuttle (USA), Buran (USSR), Hopper and Hermes (ESA) are identical and any of them can be used as a model to calculate temperature changes and pressure in timing.

A conventional trajectory and set of influence levels have been selected for the development of the TPS in the frame of the LIGHT-TPS project. The volume of ground tests has also been defined.

An analysis of existing TPS for reusable spacecrafts has been performed. In general terms, major difficulties in designing such structures are large thermal expansions of the outer panel when heated, for which compensation can be performed by overhead cover (design of NASA Langley Research Center and Astrium) or spaced apart and between them a metal hardening is placed. In both cases, there is a problem of sealing the gaps, which decrease the reliability of the structure.

All analysed thermal protective structures are under development. For the technical realization of a cost-effective and reliable TPS, new perspective materials, new technologies and new design solutions are required.

Main achieved results in scenario A: In first place, new heat resistant oxide dispersion-strengthened powdered and sintered alloys on the basis of NiCr and Nb with densities down to 7.450 and 5.558 g/cm^3, respectively, have been developed. Relevant thermo-mechanical properties have been characterized within the temperature range of 20 -1200 °C. Developed materials have been hot/cold rolled to foils with thicknesses down to 0.06 mm.

For the developed NiCr alloy, the tensile strength limit at room temperature amounted to 1020 MPa, while the corresponding value at 800 °C was equal to 542 MPa. In the case of the Nb alloy, the measured tensile strength limit at room temperature and at 1100 °C amounted to 900-1000 and to 80-110 MPa, respectively. On the other side, it has been established that the new NiCr- and Nb- base alloys feature over a good thermo-cycling resistance up to 1200 °C (> 100 cycles).

Two TPS mock-ups have been manufactured out of the developed NiCr alloy and corresponding structural elements: 1st mock-up in size of 310 x 150 mm, consisting of two tiles of 150 x 150 mm each; 2nd mock-up in size of 165 x 165 mm, consisting of four tiles of 75 x 75 mm each. The 1st mock-up was tested under complex mechanical loading conditions, selected to simulate the expected operational loads. The 2nd mock-up was aimed at determining the thermo-mechanical strength of TPS structure. The developed TPS has been qualified in TRL4.

Potential impact and use in scenario A: The project has developed a TPS for space applications, above all designed for a reusable spacecraft, which matches the expected weight requirement (<10 kg/m^2). Nevertheless, in order to ensure the robustness and reliability of the system, following aspects will still require further R&D works: (1) The method for joining the honeycomb construction with upper and lower shells (to guarantee a better homogeneity throughout the joining surface) and (2) the technology for manufacturing the insulation blocks (to increase their mechanical strength and stability).

At the same time, in order to exploit the developed TPS, it will necessary to increase the TRL from 4 to at least 7 (system prototype demonstration in operational environment). This implies the readiness for flight test demonstration, which is in fact the final stage in the TPS development.

The developed TPS can be implemented in unmanned spacecrafts, capable of performing the gliding descent close to the trajectory followed by the Space Shuttle, Buran or any other reusable spacecraft under development.

Currently, there are several projects aimed at the development reusable space systems (RSS). This is exactly where the TPS developed within this project can be applied. The obtained results could quickly be adapted for exploitation in practically any RSS, e.g. Boeing X-37(B), CST-100, Dream Chaser, Space Ship Two, New Shepard (all in USA), Skylon – the UK, Avatar – India, Shenlong – China, MSS-1 – Russia.

Scenario B: In order to stablish reference service parameters for demonstration of the UHTCs to be developed in the frame of the project, the heating distribution environment and pressure in the nosecap of the re-entry vehicle X-38 have been analysed in addition to the requirements collected for scenario A. The trajectory of X-38 is similar to those of Space Shuttle, Buran, Hopper and Hermes.

Innovation brought in scenario B: Thanks to their extremely high melting point (above 3000°C) and their unique combination of thermo-physical and engineering properties, ultra-high temperature ceramics (UHTCs) and coatings on its basis are envisaged as promising candidates for application at very high temperatures. Specially, ZrB_2 has several advantages over other metal-based borides and carbides. One critical issue in the production of ZrB_2-based ceramics is the achievement of fully dense bodies/coatings, which is the base-line condition to achieve good thermo-mechanical properties. Owing to the strong covalent bonds featuring all UHTCs, processing temperatures above 2000°C and the application of very high pressures are required to densify these materials. However, the microstructure deriving from such extreme processing conditions are coarse, with trapped porosity and hence with poor oxidation and mechanical performances.

In view of these limitation, the addition of ***sintering additives*** has proved to be a suitable approach to decrease the sintering temperatures down to 1650°C and obtain better properties. The innovation brought by LIGHT-TPS consists on the investigation of new UHTC composites based on either the ZrB_2-SiC or the ZrB_2-$MoSi_2$ systems, that will be suitable for application at temperatures between 1600 and 1800 °C under the thermo-erosive influence of heterogeneous gas streams containing hard and liquid particles. The addition of sintering additives should allow the development of new UHTC mixtures suitable for the production of both UHTC-based bulk components and coatings.

Main achieved results in scenario B: On the one side, UHTC bulks from the ZrB_2-SiC and ZrB_2-MoSi2 systems possessing room temperature strength in the order of 500-730 MPa and the lowest specific weight gain upon exposure to oxidation at 1500°C were synthetized. It was concluded that little amount of SiO_2-former, introduced as SiC or transition metal silicide, is beneficial to enable densification, to limit grains growth and to protect from oxidation. However, the amount of such SiO_2-former has to be carefully controlled to limit the gas evolution in the subsurface scales and bubbles formation upon oxidation above 1600°C. The bending strength at 1400-1500°C of selected compositions remains almost constant compared to that at room temperature. Bulks containing WC developed at CNR even enabled to keep a strength over 700 MPa when tested at 1500°C in air. For the developed materials, the creep starting temperature ranges 1760 - 1930 °C and is max when B_4C and WC are used as additives (1910 - 1930 °C). Depending on SiC amount and secondary phases, the CTE ranges from 4.8 to 7.9 10^{-6}/C. Under thermo-cycling oxidation at 1650°C, none of the investigated materials showed oxide spallation and the best results were achieved when ZrB_2 was sintered with solely $MoSi_2$ or simultaneous addition of $MoSi_2$ and CrB_2.

After a careful assessment of collected results, following compositions were selected for the developments of coatings: ZrB_2 + 3 vol% SiC + 5 vol% WC (outstanding HT mechanical properties in addition to the highest relative density and relative good oxidation resistance) and ZrB_2 + 15 vol% $MoSi_2$ (combination of good mechanical properties with outstanding oxidation resistance). Alternative atmospheric thermal spray depositions processes were investigated, leading to homogenous and dense UHTC single layers on the basis of ZrB_2-3SiC-5WC, ZrB_2-(15-20)$MoSi_2$ and ZrB_2-20SiC-(10-20)AlN. Accelerated oxidation tests have shown the potential of these UHTC coatings for the oxidation protection of non-oxide CMC substrates (C/C and C/SiC composites).

