Annex I – JRP protocol

Version Date: 25 May 2023

22RPT03 MultiFixRad

Improving the realisation of the kelvin by multiple fixed point radiation thermometry

Start date: 01 June 2023

Duration: 36 months

Coordinator
Åge Andreas Falnes Olsen
JV

Glossary

BIPM	International Bureau of Weights and Measure
CCT	Consultative committee for thermometry, part of BIPM
CCT-K10	A key comparison in radiation thermometry from 960 °C to 3000 °C
CMC	Calibration and measurement capability
DI	Designated institute
FPC	Fixed point cell
HTFP	High-temperature fixed point
IEA	International Energy Agency
InK, InK 2	Implementing the new kelvin, European research projects to support the redefinition of the kelvin
ITS-90	International temperature scale of 1990
MeP-K	Mise-en-pratique, or best practice, for the realisation of the kelvin
NMI	National metrology institute
Real-K	Realising the new kelvin, European research project to support dissemination of the new kelvin
SSE	Size-of-source effect
RMO	Regional metrology organisation
RT	Radiation thermometry
TC-T	EURAMET technical committee for thermometry
WG NCTh(erm)	CCT working group for non-contact thermometry

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Section A: Key data

A1 Project data summary

Coordinator contact details:

Coordinator:	Åge Andreas Falnes Olsen
Address:	JV, P.O. Box 170, NO-2027 Kjeller, Norway
Phone:	+47 988 10 363
Email:	aao@justervesenet.no

Participant details:

a. Participants

no.	Participant Type	Short Name	Organisation legal full name	Country
1	Internal Beneficiary	JV	Justervesenet	Norway
2	Internal Beneficiary	CMI	Cesky Metrologicky Institut	Czechia
3	Internal Beneficiary	CNAM	Conservatoire national des arts et métiers	France
4	Internal Beneficiary	DFM	Dansk Fundamental Metrologi A/S	Denmark
5	Internal Beneficiary	LNE	Laboratoire national de métrologie et d'essais	France
6	Internal Beneficiary	RISE	RISE Research Institutes of Sweden AB	Sweden
7	Internal Beneficiary	SMU	Slovenský Metrologický Ústav	Slovakia
8	Internal Beneficiary	TUBITAK	Turkiye Bilimsel ve Teknolojik Arastirma Kurumu	Türkiye
9	Internal Beneficiary	UL	Univerza v Ljubljani	Slovenia
10	External Beneficiary	DTU	Danmarks Tekniske Universitet	Denmark

A2 Financial summary

	Internal Beneficiaries	External Beneficiaries	Unfunded Beneficiaries	Associated Partners	Total
Labour (€)	527 000.00	75 000.00			602 000.00
Subcontracts (€)					
T&S (€)	44 000.00	3 000.00			47 000.00
Equipment (€)					
Other Goods, Works and Services (€)	50 680.00	10 000.00			60 680.00
Internally Invoiced Goods and Services (€)	2 000.00				2 000.00
Indirect (€)	155 420.00	22 000.00			177 420.00
Total costs (€)	779 100.00	110 000.00			889 100.00
Costs as % of Total costs	88 %	12 %	0 %	0 %	
Total Eligible Costs (€)	779 100.00	110 000.00			889 100.00
EU contribution (€)	**779 100.00**	**110 000.00**			**889 100.00**
EU contribution as % of total EU contribution	88 %	12 %	0 %	0 %	
Months	83.5	8.1			91.6

A3 Work packages summary

WP No	Work Package Title	Active Participants (WP leader in bold)	Months
WP1	Establishing the required basic competence on the realisation of the temperature scale and the MeP-K at the less experienced institutes	**CMI**, CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK, UL, DTU	13.5
WP2	Realisation of medium and high temperature fixed points	**SMU**, CMI, CNAM, DFM, JV, LNE, RISE, TUBITAK, UL, DTU	26.9
WP3	Establishing scale implementations using the multi-fixed point scheme	**TUBITAK**, CMI, CNAM, DFM, JV, LNE, RISE, SMU, UL, DTU	19.0
WP4	Comparison with potential linkage to the CCT-K10 key comparison	**CNAM**, CMI, LNE, JV, RISE, SMU, TUBITAK, UL	14.3
WP5	Creating impact	**LNE**, CMI, CNAM, DFM, JV, RISE, SMU, TUBITAK, UL, DTU	8.1
WP6	Management and coordination	**JV**, CMI, CNAM, DFM, LNE, RISE, SMU, TUBITAK, UL, DTU	9.8
		Total months	**91.6**

The information in tables A2 and A3 reflect the estimates of resources as of the start of project in June 2023. The tables will not necessarily be updated during the course of the project.

Section B: Overview of the research

B1 Summary of the project

Overview

Highly accurate and traceable high temperature measurements are critical to a number of European industries, including metallurgical industries, glass, graphite and fertiliser production. Currently, there are regional gaps in the dissemination of the temperature scale with primary techniques at high temperatures. The *mise-en-pratique* of the new definition of the kelvin (*MeP-K*) offers new possibilities to realise and disseminate thermodynamic temperature using multiple high-temperature fixed points to calibrate a radiation thermometer, which is then used as an interpolating instrument. The project aims to assist 6 less experienced European national metrology institutes and designated institutes (JV, RISE, DFM, CMI, SMU, and UL) in establishing their own primary reference scales for thermometry using this approach. The improved high-temperature measurement standards will respond to industrial needs in the countries and enable participation in development projects for fundamental thermometry at high temperature, and at the highest scientific level.