Potential impact and use in scenario B: Developed UHTCs in form of either bulk and coatings, could be implemented for the development of next generation of either: (1) TPSs for space vehicles flying at hypersonic speeds (i.e. greater than Mach 5) or (2) Nozzles of solid or hybrid aerospace rocket motors. Generally spoken, the newly developed UHTC coatings and bulks can be considered as a potential candidate where missions require a TPS system with heat loads above those state-of-the-art reusable TPSs can bear. Results achieved on flat CMC tiles could easily be extrapolated to more complex geometries (e..g. hemispheric, cylindrical, wedged, double tilted and even non-symmetric geometries) and with nearly no limitations in the size of the components. In this sense, in medium or long-term perspectives and for new missions where materials able to survive service temperatures above 1600 ºC will become of more interest, there is a good potential to bring results arising in LIGHT-TPS to this market. Concerning rocket nozzles, for projected service temperature exceeding 1600°C, the good chemical and thermal stability of the developed UHTC coatings and bulks makes them a good candidate for use in extreme environments, e.g. hypersonic flight and propulsion. Their application in nozzle extensions could lead to higher dimensional stability during firing in combustion chambers of high performance rockets for civil aerospace propulsion.

Dissemination activities:

<u>Public website:</u> The public website has been maintained during the entire period starting from the launch at the beginning of the project (http://light-tps.eu/). Domains related to project meetings, publications and events have been constantly updated. All available key publications are downloadable from the website.

<u>Dissemination</u>: A promotion video of the project was developed. The information in the video provides a general insight into the project goals, major results, and scientific objectives. It is more suitable for professionals, as it includes specific references to materials, processes, target values of characteristics, etc. At the same time, it allows a person without a professional background to understand the general purpose of the project.

The content is structured in accordance with the general structure of the project work plan and embraces 3 areas:

- N-Cr and Nb based alloys and respective production technologies;
- Ultra-high temperature ceramic materials, production technologies and technologies for deposing ceramic coatings on various substrates;
- General design of the TPS elements in a structure, meeting the requirements of the target space mission.

Access to the promotional video can be obtained directly from the project website http://www.light-tps.eu/ (home page, on the bottom). The video is also available for streaming from Youtube: http://youtu.be/1dpowljWWco

Additionally, several dissemination activities have been undertaken by the consortium to present the project results in scientific events (mostly international conferences), 53 in total. 35 publications have been submitted to scientific journals (roughly half of them with open access). A workshop was organized by the consortium in the framework of the Space Conference at the Berlin International Aerospace Exhibition (ILA 2016). The workshop took place on June 01, 2016. The project promotional video and dissemination materials were distributed through the stand of YUZHNOJE. As a second joint dissemination activity from the consortium, a session was dedicated to the LIGHT-TPS project was collocated with the Symposium ZU: "Advanced Composite Materials: production, testing, applications" in the frame of the E-RMS FALL 2016 between 19-22th of September 2016 at the Warsaw University of Technology.

Exploitable project results and exploitation planning:

Following exploitable results (ER) have been achieved during the project:

ER1: New method for the thermal spray deposition of oxidation protective coatings on the basis of UHTCs (Owner: TECNALIA). IPR exploitation: Industrial secret.

ER2: Methods for preparing UHTC powders with desired diameter and inner cohesion for thermal spray deposition process (Owner: CNR). IPR exploitation: Industrial secret.

ER3: Non-oxide CMCs (C/C and C/C-SiC) coated with UHTCs for improved oxidation resistance (Owners: DLR, TECNALIA, CNR, IPMS). IPR exploitation: Industrial secret.

ER4: Preparation of ultra-refractory UHTC bulks with high strength above 1900°C (Owner: CNR). IPR exploitation: Industrial secret.

ER5: Alloys for cost-competitive protective TPS of reusable spacecrafts for prolonged operation at elevated temperatures (Owner: IPMS). IPR exploitation: Ukrainian patent № 108096 "Method for obtaining a heat-resistant alloy based on nichrome"; Ukrainian patent № 115259 "Method for obtaining a heat-resistant alloy".

ER6: Method of rolling dispersed-hardened alloys (Owner: IPMS). IPR exploitation: Patented.

ER7: Equipment and test methods for sharp edges models of hypersonic aircraft (Owner: IPMS). IPR exploitation: None.

ER8: Novel method of diffusion welding three-layer honeycomb panels (Owner: IEW). IPR exploitation: Ukrainian patent for utility model, № 114804 Ukraine 2017, МПК B23K 20/00, B23K 20/16.

ER9: Novel method diffusion welding three-layer honeycomb panels (Owners: IEW, SRI). IPR exploitation: Ukrainian patent for utility model, № 113424 Ukraine, 2017, МПК B23K 20/14.

ER10: Novel design of three-layer panel and method of its diffusion welding (Owners: IEW, YUZHNOYE). IPR exploitation: Ukrainian patent application №201701746 -23.02.2017-.

ER11: Novel method of the probabilistic risk assessment of the influence of the free space environment on the superlight-weight thermal protection system (TPS) (Owner: SRI). IPR exploitation: None.

ER12: System-theoretical approach to modeling and optimization of superlight-weight thermal protection system that based on the following models: synergetic, physical, and computational. (Owner: SRI). IPR exploitation: Company secret.

ER13: Novel method of TPS temperature properties modeling (Owner: SRI). IPR exploitation: Utility model.

ER14: Novel method of real time estimation of temperature distribution in a TPS using observer (Owners: SRI, IEW). IPR exploitation: In progress.

ER15: Novel method for calculating thermal fields in complex physical objects (Owner: SRI). IPR exploitation: Utility model.

ER16: Multilayer thermal protection system (Owner: YUZHNOYE). IPR exploitation: Ukrainian utility model 201709008.

ER17: Technology for high temperature soldering of elements during TPS assembly (i.e. joining of three-layered panels using the U-type element as well as for attachment of supports) (Owner: YUZHNOYE). IPR exploitation: Industrial secret.

ER18: Technology for light thermal insulation tiles manufacturing based on silica fibers, operating under 1200°C (Owner: YUZHNOYE). IPR exploitation: Industrial secret.

ER19: Special testing equipment and tooling for complex testing (Owner: YUZHNOYE). IPR exploitation: None.

2.5. The address of the project public website and relevant contact details

http://www.light-tps.eu/

Main content:

- The website is a kind of “business card” of the project contacting general and public information on:
- Project general mission and operational objectives
- Concise summary of the project activities
- Consortium composition
- Project meetings (short reports and public presentations)
- Contact details.
- News (permanently updating context-connected steam of project news, as well as other news relevant to the project objectives)
- Public downloads. The download section allows the access to public documents and other information resources developed by the project. Cross-linkage with other relevant information sources will be ensured. Examples of such public documents are project promotional materials, public scientific reports, open publications, information on patents, etc.

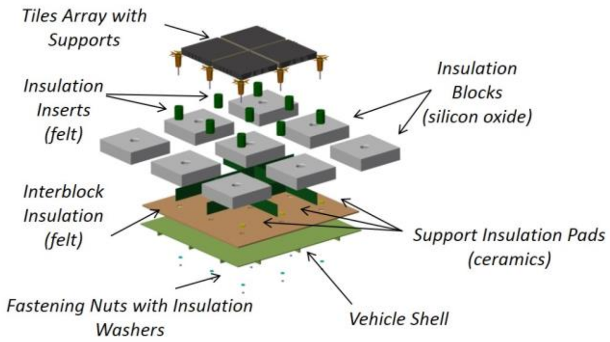
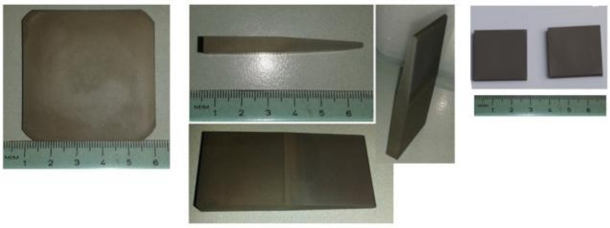
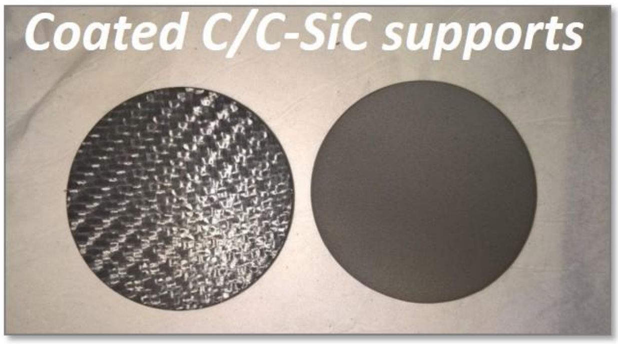
The same corporate design developed for the project was used for the website as well as for other public dissemination materials, for example the logo (see below)

Contact details:

Dr.-Ing. María Parco (Project Coordinator)
Head of the Thermal Spray Group
Industry and Transport Division
TECNALIA
Parque Tecnológico de San Sebastián
Mikeletegi Pasealekua, 2
E-20009 Donostia-San Sebastián - Gipuzkoa (Spain)
T +34 946 430 850 (International calls)
F +34 946460900 (International)
maria.parco@tecnalia.com
www.tecnalia.com

2.6. Illustrative and promotional material

Project logo, diagrams or photographs illustrating and promoting the work of the project (including videos, etc…), as well as the list of all beneficiaries with the corresponding contact names can be submitted without any restriction.

 General view of TPS design developed in LIGHT-TPS	 LIGHT-TPS_Overview of NiCr-base honeycomb panel prototype (single tile)
 Bulk UHTC (ZrB_2-WC-SiC) manufactured by Hot Pressing at CNR	 C/C-SiC support, uncoated (left) and with ZrB_2-5WC-3SiC coating deposited by Shroud Plasma Spraying (right)
LIGHT-TPS Project logo	 Project banner

The video is also available for streaming from Youtube: http://youtu.be/1dpowljWWco

3. USE AND DISSEMINATION OF FOREGROUND

3.1. Section A (public)

This section includes two templates

- Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Template A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	*Ultra-high Temperature Ceramics Behavior under the Impact of Concentrated Solar Radiation, Oxidation and Erosion in Gas Flows*	*O.N. Grigoriev (IPMS)*	*"Space Investigations in Ukraine 2012-2014, Report COSPAR*		*Academperiodika*	*Kyiv, Ukraine*	*2014*	*pp. 126-132*	*ISBN: 978-966-360-316-2*	*no*
2	*Selection of heat insulation for multilayer thermal protection structures of re-entering spacecraft*	*I. Husarova (YUZHNOYE)*	*System design and analysis of aerospace structures characteristics*	*b. XVII, 2014*	*University of Dniepropetrovsk*	*Ukraine*	*2014*	*pp. 54-62.*	*ISSN 2524-0188*	*yes*
3	*Studying of insulation characteristics of heat-*	*I. Husarova (YUZHNOYE)*	*University of Dniepropetrovsk*	*b.22. 2014*	*University of Dniepropetrov*	*Ukraine*	*2014*	*p.35-40*	*ISSN 2409-4056*	*yes*

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

	resistant materials for re-entering spacecraft.		*bulletin*		*sk*					
4	*Prospective thermal protection structure of re-entering spacecraft with metallic load-bearing element.*	*I. Husarova (YUZHNOYE)*	*Collection of research papers of National Aerospace University, Kharkiv Aviation Institute “issues of designing and manufacturing of flight vehicle”.*	*Issue 4(80)*	*Kharkiv Aviation Institute*	*Kharkiv, KhAI, Ukraine*	*2014*	*p. 28-44*		*yes*
5	*Interaction Between ZrB_2–$MoSi_2$ Cermets and Oxide Melts.*	*A. D. Panasyuk (IPMS)*	*Powder Metallurgy and Metal Ceramics*	*Volume 53, Issue 5–6*	*Springer*	*Germany*	*September 2014*	*pp 330–334*	*DOI: 10.1007/s11106-014-9620-4.*	*no*
6	*ZrB_2 based laser coating on graphite*	*I. A. Podchernyaeva (IPMS)*	*Powder Metallurgy and Metal Ceramics*	*Volume 53, Issue 11–12*	*Springer*	*Germany*	*March 2015*	*pp. 688 – 692*	*DOI: 10.1007/s11106-015-9664-0.*	*no*
7	*Corrosion Resistance of Ultrahigh-Temperature Zirconium Boride Ceramics Under Concentrated Solar Radiation.*	*I.P. Neshpor (IPMS)*	*Powder Metallurgy and Metal Ceramics,*	*Volume 54, Issue 3-4*	*Springer*	*Germany*	*July 2015*	*pp. 189-193*	*DOI 10.1007/s11106-015-9697-4.*	*no*
8	*Thermal protection tile structures of shuttlecraft with different external load-carrying elements.*	*V.G. Tikhy (YUZHNOYE)*	*The Paton welding journal*	*Issue 3-4, 2015*	*Paton Publishing House*	*Kiev, Ukraine*	*April 2015*	*pp. 63 - 68*	*DOI: 10.15407/tpwj2015.04.09 ISSN 0957-798X. URL: http://patonpublishinghouse.com/rus/journals/tpwj/2015/04/09*	*yes*
9	*Thermal-protection structures of reusable spacecraft with different external load-bearing elements*	*V.G. Tikhy (YUZHNOYE)*	*Automatic welding*	*Issue 3-4, 2015*	*Paton Publishing House*	*Kiev, Ukraine*	*2015*	*pp. 66 - 71*	*ISSN 0005-111X*	*Yes*
10	*Two-stage configuration burner device for high-vilocity air liquid-fuel spraying.*	*Yu. Yevdokymenko (IPMS)*	*Herald of aero engine building*	*No.2 /2015*	*AO “Motor Sich*	*Zaporozhye, Ukraine*	*2015*	*pp. 143-148.*	*ISSN 1727-0219*	*no*