Need

The recent redefinition of the kelvin, and the new *MeP-K*, opens up a new pathway for dissemination of the temperature scale. The most common instruments for disseminating temperature remain thermocouples for temperatures up to around 1500 °C, but these require calibration against primary references. The less experienced institutes in this project (JV, RISE, DFM, CMI, SMU and UL) are all well-established intermediate level national metrology institutes (NMIs) and designated institutes (DIs) in Europe, but they currently lack a realisation of high temperature primary standards. The participants represent countries with substantial production, processing, and manufacturing industries with expressed needs for improved high temperature standards, including the metallurgical industry, manufacturing of building materials and H_2 production.

Following the recent redefinition of the kelvin one of the most promising primary reference standards for high temperature is to interpolate between high temperature fixed points, whose transition temperatures have been established with high accuracy, using a radiation thermometer as the interpolation instrument. However, the method has not yet been implemented on a large scale outside the major NMIs. An important pillar of the metrological community is the ability to compare results across different institutions and countries, but this requires that a certain number of institutes are capable of realising the quantity to be compared. To address these aims some less experienced NMIs/DIs need to develop primary thermometry capabilities, including the ability to construct, characterise, use and maintain fixed points intended for radiometric applications, and to establish a primary temperature scale in line with the revised MeP-K. By taking a coordinated approach this will help the European metrology community to improve its robustness, but at the same time avoid fragmented and uncoordinated capacity building. The consortium will create nascent regional centres of excellence in the field, by coordinating the activity in the Scandinavian and central European regions, respectively.

Objectives

The overall objective of this project is to endow six European NMIs (JV, RISE, DFM, SMU, CMI and UL) with the competence and resources to realise a primary high temperature scale at the highest level, in accordance with the revised MeP-K. The specific objectives are:

1. To transfer knowledge to the less experienced institutes on the theoretical and experimental aspects of the realisation of the ITS-90 by extrapolation from a single fixed point. An important part of this includes knowledge about the characterisation of the radiometer used to extrapolate temperature, such as its size-of-source sensitivity, linearity and spectral response.
2. To construct a set of medium- to high-temperature fixed points for radiation thermometry adapted to the technical means of less experienced NMIs/DIs. This includes assessment of the quality of the cells and experimental determination of the optimal thermal conditions for their use.
3. To realise the MeP-K through the application of the multi fixed point scheme using a variety of radiation thermometers and temperature ranges in accordance with the needs of less experienced NMIs/DIs, and to compare several realisations to the ITS-90. The target uncertainty of the realisations is 0.6 °C at 1500 °C and 1 °C at 2000 °C.
4. To perform an interlaboratory comparison, aiming to establish linkage to key comparison CCT-K10, to underpin improved calibration and measurement capabilities (CMCs) for participant laboratories in the field of radiation thermometry.
5. To facilitate the take up and long term operation of the capabilities, technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs/DIs, calibration and

testing laboratories), standards developing organisations (e.g. CIPM CCT, EURAMET TC-T), and end users (e.g. metal forming, building insulation, and steam reforming).

Progress beyond the state of the art and results

Knowledge transfer on the theoretical and experimental aspects of using ITS-90 and high-temperature fixed points

Above the freezing point of Ag (961.78 °C), the ITS-90 [1] is defined by extrapolating the Planck radiation from a blackbody at either the Ag, Au or Cu fixed points. While many laboratories perform some sort of scale dissemination this way, few have the capabilities to carry out a thorough characterisation of the pyrometer used in the extrapolation, including control of the linearity, spectral response and size-of-source (SSE) sensitivity. Leveraging CNAM's, LNE's and TUBITAK's extensive experience and competence in thermometry, personnel from the less experienced NMIs/DIs (JV, CMI, SMU, RISE, DFM and UL) will be trained in the relevant aspects of high temperature pyrometry, including the determination of thermodynamic temperature for a range of high temperature fixed points and the characterisation of radiometers. In addition, the opportunities for smart specialisation in the Scandinavian and the central European regions will be explored.

Construction of medium and high-temperature fixed point cells

High temperature fixed points are non-trivial to construct, characterise and use. Some fixed point cells are prone to damage, which means that a laboratory must expect to regularly replace or characterise their cells. While some of the less experienced laboratories have some limited previous experience with a small set of high temperature fixed points, none of them currently have experience of the construction nor characterisation of cells for radiometric use. Again, CNAM, LNE and TUBITAK will provide expertise, including know-how from earlier projects SIB01 InK, 15SIB02 InK 2 and 18SIB02 Real-K, to enable the less experienced institutes to acquire the necessary capacity to construct, characterise, use and maintain fixed points intended for radiometric applications in-house in the long run. The cells constructed will include Al (660.323 °C), Ag (961.78 °C), Cu (1084.62 °C), Fe-C (1154 °C), Co-C (1324.24 °C), Pd-C (1492 °C), Pt-C (1738.28 °C) and Re-C (2474.69 °C). To build this capacity without support would take many years, however within the project this process is shortened dramatically.

To realise the new MeP-K through a multi-fixed point scheme

The current scale realisation at the participants is either based on thermocouple calibration at fixed points from the intermediate range from 660 °C (Al freezing point) and upwards, or radiometric extrapolation in line with ITS-90, but with relatively high uncertainties. None of the less experienced institutes have a primary realisation of temperature according to the revised MeP-K. In this project the less experienced institutes will be equipped with the experience, skills and knowledge to implement a continuous temperature scale using interpolation between 3 or more high-temperature fixed points. The target uncertainty of the realisations is 0.6 °C at 1500 °C and 1 °C at 2000 °C. The consortium will also explore an interpolation scale for intermediate temperatures, which aims to rival thermocouples from 660 °C and upwards. New measurements will be carried out on the aluminium and silver points, using the extrapolation technique of ITS-90 to scale the radiometric measurements down from the Cu point.

To perform an interlaboratory comparison with the possibility of linkage to CCT-K10

Currently none of the less experienced laboratories can connect with key comparisons in the field. A comparison will be organised and performed to document and validate the new temperature scale realisations at the less experienced NMIs/DIs. The comparison will enable the participating institutes to link to the CCT-K10 via the French institutes (LNE and CNAM). The results of the comparison will also provide a first testcase for the new MeP-K. If successful, the comparison will strengthen the idea that the interpolation scheme is a viable path to realise a thermodynamic temperature scale beyond the highest-ranking institutes.

Outcomes and Impact

Outcomes for industrial and other user communities

The new capabilities established in this project will aid regional accredited laboratories and industrial stakeholders. A number of energy intensive industrial processes, such as metallurgical processing, fertilizer, glass and graphite production, take place at high temperatures in excess of 1000 °C, where the accurate control of temperature may affect the quality of the end product. With improved reference standards, the NMIs and DIs will be able to supply stable and precise calibration services to regional customers, which in turn will enable improved temperature measurements in industrial applications. Precise reference standards pave the way for new techniques for applied thermometry, which in turn may lead to improved process control. The project will demonstrate examples of the dissemination of the new scale at three industrial environments during the project. One method will be by transfer using an interpolation instrument calibrated at fixed points, which is close to the traditional way to transfer traceability. A second method will deploy a calibrated fixed point at the factory to enable a local calibration directly against this point. If successful, this will directly enhance the temperature measurements at the end users.

Outcomes for the metrology and scientific communities

The direct outcome of this project will be to assist six less experienced European NMIs and DIs (JV, RISE, DFM, CMI, SMU and UL) to establish a primary temperature scale in line with the revised MeP-K that followed the redefinition of the kelvin in 2019. In particular the participants will implement the interpolation scheme, where precise radiometers are used as interpolation instruments that are calibrated using three or more temperature fixed points. This will enable these institutes to (i) be in a position to submit CMCs for new or improved calibration services within the range 961.78 °C to 2474.69 °C, (ii) help disseminate a more precise high temperature scale in Europe, and (iii) contribute to future research and collaborations in high temperatures, such as the European Partnership on Metrology calls on Industry, Integrated European Metrology and Fundamental Metrology. The less experienced NMIs/DIs will all benefit from a potential opportunity to link to the CCT-K10 key comparison, as this will help document their measurement capability at the end of the project and allow them to register updated and improved CMC values in the Key Comparison database. An important aim with this project is to foster regional collaboration and specialisation within EURAMET. The consortium consists of European NMIs and DIs that conveniently cluster in two regions, the Scandinavian and central European regions. This enables the consortium to create centres of excellence to cover regions beyond individual countries. The strategic outlook of CCT for the 2020s calls for further development and dissemination of primary thermometry techniques, and this project will enable the less experienced institutes to contribute to this work.

Outcomes for relevant standards

The new MeP-K acknowledges the interpolation scheme as a primary thermometry method, but it has not yet been implemented beyond the largest NMIs. The project will produce the first technical guide for the implementation of a thermodynamic temperature scale. The aim is for this to eventually be a EURAMET guide, and it will be developed to fulfil the needs expressed by the EURAMET TC-T but also the CCT. The experience from work within the project is expected to inform the CCT on relevant aspects of the new MeP-K.

Longer-term economic, social and environmental impacts

There are a number of industrial processes with high importance for the green transition that involve processing steps at high temperature, which are widely employed in the countries represented in the consortium. Examples range from the manufacturing of solar cells, steam reforming for H_2 production, the production of graphite for Li-ion batteries, to manufacturing building insulation materials. High temperature measurement is also important in combustion processes, such as ICE engines, waste incineration or power plants. Improved high temperature standards and measurements are the basis for optimising these processes, which in turn may improve product quality, enhance efficiency, and reduce the resource footprint of the processes.

B2 Excellence

B2.a <u>Overview of the objectives</u>

The overall objective of this project is to endow six European NMIs (JV, RISE, DFM, SMU, CMI and UL) with the competence and resources to realise a primary high temperature scale at the highest level, in accordance with the revised MeP-K [1]. The project will also demonstrate the new capabilities in three different ways: by conducting an interlaboratory comparison, by publishing two peer reviewed papers demonstrating progress in the field, and by demonstrating examples of dissemination to industrial stakeholders.