11	*Materials and structures of reusable spacecraft heat protection*	*I. Husarova (YUZHNOYE)*	*Ukrainian Materials Research Society Bulletin, 2016*	*1 (9) 2016*	*KIM*	*Ukraine*	*2016*	*pp.48-55*	*ISSN2310-9688*	*yes*
12	*Development of the hot-strength alloy based niobium for thermal protection of rocket and space technology products.*	*V.P. Solntcev, (IPMS)*	*Herald of aero engine building*	*No. 2 /2016.*	*AO "Motor Sich*	*Zaporozhye, Ukraine*	*2016*	*pp. 198-206.*	*ISSN 1727-0219.*	*no*
13	*Development of heat-resistant niobium-based alloy for thermal protection of rocket space technology.*	*V. Solntsev (IPMS)*	*"Space investigations in Ukraine 2014-2016", report COSPAR*	*-*	*Academperiodika*	*Kyiv, kraine*	*2016*	*pp. 98-103.*	*ISSN 978-966-360-316-2.*	*no*
14	*Burner for high-velocity air-fuel spraying of ZrB2 based coatings for aerospace technics.*	*Yu. Evdokimenko (IPMS)*	*Space Investigations in Ukraine 2014-2016", report COSPAR,*	*-*	*Academperiodika*	*Kyiv, kraine*	*2016*	*pp. 114-116.*	*ISSN 978-966-360-316-2.*	*no*
15	*Combined effects of WC and SiC on densification and thermo-mechanical stability of ZrB2 ceramics.*	*F. Monteverde (CNR)*	*Materials and Design*	*109*	*Elsevier BV*		*2016*	*pp. 396–407*	*DOI: 10.1016/j.matdes.2016.06.114.* *eISSN: 0261-3069*	*Yes*
16	*Microstructure evolution of a W-doped ZrB2 composite upon high-temperature oxidation,*	*L. Silvestroni (CNR)*	*Journal of the American Ceramic Society*	*100 [4]*	*Blackwell Publishing*	*UK*	*2017*	*pp. 1760–1772*	*DOI: 10.1111/jace.14738.*	*no*
17	*Super-strong materials for temperatures exceeding 2000°C.*	*L. Silvestroni (CNR)*	*Scientific Reports.*	*No. 7, Article number: 40730*	*Nature Publishing Group*	*UK*	*2017*	*pp. 40730*	*DOI: 10.1038/srep40730.*	*yes*
18	*Diffusion welding in vacuum thin sheet of nickel alloy*	*Yu. Falcenko (IEW)*	*Technical Science and Technology*	*Issue 4, 2016*	*Chernihiv National University of Technology*	*Chernigiv, Ukraine*	*2016*	*pp. 87 - 96*	*ISSN 2519-4569*	*Yes*
19	*Evaluation of high temperature resistance of three-layer*	*I.A. Gusarova (YUZHNOYE)*	*The Paton welding journal*	*Issue 12, 2016*	*Paton Publishing House*	*Kiev, Ukraine*	*2016*	*pp. 29 - 34*	*DOI: 10.15407/tpwj2016.12.05*	*no*

	honeycomb panel produced from YuIPM-1200 alloy by vacuum diffusion welding								*URL: http://patonpublishinghouse.com/eng/journals/tpwj/2016/12/05/*	
20	*Evaluation of high temperature resistance of three-layer honeycomb panel produced from YuIPM-1200 alloy by vacuum diffusion welding*	*I.A. Gusarova (YUZHNOYE)*	*Automatic welding*	*Issue 12, 2016*	*Paton Publishing House*	*Kiev, Ukraine*	*2016*	*pp. 31 - 35*	*ISSN 0005-111X*	*no*
21	*Gradient Laser ZrB2–MoSi2 Coating on Graphite,*	*I. A. Podchernyaeva (IPMS)*	*Powder Metallurgy and Metal Ceramics*	*Volume 54, Issue 11–12*	*Springer*	*Germany*	*March 2016*	*pp 679–685*	*DOI.10.1007/s11106-016-9762-7.*	*no*
22	*Sintering of Zirconium Diboride and Phase Transformations in the Presence of Cr3C2,*	*O. N. Grigoriev (IPMS)*	*Powder Metallurgy and Metal Ceramics*	*Volume 55, Issue 3–4,*	*Springer*	*Germany*	*July 2016*	*pp 185–194*	*DOI.10.1007/s11106-016-9793-0.*	*no*
23	*Space factors influence on superlight-weight thermal protection system: concept, modeling, and risk analysis*	*V. Yatsenko (SRI)*	*Technical Science and Technology*	*Issue 1, 2017*	*Chernihiv National University of Technology*	*Chernigiv, Ukraine*	*2017*	*pp. 68 - 78*	*ISSN 2519-4569*	*yes*
24	*Vacuum diffusion welding of foil from powder nickel-chromium alloy*	*I.A. Gusarova (YUZHNOYE)*	*The Paton welding journal*	*Issue 3, 2017*	*Paton Publishing House*	*Kiev, Ukraine*	*2017*	*pp. 25 - 32*	*DOI: 10.15407/tpwj2017.03.04 URL: http://patonpublishinghouse.com/eng/journals/tpwj/2017/03*	*no*
25	*Vacuum diffusion welding of foil from powder nickel-chromium alloy*	*I.A. Gusarova (YUZHNOYE)*	*Automatic welding*	*Issue 3, 2017*	*Paton Publishing House*	*Kiev, Ukraine*	*2017*	*pp. 31 - 39*	*ISSN 0005-111X*	*no*
26	*Diffusion welding in a vacuum of a heat-resisting alloy on a Ni-base*	*L. Petrushynets (IEW)*	*Technical Science and Technology*	*Issue 3, 2017*	*Chernihiv National University of Technology*	*Chernigiv, Ukraine*	*2017*	*pp 63 - 71*	*ISSN 2519-4569*	*yes*
27	*Effect of temperature of heating on structure and chemical*	*Iurii Falchenko (IEW)*	*Comprehensive assurance of quality of*	*V.2, 2017.*	*Chernigiv National University of*	*Chernigiv: Ukraine*	*2017*	*pp 67- 68*	*ISBN 978-966-2188-78-3*	*Yes*

	composition of the compounds coating Ni - Ni-Cr alloy.		technological processes and systems (KZYAPTS-2017)		Technology					
28	Kinetics of Shrinkage, Structurization, and the Mechanical Characteristics of Zirconium Boride Sintered in the Presence of Activating Additives	O. N. Grigoriev (IPMS)	Powder Metallurgy and Metal Ceramics	Volume 55, Issue 11–12	Springer	Germany	March 2017	pp 676–688	DOI. 10.1007/s11106-017-9855-y.	No
29	Nickel-based powder alloys and the technology of heat-resistant structures of returned aerospacecrafts development.	I.A. Gusarova (YUZHNOYE)	Herald of aero engine building	No.2 /2017	AO "Motor Sich	Zaporozhye, Ukraine	2017	pp 158-163.	ISSN 1727-0219.	no
30	Study of thermos erosion characteristics of ultra-high temperature ceramics in the conditions of high-temperature heating in supersonic stream of combustion products.	Yu. Yevdokymenko (IPMS)	Scientific notes. Intercollegiate collection (according to the branches of knowledge "Technical sciences").	Issue 58	Lutsk: Publishing House of Lutsk National Technical University	Lutsk, Volinia, Ukraine	2017	pp 153-161.	ISSN 24-15-39-56.	no
31	Thermal tests of materials for the leading edges of hypersonic vehicle	Yu. Yevdokymenko (IPMS)	Scientific notes. Intercollegiate collection (according to the branches of knowledge "Technical sciences").	Issue 58	Lutsk: Publishing House of Lutsk National Technical University	Lutsk, Volinia, Ukraine	2017	pp 145-152.	ISSN 24-15-39-56.	no
32	Development of rolling modes for samples made from nichrome powder alloy and their testing at operating temperatures	V. Solntsev (IPMS)	International journal for science, technics and innovations for the industry	YEAR XI, Issue 5	Published by Scientific technical Union of Mechanical Engineering	Sofia, Bulgaria	2017,	pp. 254-257.	ISSN PRINT 1313-0226 ISSN WEB 1314-507X	no