The specific objectives of the project are:

1. To transfer knowledge to the less experienced institutes on the theoretical and experimental aspects of the realisation of the ITS-90 by extrapolation from a single fixed point. An important part of this includes knowledge about the characterisation of the radiometer used to extrapolate temperature, such as its size-of-source sensitivity, linearity and spectral response. (WP1)

2. To construct a set of medium- to high-temperature fixed points for radiation thermometry adapted to the technical means of less experienced NMIs/DIs. This includes assessment of the quality of the cells and experimental determination of the optimal thermal conditions for their use. (WP1, WP2)

3. To realise the MeP-K through the application of the multi fixed point scheme using a variety of radiation thermometers and temperature ranges in accordance with the needs of less experienced NMIs/DIs, and to compare several realisations to the ITS-90. The target uncertainty of the realisations is 0.6 °C at 1500 °C and 1 °C at 2000 °C. (WP3)

4. To perform an interlaboratory comparison, aiming to establish linkage to key comparison CCT-K10, to underpin improved calibration and measurement capabilities (CMCs) for participant laboratories in the field of radiation thermometry. (WP4)
5. To facilitate the take up and long term operation of the capabilities, technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs/DIs, calibration and testing laboratories), standards developing organisations (e.g. CIPM CCT, EURAMET TC-T), and end users (e.g. metal forming, building insulation, and steam reforming). (WP5)

B2.b List of deliverables

Relevant objective (Activity delivering the deliverable)	Deliverable number	Deliverable description	Deliverable type	Participants (Lead in bold)	Delivery date
1 (A1.1.5)	D1	Training materials on the temperature scale realisation in ITS-90 and the MeP-K for use in the radiation thermometry community for later training	E-learning materials, PowerPoint presentations	**CMI**, CNAM, DFM, JV, LNE, RISE, SMU, UL, TUBITAK, DTU	Aug 2024 (M15)
1 (A1.3.5)	D2	Report detailing the progress made by the less experienced NMIs/DIs during the project in developing capability in the temperature scale realisation within ITS-90 and the MeP-K at higher temperatures	Report	**UL,** CMI, DFM, JV, RISE, SMU	May 2026 (M36)
2 (A2.3.6)	D3	Report describing the fixed-point cells (Al (660.323 °C), Ag (961.78 °C), Cu (1084.62 °C), Fe-C (1154 °C), Co-C (1324.24 °C), Pd-C (1492 °C), Pt-C (1738.28 °C) and Re-C (2474.69 °C)) constructed in the project, the results of the characterisation measurements and a summary of the optimisation processes. The target uncertainty in the practical realisation of the transition temperature is less than 0.6 °C (k=2)	Report	**RISE,** CMI, DFM, JV, SMU, TUBITAK, UL, DTU	Jan 2025 (M20)
2 (A2.3.8)	D4	Publication on the determination of the thermodynamic temperature of the freezing point of Al and/or Ag, performed by the ratio method relating it to the Cu point	Peer reviewed paper	**LNE,** CMI, JV, CNAM	Nov 2025 (M30)
3 (A3.2.5)	D5	Publication on the realisation of the radiometric high-temperature scale using multiple fixed points, the associated uncertainties and the characteristics of each participants' scheme. The target uncertainties for the implementation of the scale are less than 0.6 °C at 1500 °C and 1 °C at 2000 °C.	Peer reviewed paper	**JV**, CMI, CNAM, DFM, LNE, RISE, SMU, TUBITAK, UL, DTU	May 2026 (M36)
3 (A3.3.5)	D6	Report on the comparisons of the newly developed temperature scale realisations against ITS-90 over the range 1000 °C to 2500 °C	Report	**RISE**, DTU, DFM, JV, LNE, SMU, TUBITAK, UL	May 2026 (M36)

Relevant objective (Activity delivering the deliverable)	Deliverable number	Deliverable description	Deliverable type	Participants (Lead in bold)	Delivery date
4 (A4.2.5)	D7	Draft A report on the comparison of the *mise en pratique* of the kelvin over the range 1000 °C to 2500 °C	Comparison report	**CNAM**, CMI, JV, LNE, RISE, SMU, TUBITAK, UL	May 2026 (M36)
5 (A5.2.3)	D8	Best practice guide / EURAMET guide on indirect primary thermometry using high temperature fixed points (HTFPs)	Best practice guide	**CMI**, all participants	May 2026 (M36)
5	D9	Evidence of contributions to or influence on new or improved international guides, recommendations and standards with a specific focus on the following guides and committees: CCT WG NCTherm, EURAMET TC-T, EURAMET TC-T WG best practice and IEC TC 65/SC 65B/WG 5 sub group RT. Examples of early uptake of project outputs by end-users. Updated dissemination, communication and exploitation plan.	Reporting documents	**JV**, all participants	May 2026 (M36)
n/a	D10	Delivery of all technical and financial reporting documents as required by EURAMET	Reporting documents	**JV**, all participants	May 2026 (M36 + 60 days)

B2.c Need for the project

The recent redefinition of the kelvin, and the new mise-en-pratique (*MeP-K)*, opens up a new pathway for dissemination of the temperature scale. The most common instruments for disseminating temperature remain thermocouples for temperatures up to around 1500 °C, but these require calibration against primary references. For even higher temperatures there are few, if any, viable contact thermometer alternatives, and radiation thermometry is de facto the only means of disseminating temperature. Within the ITS-90 [2] this is accomplished by a ratio method, where the temperature is deduced from the signal ratio at the unknown temperature and at one of three optional fixed points (the freezing points of Ag, Au or Cu). The Planck law, which provides the physical description of the radiation intensity, enables this extrapolation. In fact, with complete knowledge of the geometry of the object and the properties of the radiometer used to measure the blackbody radiation, this technique can be used to infer the temperature with no reference to other temperatures: hence, it is a primary method for temperature measurement. Above around 1000 °C this remains the most precise primary thermometry method.

A radiometer with sufficient precision is demanding to construct and requires a direct comparison with radiometric standards at the highest level. Several European NMIs currently lack the capacity for this, and hence lack a primary realisation of a temperature scale at high temperature.

A very promising alternative method of scale dissemination is by calibrating radiometers at a few fixed points with known thermodynamic temperature. This greatly reduces the burden on the radiometer characterisation because it is possible to replace some of the properties of the radiometer with fitting parameters in simplified mathematical models, while retaining a close link to the Planck law. Such an interpolation method is one of the recommended primary realisations of temperature in the new MeP-K, where it has been coined the indirect primary method. It has still not been widely distributed beyond the highest ranking NMIs in the world. This project will in many ways provide the proof of principle for this dissemination route, and at the same time help the less experienced NMIs/DIs gain capabilities that will enable them to participate in future high temperature research at the highest scientific level. Ultimately this will benefit the metrology community of Europe as well.

A cornerstone for the indirect method is a reliable and precise determination of the actual transition temperatures of the high-temperature fixed points. This project will build on the work in previous and existing EMRP and EMPIR projects, SIB01 InK project and its follow-up 15SIB02 InK 2, and the ongoing 18SIB02 Real-K, where the temperatures of several high temperature fixed points have been accurately determined.

The less experienced participants in this consortium all represent countries with many users of high temperature measurements, such as the glass industry (Denmark, Sweden, Czechia, Slovenia), metallurgical industry (Norway, Sweden, Czechia, Slovenia), graphite production (Norway), and manufacturers of measurement instruments (Sweden). There is a growing need for calibration services at high temperatures that are able to provide robust traceability, and for an improved precision of the primary references. Current industrial practices typically lead to large uncertainties, or even avoid direct temperature measurement altogether. Improved calibration services at high temperature are the foundation for more precise industrial temperature measurements.

The objectives in this project form a natural progression towards the main aim of providing the less experienced NMIs/DIs with the new temperature scale dissemination capabilities. Objective 1 ensures that representatives at the less experienced NMIs/DIs possess the necessary basic knowledge to realise a radiation thermometry scale; objective 2 aids and demonstrates the construction and characterisation of fixed point cells by the less experienced NMIs/DIs; objective 3 uses the fixed points to calibrate an interpolating instrument to realise a continuous scale; and objective 4 demonstrates and documents the new performance level for each less experienced NMI/DI via a regional comparison with the potential for linkage to the key comparison CCT-K10.

B2.d Progress beyond the state of the art

Knowledge transfer (objective 1):

Current state of the art

The six less experienced NMIs/DIs, CMI, DFM, JV, RISE, SMU and UL, are currently at different levels in their ability to disseminate the temperature scale. Some (JV) do not realise the temperature scale beyond 1100 °C and use thermocouples as interpolating instruments down to the freezing point of Al (660.323 °C). Others have tentative realisations for higher temperatures, either as a basic radiometric extrapolation or as thermocouple calibrations at a small number of fixed points.

At present, the less experienced laboratories do not fully characterise radiometers in terms of spectral response, size-of-source or linearity, and those that do implement a basic extrapolation and are forced to use a fairly large uncertainty.

Progress beyond the state of the art

The project will equip the less experienced laboratories with the skills needed to implement an extrapolation scheme such as prescribed in the ITS-90 with the highest possible accuracy. They will be informed of the results and outputs from relevant previous EMRP and EMPIR projects, the SIB01 InK, 15SIB02 InK 2 and 18SIB02 Real K, in particular relating to the determination of thermodynamic temperature for a range of high temperature fixed points. Furthermore, characterisation techniques for radiometers are the foundation for more fundamental measurements in thermometry research, such as the determination of thermodynamic transition temperatures of fixed points and are also useful in an implementation of an interpolation scale. The experimental capacity to characterise radiometers properly will be made available to all the participants via a suitable regional specialisation, which will be considered in more detail during the project.

Constructing and characterising high temperature fixed points (objective 2):

Current state of the art

While some of the less experienced laboratories have some limited previous experience with a small set of high temperature fixed points, none of them currently have experience of the construction of cells for radiometric use. In addition, none of the less experienced institutes have experience in the proper characterisation of cells for radiometric use.

For the temperature range between around 660 °C and 1000 °C, it is currently difficult to identify precise primary thermometry methods. The range is currently too high for acoustic thermometry, for instance. Radiation thermometry, however, is a promising candidate, and recent European efforts have been pushing in this direction, for instance in the project 15SIB02 InK 2. However, in order to establish an interpolation scheme over the largest temperature range, as this project aims to achieve, it will be beneficial to determine the thermodynamic freezing temperature of fixed points below the Cu point, namely Al and/or Ag.

Progress beyond the state of the art

The less experienced laboratories will gain the practical experience, skills and new capabilities to construct, characterise and use fixed points intended for radiometric applications. This will include the handling of cell material, and design and choice of materials for cell enclosures. The cells constructed will comprise Al (660.323 °C), Ag (961.78 °C), Cu (1084.62 °C), Fe-C (1154 °C), Co-C (1324.24 °C), Pd-C (1492 °C), Pt-C (1738.28 °C) and Re-C (2474.69 °C). These capabilities will help not only to validate and document the performance of fixed points, but will also enable the participants to quantify uncertainty contributions and improve the precision substantially, with the aim of reaching state-of-the-art levels at the fixed points.

For the temperature range between 660 °C and 1000 °C, an interpolating radiometric scale has the potential to rival scales realised with noble metal thermocouples, such as Au-Pt or Pt-Pd. The aim is to achieve an uncertainty better than 80 mK (95 % coverage), and to help improve the determination of the thermodynamic temperature of the freezing point of Al.