					"INDUSTRY 4.0"					
33	*Internal stresses in ZrB2 – SiC ceramics after hot pressing and creep.*	*O.N. Grigoriev (IPMS)*	*Submitted to the Powder metallurgy and Metal Ceramics*	*In progress*	*Springer New York*	*United States*	*2018*	*.*		*No*
34	*Effect of powder feedstock features on the microstructure of UHTC coatings.*	*M. Parco (TECNALIA)*	*TBD*	*In Progress.*	*TBD*		*2018*			*TBD*
35	*ZrB2-MoSi2 Shrouded Plasma Spray Deposited Coatings on C/C and C/C-SiC Substrates.*	*O. Grigoriev (IPMS)*	*TBD*	*In Progress.*	*TBD*		*2018*			*TBD*

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[4]	Main leader	Title	Date/Period	Place	Type of audience[5]	Size of audience	Countries addressed
1	*Project website*	*ECM*	*Public web site of the project*	*1 May 2014*	http://www.light-tps.eu/	*Scientific community, Industry, Civil society, Policy makers, Medias*	*6000*	*International*
2	*Conferences*	*YUZHNOYE*	*Thermal protection structures of reusable spacecraft.*	*September 2014*	*Kiev, Ukraine*	*Scientific Community*		*Ukraine*
3	*Media briefings*	*TECNALIA*	*New materials and construction technologies for super light-weight thermal protection systems*	*19/11/2014*	*DOI: 10.2769/88565*	*Scientific community, Industry, Civil society, Policy makers, Medias*	*6000*	*International*
4	*Oral presentation to a scientific event*	*TECNALIA*	*Super light-weight thermal protection system for space application (LIGHT-TPS)*	*27th February 2015*	*San Sebastian, Spain*	*Scientific Community, Industry, Policy makers*	*70*	*Europe*
5	*Oral presentation to a scientific event*	*YUZHNOYE*	*New materials and technology for reusable re-entering spacecraft.*	*April 2015.*	*Dniepropetrovsk, Ukraine*	*Scientific Community, Industry,*	*200*	*International*
6	*Oral presentation to a scientific event*	*CNR*	*Ultra-High Temperature Ceramic Matrix Composites: Short vs continuous fibers*	*12-16 April 2015*	*Australia*	*Scientific Community*	*100*	*International*

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

7	*Oral presentation to a scientific event*	*SRI*	*Optimization methods in material science: synergetics, dynamical models, and optimization problems*	*15 May 2015*	*Kiev, Ukraine*	*Scientific Community*	*300*	*International*
8	*Oral presentation to a scientific event*	*IEW*	*Diffusion welding of high-temperature ni-cr alloy foil*	*20-22 may 2015*	*Kiev, Ukraine*	*Scientific Community*	*150*	*International*
9	*Oral presentation to a scientific event*	*IEW*	*Technology of honeycomb core preparation for welding three-layer elements of satellite protection*	*20-22 may 2015*	*Kiev, Ukraine*	*Scientific Community*	*150*	*International*
10	*Oral presentation to a scientific event*	*IEW*	*Producing three-layer honeycomb panels from Ni-Cr based powder alloy*	*23-26 may 2015*	*Kiev, Ukraine*	*Scientific Community*	*120*	*International*
11	*Oral presentation to a scientific event*	*IEW*	*Vacuum diffusion welding of sheets from Ni-Cr powder alloy*	*23-26 may 2015*	*Kiev, Ukraine*	*Scientific Community*	*120*	*International*
12	*Oral presentation to a scientific event*	*SRI*	*Superlight-weight thermal protection systems for space applications: conception, methods, and applications*	*29 June – 3 July 2015*	*Krakow, Poland.*	*Scientific Community*	*400*	*International*
13	*Oral presentation to a scientific event*	*IPMS*	*Two-stage configuration burner device for high-vilocity air liquid-fuel spraying*	*5 - 10 September 2015*	*Koblevo, Ukraine.*	*Scientific Community*	*236*	*International*
14	*Poster presentation to a scientific event*	*IEW*	*New possibilities for solid-phase joining of difficult-to-weld aircraft materials using nanolayered foils*	*25-27 November 2015*	*Bologna, Italy*	*Scientific Community*	*500*	*International*

15	*Oral presentation to a scientific event*	*YUZHNOYE*	*Conceptual design of thermal protection system with all-welded metallic outer shell and internal fibrous insulation layer for reusable space vehicle.*	*19-22 of April 2016*	*Noordwijk, the Netherlands*	*Scientific community, Industry, Policy makers*		*International*
16	*Oral presentation to a scientific event*	*CNR*	*Development of refractory composites for extreme aerospace environments*	*2-3 May 2016*	*Texas, USA*	*Scientific Community*	*50*	*International*
17	*LIGHT-TPS Workshop*	*Tecnalia*	*Presentation of LIGHT-TPS project*	*1-4 June 2016*	*Berlin*	*Scientific community, Industry, Policy makers*	*40*	*Europe*
18	*LIGHT-TPS Workshop*	*CNR*	*Development of UHTCs and coatings on their basis for TPS applications.*	*1-4 June 2016*	*Berlin*	*Scientific community, Industry, Policy makers*	*40*	*Europe*
19	*LIGHT-TPS Workshop*	*YUZHNNOYE*	*Development of super-light multilayer TPS for reusable space systems*	*1-4 June 2016*	*Berlin*	*Scientific community, Industry, Policy makers*	*40*	*Europe*
20	*LIGHT-TPS Workshop*	*IPMS*	*Development of Super-Light Weight Alloys on the Basis of NiCr and Nb and Honeycomb Structure on the Base of Them*	*1-4 June 2016*	*Berlin*	*Scientific community, Industry, Policy makers*	*40*	*Europe*
21	*LIGHT-TPS Workshop*	*SRI*	*Analysis and Optimization of TPS Temperature Fields During Diffusion Welding Process.*	*1-4 June 2016*	*Berlin*	*Scientific community, Industry, Policy makers*	*40*	*Europe*
22	*Flyer*	*ECM*	*LIGHT-TPS flyer*	*1 June 2016*	*Berlin*	*Scientific community, Industry, Policy makers,*	*1000*	*International*