<u>Implementing an interpolating scale and ITS-90 realisation by extrapolation (objective 3):</u>

Current state of the art

At present, none of the NMIs/DIs can construct and realise a sufficient number of distinct fixed points to enable an interpolation scale as described in the current MeP-K. They have insufficient facilities for the proper and careful characterisation measurements of the pyrometers used as interpolating instruments, and some lack suitable pyrometers altogether. Finally, they lack suitable mechanical structures to enable the correct alignment of the pyrometer and the fixed-point cavity.

For medium range temperatures between the freezing point of Al (660.323 °C) to the freezing point of Ag (961.78 °C) the less experienced NMIs/DIs currently use fixed point calibrated noble metal thermocouples.

Progress beyond the state of the art

Once the less experienced laboratories have operational fixed-points, they will implement a continuous temperature scale with various radiometers as interpolating instruments. The target uncertainty of the realisations is 0.6 °C at 1500 °C and 1 °C at 2000 °C. The NMIs/DIs will develop the capability to calibrate, analyse and properly evaluate uncertainty for an interpolation instrument, with a limited number of calibration points. During the project some of the less experienced NMIs/DIs will assemble a radiometer, properly characterise it, and apply it as an interpolating instrument.

<u>Conducting a regional comparison (objective 4):</u>

Current state of the art

Currently none of the less experienced NMIs/DIs can connect with key comparisons in the field.

For the metrological community at large, the new temperature scale dissemination technique with multiple fixed points for radiation thermometry has not yet been widely used. While the technique in principle and in theory is a convenient scale dissemination, this has not been demonstrated so far.

Progress beyond the state of the art

A comparison will be organised and performed to document and validate the new temperature scale realisations at the less experienced NMIs/DIs. The comparison will directly enable the participating institutes to link to the CCT-K10 via the experienced French institutes (LNE and CNAM). This will extend the network of documented, capable institutes in Europe for this type of calibrations.

The results of the comparison will also provide a first testcase for the new MeP-K. If successful, the comparison will strengthen the idea that the interpolation scheme is a viable path to realise a thermodynamic temperature scale beyond the highest-ranking institutes. It will provide direct comparisons between different scale implementations, using different radiometers, fixed points and furnaces, and may thus inform the CCT on the robustness of the technique.

B2.e <u>Gender dimension</u>

This project concerns the development and implementation of a temperature scale at high temperature according to the *MeP-K*, and does not have any particular gender-specific consequences or any foreseen gender-specific findings. Implementations of such a scale have several potential benefits in society at large, for instance by enabling better process management in a number of industrial settings. In turn, this has the potential to reduce the energy usage, the process waste, or to improve the operational safety. It may also affect safety mechanisms implemented in society to reduce consequences of fires, for instance. However, neither of these potential benefits differ for men and women.

The dissemination activities include reports, peer reviewed papers and practical demonstrations of high temperature standards deployed at industrial stakeholders. The results of the demonstrations are not expected to affect one specific gender in any particular way. The project will communicate its dissemination activities in a manner that highlights to all genders the benefits of the project.

B2.f Open science

Open science is an approach based on open cooperative work and systematic sharing of knowledge and tools as early and widely as possible in the process. The project will include open science practices as they have the potential to increase the quality and efficiency of research and accelerate the advancement of knowledge and innovation by sharing results, thus making them more reusable and improving their reproducibility. The project will follow open science practices as per Regulation (EU) 2021/695 establishing Horizon Europe – the Framework Programme for Research and Innovation, laying down its rules for participation and dissemination.

(i) Early and open sharing

The training material developed and used in WP1 will be made publicly available via the e-learning platform of BIPM. To maintain blindness in the comparison in WP4, the data will not be made public until after the draft A report has been accepted by the participants. The protocol and the final report, however, will be public as soon they are ready, and the data available under the DMP.

Other reports published by consortium members will be made public as soon as possible. The project aims for five peer reviewed papers, which will be published under open access. The journal will be selected based on the target audience. Pre-prints of the project manuscript(s) will be submitted to a suitable open access platform. The scientific publication process can take a significant amount of time, depending on the selected journal. To accelerate the dissemination of results, ahead of publishing, preprints will be submitted by the project to widely used and accessible repositories, selecting those that are most relevant to their stakeholders. Target pre-print archives for the project will include arxiv, preprints.org and techrxiv.

(ii) Research output management

The project will manage the digital research data generated in the project responsibly and according to the requirements in the Grant Agreement. The consortium will make reasonable efforts to meet the FAIR principles, although it may be challenging to meet all the criteria proposed by Bahim *et al* [3]. In particular, the consortium will

- establish a data management plan (DMP) and regularly update it
- deposit data in a trusted repository, and ensure open access, in accordance with the DMP. The licensing will be determined in the DMP, but will likely be Creative Commons Attribution International Public License (CC BY) or Creative Commons Public Domain Dedication (CC 0), following the principle 'as open as possible as closed as necessary', according to the Grant Agreement.
- provide information via the repository about any research output or any other tools and instruments needed to re-use or validate the data
- ensure that metadata of deposited data will be open under CC 0 or equivalent, is supplied in line with the FAIR principles and provided with information as per the conditions in the Grant Agreement.

(iii) Measures to ensure reproducibility of research outputs

An integral part of the project is to compare outputs from different laboratories, which naturally enforces data and result sharing in a reproducible manner. The comparison undertaken in WP4 serves as an important verification of the reliability and reproducibility of the results in the project. It will compare the scale realisations between the participants, and also compare the scales developed within the project to the CCT-K10 reference values. Some of the scales will also be compared to the ITS-90, which is a further check of their reliability.