						Medias.		
23	*Video*	*ECM*	*LIGHT-TPS video*	*1 June 2016*	*Berlin*	*Scientific community, Industry, Civil society, Policy makers, Medias*	*2000*	*International*
24	*Poster*	*ECM*	*LIGHT-TPS poster*	*1 June 2016*	*Berlin*	*Scientific community, Industry, Civil society, Policy makers, Medias*	*2000*	*International*
25	*Oral presentation to a scientific event*	*IPMS*	*Development of heat-resistant niobium-based alloy for thermal protection of rocket space technology*	*30 July - 7 August, 2016*	*Istanbul.*	*ISSN 978-966-360-316-2.*		*International*
26	*Oral presentation to a scientific event*	*IPMS*	*ZrB2 - Based Ultra-High-Temperature Ceramics Oxidation Behaviour.*	*30 July - 7 August, 2016*	*Istanbul.*	*ISSN 978-966-360-316-2.*		*International*
27	*Oral presentation to a scientific event*	*SRI*	*The influence of the free space environment on the super lightweight thermal protection system: Conception, methods and risk analysis*	*30 July - 7 August, 2016*	*Istanbul.*	*ISSN 978-966-360-316-2.*		*International*
28	*Oral presentation to a scientific event*	*IPMS*	*Equipment for high-speed air-fuel spraying of coatings based on ZrB_2 for aerospace engineering*	*22-27 August 2016*	*Odesa, Ukraine*	*Scientific Community*	*200*	*Ukraine*
29	*Oral presentation to a scientific event*	*IPMS*	*Thermal tests of material samples for leading edge of hypersonic flying*	*22-27 August 2016*	*Odesa, Ukraine*	*Scientific Community*	*204*	*Ukraine*

			apparatus					
30	*Oral presentation to a scientific event*	*IPMS*	*Heat-resistant niobium-based alloy for rocket space technology*	*5 - 10 September 2016*	*Koblevo, Ukraine.*	*Scientific Community*	*181*	*International*
31	*Oral presentation to a scientific event*	*IPMS*	*Current trends in creating a new generation of heat-resistant metal powder materials for thermal protection of reusable spacecrafts*	*19-22 September, 2016*	*Warsaw, Poland.*	*Scientific Community*	*50*	*International*
32	*Oral presentation to a scientific event*	*YUZHNOYE*	*Composite ceramic materials for reusable spacecrafts*	*19-22 September, 2016*	*Warsaw, Poland.*	*Scientific Community*	*50*	*International*
33	*Oral presentation to a scientific event*	*TECNALIA*	*Development of UHTC coatings using a Shrouded Plasma Spray (SPS) technique*	*19-22 September, 2016*	*Warsaw, Poland.*	*Scientific Community*	*50*	*International*
34	*Oral presentation to a scientific event*	*IPMS*	*ZrB2 – Based Ceramics Thermal Sprayed Coatings.*	*19-22 September, 2016*	*Warsaw, Poland.*	*Scientific Community*	*50*	*International*
35	*Oral presentation to a scientific event*	*IPMS*	*The Mechanism of UHTCs Structure and Properties Formation.*	*19-22 September, 2016*	*Warsaw, Poland.*	*Scientific Community*	*50*	*International*
36	*Poster presentation to a scientific event*	*IEW*	*Diffusion welding of ni-cr alloy in vacuum using porosity interlayers for production of honeycomb sandwich panels*	*19-22 September, 2016*	*Warsaw, Poland*	*Scientific Community*	*2500*	*International*
37	*Oral presentation to a scientific event*	*CNR*	*Ultra-high temperature CMC with self-healing capability.*	*20-23 September 2016*	*Rome, Italy*	*Scientific Community*	*50*	*International*
38	*Poster presentation to a scientific event*	*IEW*	*Influence of chemical composition*	*1 - 2 December 2016*	*Kyiv, Ukraine.*	*Scientific Community*	*100*	*Ukraine*

			nanolayer foils to form compounds of heat-resistant nickel-based alloy at DWV					
39	*Oral presentation to a scientific event*	*CNR*	*Ceramic Composites for Extreme Environments: Effect of W Doping*	*30-31 March 2017*	*Cambridge,UK*	*Scientific Community*	*30*	*International*
40	*Oral presentation to a scientific event*	*IEW*	*Effect of temperature of heating on structure and chemical composition of the compounds coating Ni - Ni-Cr alloy*	*24-27 april 2017*	*Chernigiv, Ukraine*	*Scientific Community*	*300*	*International*
41	*Oral presentation to a scientific event*	*SRI*	*Modeling and investigation of superlight-weight thermal protection system for space application (Plenary report)*	*23-26 May 2017*	*Kiev, Ukraine.*	*Scientific Community*	*450*	*International*
42	*Oral presentation to a scientific event*	*IPMS*	*High velocity air-fuel spraying of heat-protection and wear-resistance coatings*	*13-16 March 2017*	*Sofia, Bulgaria*	*Scientific Community, Industry,*	*70*	*International*
43	*Oral presentation to a scientific event*	*IEW*	*Producing three-layer honeycomb panels from Ni-Cr based powder alloy. 9th International conference of young scientists on welding and related technologies*	*23-26 May 2017*	*Kyiv, Ukraine*	*Scientific Community, Industry*		*Ukraine*
44	*Oral presentation to a scientific event*	*IEW*	*Vacuum diffusion welding of sheets from Ni-Cr powder alloy // 9th International conference of young scientists on welding*	*23-26 May 2017*	*Kyiv, Ukraine*	*Scientific Community, Industry*		*Ukraine*

			and related technologies					
45	*Oral presentation to a scientific event*	*IPMS*	*Preparation of dispersion-strengthened nichromes and the features of their thermomechanical processing*	*23-26 May 2017*	*Dnepropetrovsk, Ukraine*	*Scientific Community, Industry*	*567*	*International*
46	*Oral presentation to a scientific event*	*IPMS*	*Study of thermoerozion characteristics of ultra-high temperature ceramics in the conditions of high-temperature heating in supersonic stream of combustion products*	*30 May-3 June 2017*	*Lutsk, Ukraine*	*Scientific Community*	*70*	*International*
47	*Oral presentation to a scientific event*	*IPMS*	*Thermal tests of materials for the leading edges of hypersonic vehicle*	*30 May-3 June 2017*	*Lutsk, Ukraine*	*Scientific Community*	*70*	*International*
48	*Oral presentation to a scientific event*	*IPMS*	*Influence of the technology of obtaining ultra-high temperature ceramics on the ZrB_2-based on its corrosion resistance*	*30 May-3 June 2017*	*Lutsk, Ukraine*	*Scientific Community*	*70*	*International*
49	*Oral presentation to a scientific event*	*IPMS*	*Thermoerosion testing of coatings based on ultra-high-temperature ceramics on substrates from composite carbon-carbon material*	*19-22 June 2017*	*Varna, Bulgaria*	*Scientific Community, Industry,*	*60*	*International*
50	*Oral presentation to a scientific event*	*IPMS*	*Development of rolling modes for*	*19-22 June 2017*	*Varna, Bulgaria*	*Scientific Community*	*60*	*International*

			samples made of nichrome powder alloy and their testing at operating temperatures					
51	*Oral presentation to a scientific event*	*IPMS*	*Processes and mechanisms of refractory borides activated sintering at UHTCs production*	*5-8 July 2017*	*Athens, Greece*	*Scientific Community*	*65*	*International*
52	*Oral presentation to a scientific event*	*IPMS*	*Equipment and Test Results for Zirconium Diboride-Based Materials for Heat-Stressed Elements of Hypersonic Aircraft*	*21-25 August 2017*	*Odesa, Ukraine.*	*Scientific Community*	*72*	*Ukraine*
53	*Oral presentation to a scientific event*	*SRI*	*Modeling of heat propagation processes in a thermal protection system for space application*	*21-25 August 2017*	*Odesa, Ukraine.*	*Scientific Community*	*72*	*Ukraine*
54	*Oral presentation to a scientific event*	*SRI*	*Space factors influence on super light-weight thermal protection system: concept, modeling, and risk analysis*	*21-25 August 2017*	*Odesa, Ukraine.*	*Scientific Community*	*72*	*Ukraine*
55	*Oral presentation to a scientific event*	*IPMS*	*Development of the hot-strength alloy based niobium for thermal protection of rocket and space technology products*	*2-10 September 2017*	*Koblevo, Ukraine*	*Scientific Community, Industry,*	*134*	*International*
56	*Oral presentation to a scientific event*	*SRI*	*Space weather factors influence on superlight weight thermal protection system: modeling results*	*14 - 18 November 2016*	*Ostende, Belgium*	*Scientific Community, Industry*	*70*	*International*