CMI, CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK and UL are either accredited or they work in compliance with ISO/IEC 17025. This enables the participants to demonstrate that they operate competently and generate valid results, thereby promoting confidence in their work.

The project will disseminate its results to relevant technical committees / standardisation bodies such as CCT WG NCTherm, EURAMET TC-T, EURAMET TC-T WG best practice and IEC TC 65/SC 65B/WG 5 sub group RT in order to provide a further layer of peer review of the project's results.

The project will provide digital or physical access to the results needed to validate the conclusions of scientific publications.

(iv) providing open access to research outputs

The project will undertake responsible management of research data in line with the FAIR principles and open access to research data under the principle 'as open as possible, as closed as necessary', as per the Grant Agreement.

Project participants will publish documented source code on the curve-fitting of calibration data and the computation of uncertainty for interpolation points. The code will be accompanied by adequate documentation to enable easy use and reuse. The sharing platform will likely be GitHub, but other alternatives may be used if appropriate.

The project will provide open access to scientific publications under the conditions in the Grant Agreement;

- at the latest at the time of publication, a machine-readable electronic copy of the published version or the final peer-reviewed manuscript accepted for publication, will be deposited in a trusted repository for scientific publications
- immediate open access will be provided to the deposited publication via the repository, under the latest available version of CC BY or a licence with equivalent rights
- information will be given via the repository about any research output or any other tools and instruments needed to validate the conclusions of the scientific publication
- metadata of deposited publications will be open under a CC 0 or equivalent licence, in line with the FAIR principles and provided with information as per the conditions in the Grant Agreement.

(v) participation in open peer-review

The project will include Open Research Europe (ORE) as a possible target journal for the project's publications. ORE is an open peer-review journal recently set-up by the EC for use by their project's beneficiaries. It is a no-fee, open access, open peer-reviewed publishing venue for EU-funded research, where reviewers' comments and recommendations and authors' feedback are open for others to view.

(vi) involving all relevant knowledge actors in the co-creation of R&I agendas and contents

The project will establish a LinkedIn group which will serve as the platform for stakeholder interaction. Regular news items about the project progress will be posted, including major milestones, successful completion of smaller activities, or the launch of the comparison in WP4. The LinkedIn group will also be used to invite stakeholder feedback in various ways, including for instance by inviting to workshops.

Throughout the project the participants will liaise closely with the EURAMET TC-T, where all participants are represented, and CCT, where several of the participants are represented.

B2.g Research data management and management of other research outputs

Types of data/research outputs

The data/research outputs will be generated from characterisation measurements, calibrations and the comparison conducted in work package 4. The data formats comprise common image formats, Excel, binary data files (with explanations in ASCII headers), text data, Word, PowerPoint, PDF, and XML. If appropriate open scientific data formats such as HDF5 and NetCDF will be used. The amount of data generated in the project is unknown, but likely to be less than 0.5 TB.

The research outputs will include a comparison protocol, teaching material, a best practice guide, technical drawings and layout plans, reports, and scientific papers.

The project will make use of existing data in many forms, such as data sheets for materials, previous work at the experienced NMIs, and outputs from previous projects SIB01 InK, 15SIB02 InK 2 and 18SIB02 Real-K. In particular, assigned thermodynamic temperatures of the fixed points are crucial in order to establish the interpolation scales and will be used as direct input in the project.

Findability of data/research outputs

The data/research outputs (protocols, reports, training material) will be findable as each will be identifiable with a persistent and unique identifier. The metadata will provide information on the following: datasets (description, date of deposit, author(s), venue and embargo); the European Partnership on Metrology funding; grant project name, acronym and number; licensing terms; persistent identifiers, the authors involved. Where applicable, the metadata will include persistent identifiers for related publications and research outputs. The data/research outputs will be deposited and published in trusted repositories located using the Registry of Research Data Repositories https://www.re3data.org/, most likely https://data.4tu.nl or https://www.zenodo.org/.

The project will produce at least one protocol, to be used in the comparison. The protocols will be stored in a protocol exchange repository e.g. https://protocolexchange.researchsquare.com/ or https://www.protocols.io/, which will be decided when the DMP is developed early in the project.

Accessibility of data/research outputs

The project management board, consisting of the coordinator and one representative from all participants, will be responsible for managing any intellectual property rights (IPR) issues with the data generated in the project. This may arise in cases where data is acquired at industrial stakeholders, which the project plans to do, but it will be handled on a case-by-case basis. The data acquired at the participating institutes is not expected to be affected by IPR issues. Further details will be available in the DMP.

Data acquired in the laboratories of the participating NMIs will be made publicly available as soon as practically possible, in a suitable repository. This will be described in more detail in the DMP which the consortium develops in the initial stages of the project. The data/research outputs will remain accessible for the lifetime of the repository.

Interoperability of data/research outputs

The datasets will use the trusted repository's basic metadata schema for administrative data, which is compliant with the recommended standards used by DataCite (https://search.datacite.org/) and OpenAIRE (https://www.basesearch.net/). For individual datasets, the consortium will strive to use well-known formats, such as those listed above under types of research data. Relevant quality assurance following from ISO 9001 will be respected. For metadata and vocabularies, the consortium will use the repository functionality as much as possible (for administrative data Zenodo will provide standardised support), and metrology specific vocabularies such as the VIM or digital SI will be used if a digitised version is ready at the time the data is published. If necessary, project specific vocabularies will be explained and published with the data. Furthermore, metrology specific recommendations and services emerging from the EURAMET projects TC-IM 1449 (Research data management) and TC-IM 1448 (Digital calibration certificates) will be used where appropriate.