57	*Oral presentation to a scientific event*	*SRI*	*Space weather prediction using robust dynamical models: Identification, optimization and risk analysis.*	*25 July to 29 July 2017*	*Palma de Mallorca, Spain*	*Scientific Community, Industry,*	*55*	*International*

3.2. Section B (Confidential6 or public: confidential information to be marked clearly)

Part B1

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[7]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456) / URL	Subject or title of application	Applicant (s) (as on the application)
Patent	*Yes*	*01.02. 2020*	*a108096 Ukraine http://base.ukrpatent.org/searchINV/search.php?action=viewdetails&IdClaim=210446*	*PRODUCTION METHOD OF NICHROME BASED HEAT-RESISTANT ALLOY*	*IPMS (single owner)*
Patent for Utility Model	*Yes*	*01.02. 2020*	*U 115259 Ukraine http://base.ukrpatent.org/searchINV/search.php?action=viewdetails&IdClaim=234184*	*Method for obtaining a heat-resistant alloy*	*IPMS (single owner)*
Patent for Utility Model	*No*	*N/A*	*U 114808 Ukraine 2017, МПК B23K 20/00, B23K 20/16. http://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=233606&chapter=biblio*	*Method diffusion welding three layer honeycomb panels*	*IEW (single owner)*
Patent for utility model	*No*	*N/A*	*U 113424 Ukraine, 2017, МПК B23K 20/14 http://base.uipv.org/searchINV/search.php?action=viewdetails&IdClaim=231768*	*Device for diffusion welding three layer honeycomb panels*	*IEW (Co-owner), SRI (Co-owner)*
Patent	*No*	*N/A*	*a201701746 (Application submitted on 23.02.2017) http://base.uipv.org/searchInvStat/s*	*The construction of a voluminous honeycomb core and the method of manufacturing a honeycomb panel*	*IEW (single owner)*

[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[7] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

			howclaimdetails.php?IdClaim=290480&resId=1		
Patent for utility model	*No*	*N/A*	*U 2017 090 0*	*Thermal protection system of reusable spacecraft*	*YUZHNOYE (single owner)*

Part B2

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	*New method for the thermal spray deposition of oxidation protective coatings on the basis of UHTCs*	*No*		*Deposition of cost-competitive UHTC coatings on non-oxide CMCs.*	*1. Aerospace 2. energy applications*	*2018: Use result internally to make a new result to be sold, provide services pertaining to result (training, consultancy,..), Use result for further research.*	*Industrial secret*	*TECNALIA (owner)*
General advancement of knowledge	*Methods for preparing UHTC powders with desired diameter and inner cohesion for thermal spray deposition process*	*No*		*Deposition of cost-competitive UHTC coatings on non-oxide CMCs.*	*1. Aerospace 2. energy applications*	*2018: Use result internally to make a new result to be sold, provide services pertaining to result (training, consultancy,..), Use result for further research.*	*Industrial secret*	*CNR (owner)*
General advancement of knowledge	*Non-oxide CMCs (C/C and C/C-SiC) coated with UHTCs for improved oxidation resistance*	*No*		*Coated non-oxide CMCs with prolonged service life and/or suitable for higher service*	*1. Aerospace 2. energy applications*	*2020: Use result internally to make a new result to be sold, provide services pertaining to result (training, consultancy,..),*	*Industrial secret, patent.*	*DLR, TECNALIA, CNR, IPMS (co-owners)*

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[9] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
				temperatures than existing solutions		*Use result for further research.*		
General advancement of knowledge	*Preparation of ultra-refractory UHTC bulks with high strength above 1900°C*	*No*		*Production of strong and refractory ceramics*	*1. Aerospace 2. energy applications*	*2018: Use result internally to make a new result to be sold, provide services pertaining to result (training, consultancy,..), Use result for further research.*	*Industrial secret*	*CNR (owner)*
Commercial exploitation of R&D results	*Alloys for cost-competitive protective TPS of reusable spacecrafts for prolonged operation at elevated temperatures*	*Yes*	*01.02.2020*	*Cost-competitive TPS of reusable spacecrafts for prolonged operation at elevated temperatures*	*1. Aerospace 2. energy applications*	*2020: Use result internally to make a new result to be sold, - Provide services pertaining to result (training, consultancy,..), - Use result for further research, - Licensing*	*Patent № 108096 “Method for obtaining a heat-resistant alloy based on nichrome” Patent № 115259 “Method for obtaining a heat-resistant alloy”*	*IPMS (owner)*
Commercial exploitation of R&D results	*Method of rolling dispersed-hardened alloys*	*Yes*	*01.02.2020*	*Rolling of dispersion-hardened alloys such as those obtained in results 1 and 2 for thermal protection designs and*	*1. Aerospace 2. energy applications*	*2020: Use result internally to make a new result to be sold, - Provide services pertaining to result (training, consultancy,..), - Use result for*	*Patented*	*IPMS (owner)*

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
				other high temperature applications		*further research,* *- Licensing*		
Commercial exploitation of R&D results	*Equipment and test methods for sharp edges models of hypersonic aircraft*	*No*		*Equipment and test methods for sharp edges models of hypersonic aircraft*	*1. Aerospace 2. energy applications*	*2018:* *Use result internally to make a new result to be sold,* *- Provide services pertaining to result (training, consultancy,..),* *- Use result for further research*	*None*	*IPMS (owner)*
Commercial exploitation of R&D results	*Novel method of diffusion welding three-layer honeycomb panels*	*No*		*New generation of materials of intermediate layers for welding TPS*	*1. Aerospace*	*2020:* *Commercialization services development*	*Patent for utility model, № 114804 Ukraine 2017, МПК В23К 20/00, В23К 20/16.*	*IEW (owner)*
Commercial exploitation of R&D results	*Novel method diffusion welding three-layer honeycomb panels*	*No*		*New generation of welding equipment for welding TPS*	*1. Aerospace*	*2020:* *Commercialization services development*	*Patent for utility model, № 113424 Ukraine, 2017, МПК В23К 20/14*	*IEW (owner),* *SRI (Co-owner)*
Commercial exploitation of R&D results	*Novel design of three-layer panel and method of its diffusion welding*	*No*		*New design of honeycomb core adapted for solid-phase welding of TPS*	*1. Aerospace*	*2020:* *Commercialization services development*	*Patent application №201701746 -23.02.2017-*	*IEW (owner)* *YUZHNOYE (Co-owner)*
Commercial exploitation of	*Novel method of the*	*No*		*Software for the*	*1. Aerospace* *2. Automotive*	*2020:* *Own*	*None*	*SRI (owner)*

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
R&D results	*probabilistic risk assessment of the influence of the free space environment on the superlight-weight thermal protection system (TPS).*			*probabilistic risk assessment*	*industries*	*commercialization through product/services development and marketing, licensing or spinning-off.*		
Commercial exploitation of R&D results	*System-theoretical approach to modeling and optimization of superlight-weight thermal protection system that based on the following models: synergetic, physical, and computational.*	*No*		*Novel mathematical models of TPS system*	*1. Aerospace 2. Automotive industries*	*2020: Own commercialization through product/services development and marketing.*	*Company secret*	*SRI (owner)*
Commercial exploitation of R&D results	*Novel method of TPS temperature properties modeling*	*No*		*Software for the TPS temperature properties modeling*	*1. Aerospace 2. Automotive industries*	*2020: Own commercialization through product/services development and marketing.*	*Utility model*	*SRI (owner)*
Commercial exploitation of R&D results	*Novel method of real time estimation of temperature*	*No*		*Observer for real time estimation of temperature*	*1. Aerospace 2. Automotive industries*	*2020: Licensing*	*In progress*	*SRI (owner), IEW (Co-owner)*

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	distribution in a TPS using observer.			*distribution in a TPS.*				
Commercial exploitation of R&D results	*Novel method for calculating thermal fields in complex physical objects.*	*No*		*New algorithms for calculating thermal fields.*	*Thermophysics, heat-resistant materials.*	*2020: Development and marketing*	*Utility model*	*SRI (owner)*
Commercial exploitation of R&D results	*Multilayer thermal protection system*	*No*		*Creation of multilayer TPS for reusable spacecraft*	*Aerospace and energy applications*	*2018: Use result internally to make new designs of reusable spacecraft to be sold, provide services pertaining to result (training, consultancy,..), Use result for further research.*	*U201709008 Patent application submitted. Patent will be issued in 2018.*	*YUZHNOYE (owner)*
Commercial exploitation of R&D results	*Technology for high temperature soldering of elements during TPS assembly (i.e. joining of three-layered panels using the U-type element as well as for attachment of supports)*	*Yes*	*31/12/2018?*	*Assembly of multilayer TPS for reusable spacecraft*	*Aerospace and energy applications*	*2018: Use result internally to make new designs of reusable spacecraft to be sold, provide services pertaining to result (training, consultancy,..), Use result for further research.*	*Industrial secret*	*YUZHNOYE (co-owner)* *There is a co-ownership with the Kremenchuk National University named after Mykhailo Ostrohradskyi.*

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	*Technology for light thermal insulation tiles manufacturing based on silica fibers, operating under 1200°C*	*No*		*Creation of multilayer TPS for reusable spacecraft*	*Aerospace and energy applications*	*2018: Use result internally to make new designs of reusable spacecraft to be sold, provide services pertaining to result (training, consultancy,..), Use result for further research.*	*Industrial secret*	*YUZHNOYE (owner)*
Commercial exploitation of R&D results	*Special testing equipment and tooling for complex testing*	*No*		*Creation of multilayer TPS for reusable spacecraft*	*Aerospace and energy applications*	*2018: Use result internally to test new types of TPS, provide services pertaining to result (training, consultancy,..), Use result for further research.*	*None*	*YUZHNOYE (owner)*

4. REPORT ON SOCIETAL IMPLICATIONS

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	607182
Title of Project:	Super Light-Weight Thermal Protection System for Space
Name and Title of Coordinator:	Dr.-Ing. María Parco

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***Yes***
2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No
• Were those animals cloned farm animals?	No

• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	No
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	Yes
DUAL USE	
• Research having direct military use	Yes
• Research having the potential for terrorist abuse	Yes

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	TECNALIA:1	0
Work package leaders	TECNALIA:0 IPMS: 0 YUZHNOYE: 2 ECM: 0 **(in Total: 2)**	TECNALIA:1 IPMS: 4 YUZHNOYE: 0 ECM: 1 **(in Total: 5)**
Experienced researchers (i.e. PhD holders)	TECNALIA:0 IPMS: 7 YUZHNOYE: 3 IEW: 3 SRI: 0 CNR: 2 ECM:0 DLR: 0 **(in Total: 15)**	TECNALIA: 5 IPMS: 16 YUZHNOYE: 15 IEW: 3 SRI: 2 CNR: 1 ECM: 0 DLR: 3 **(in Total: 45)**
PhD Students	TECNALIA: 0 IPMS: 0 YUZHNOYE: 0 IEW: 0 SRI: 0 CNR: 0 ECM: 0 DLR: 0 **(in Total: 0)**	TECNALIA: 0 IPMS:0 YUZHNOYE: 5 IEW: 0 SRI: 1 CNR:1 ECM:0 DLR: 0 **(in Total: 7)**
Other	TECNALIA: 0 IPMS:10 YUZHNOYE: 7 IEW:2 SRI: 1 CNR: 0 ECM: 0 DLR: 0 **(in Total: 20)**	TECNALIA: 4 IPMS: 24 YUZHNOYE: 19 IEW:0 SRI: 1 CNR: 3 ECM:2 DLR: 0 **(in Total: 53)**

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**5**
Of which, indicate the number of men:	IPMS: 0 YUZHNOYE: 4(3) IEW:0 SRI: 1 CNR:0 ECM: 0 DLR: 0 **(in Total: 5)**

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?	X ○	Yes No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective … Very effective
X	Design and implement an equal opportunity policy	○ ○ ○ X ○
❑	Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○
❑	Organise conferences and workshops on gender	○ ○ ○ ○ ○
❑	Actions to improve work-life balance	○ ○ ○ ○ ○
○	Other:	

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

X No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, p

X Yes- please specify: CNR /**Lecture-** "*Ultra-High Temperature Ceramics for aerospace applications"* - Graduate students, University of Parma. Audience: 50 /CNR SRI: 3 lectures for students.

○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

X Yes- please specify: Public web site, publications, lectures.

○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

○ Main discipline[10]: 2.3 Other engineering sciences

○ Associated discipline[10]: 1.2 Physical sciences

○ Associated discipline[10]: 1.1 Mathematics and computer sciences

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ X	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No

○ Yes- in determining what research should be performed

○ Yes - in implementing the research

○ Yes, in communicating /disseminating / using the results of the project

[10] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ X	**Yes** No

12. Did you engage with government / public bodies or policy makers (including international organisations)

X No
○ Yes- in framing the research agenda
○ Yes - in implementing the research agenda
○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

X Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs **Education, Training, Youth** Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy **Research and Innovation** **Space** Taxation Transport	

13c If Yes, at which level? ○ Local / regional levels ○ National level X European level ○ International level	

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**32**
To how many of these is open access[11] provided?	**12**
How many of these are published in open access journals?	**9**
How many of these are published in open repositories?	**3**
To how many of these is open access not provided?	**20**
Please check all applicable reasons for not providing open access:	
X publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal X lack of time and resources ❑ lack of information on open access ❑ other[12]: ……………	
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**2**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	
	Registered design	
	Other	**4**

17. How many spin-off companies were created / are planned as a direct result of the project?	
Indicate the approximate number of additional jobs in these companies:	**None**

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑ Increase in employment, or	❑ In small & medium-sized enterprises
X Safeguard employment, or	❑ In large companies
❑ Decrease in employment,	❑ None of the above / not relevant to the project
❑ Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:* *36*

[11] Open Access is defined as free of charge access for anyone via Internet.
[12] For instance: classification for security project.

Difficult to estimate / not possible to quantify	❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

X Yes ○ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

X Yes ○ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

X	Press Release	X	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
X	Brochures /posters / flyers	X	Website for the general public / internet
❑	DVD /Film /Multimedia	X	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	X	English
X	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as

geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]