The project's datasets that will be deposited in the chosen trusted repository will include qualified references to other datasets from the same project and/or previous research.

Reusability of data/research outputs

The data/research outputs will either be licensed under the latest available version of the CC BY license or a license with equivalent rights as set out in the Grant Agreement. Data will, where needed, be accompanied with a suitable description to facilitate its reuse. Users will be required to acknowledge the consortium and the source of the data in any resulting publications.

The data are in common formats and can be read using widely available software (open source or commercial). Any software or data models developed by the consortium will be properly documented. Any data published in open-access journals will be usable by third parties after the datasets have been deposited in a trusted repository.

The data that does not relate to peer-reviewed publications will be made available for re-use on a case-by-case basis.

Curation and storage/preservation costs

The estimated curation and storage/preservation costs for making the data and research outputs FAIR are €500 for data deposition and € 1000 (personnel costs). These costs will be kept to a minimum by using i) suitable trusted repositories from the Registry of Research Data Repositories https://www.re3data.org/ where no additional costs are associated with long-term preservation, and ii) by making only relevant data and outputs FAIR. The estimated curation and storage/preservation costs are included in the project's budget and will be claimed if compliant with the Grant Agreement's conditions.

Participant, person or team responsible for data management and quality assurance

This consortium will not establish a Data Access Committee (DAC). The project management board will have overall responsibility for the management of data/research outputs and quality assurance. The coordinator will be responsible for coordinating updates to the data management plan and for deciding on a case-by-case basis which data/research outputs will be kept and for how long. The participant(s) that produced the data will be responsible for organising backup and storage, archiving, and for depositing the data/research outputs within the chosen repositories.

B3 Potential outcomes and impact from the project

B3.a Projected outcomes for industrial and other user communities

There are a number of industrial processes that take place at high temperatures, and where the accurate control of temperature may affect the quality of the end product. In Scandinavia, the Czechia, Slovakia and Slovenia there is a wide range of energy intensive industries operating processes at temperatures in excess of 1000 °C, and in cases reaching well above 2000 °C. Examples include the metallurgical industry, fertilizer production, glass industry and graphite production. Current practice varies between users, but include extrapolation of calibrations at lower temperatures than the actual process which leads to high uncertainty, or the use of indirect proxy measures to infer a temperature during the process, such as the power used in the furnace control.

With improved reference standards, the NMIs/DIs will be able to supply stable and precise calibration services to regional customers, which in turn will enable improved temperature measurements in industrial applications. Precise reference standards pave the way for new techniques for applied thermometry, which in turn may lead to improved process control.

During the project the participants will demonstrate examples of the dissemination of the new scale realisations at selected industrial stakeholders. These examples will cover different ways to exploit the new national capabilities. One method is by transfer using an interpolation instrument calibrated at fixed points, which is close to the traditional way to transfer traceability. A second method is to deploy a calibrated fixed point at the factory to enable a local calibration directly against this point. If successful, this will directly enhance the temperature measurements at the end users.

B3.b Projected outcomes for the metrological and scientific communities

The project will directly improve the collective European capabilities in primary thermometry at high temperatures. The less experienced NMIs/DIs JV, RISE, DFM, CMI, SMU and UL will acquire competence in the production and characterisation of their own fixed-point cells, in the characterisation of radiation thermometers that can later be applied to precision measurements of thermodynamic temperature, for instance in new fixed points. This will enable the less experienced institutes to (i) be in a position to submit CMCs for new or improved calibration services within the range 961.78 °C to 2474.69 °C and (ii) to contribute to future research and collaborations in high temperatures.

If successful, the project will expand the reach of the CCT-K10 key comparison in radiation thermometry by linking the six less experienced NMIs/DIs to CCT-K10.

The project will also in some ways serve as a testbed for the new MeP-K. While the dissemination routes using radiation thermometry are well founded in the research leading up to the redefinition of the Kelvin, it still has not been implemented on the scale proposed in this project. Each of the less experienced NMIs/DIs will implement their own scale, with their own equipment, and construct separate cells, which eventually will be compared directly against each other; thus enabling a robust check of the reliability and reproducibility of the fixed points and interpolation scheme when implemented outside the major NMIs. If successful, the project will equip the less experienced NMIs/DIs with capabilities to support the call for further development of primary thermometry techniques in the strategic outlook of CCT for the 2020s [4].

A smaller activity within the project will also test the interpolation scheme at lower temperatures, with the freezing point of Al (660.323 °C) at the lower end. This range is currently a range where the ITS-90 is difficult to realise with documented performance, and a range where there is no current alternative to radiation thermometry as a primary method. However, the precision is still unsatisfactory. This project will trial the use of radiation thermometry in this range and aims to challenge the precision of noble metal thermocouples, i.e. an uncertainty of 80 mK or better.

The project will also strengthen the regional cooperation within EURAMET. The less experienced NMIs/DIs naturally fall in two regions, the Scandinavian and the central European regions. The project will help to identify and establish areas suitable for specialisation and cooperation within these regions.

After the project the less experienced NMIs/DIs will have gained competence and capabilities to participate in several relevant future calls in the European Partnership on Metrology. High temperature standards at the highest level will likely be useful in future EPM Industry calls, since all countries involved have substantial industry where high temperature processing is relevant.

B3.c Projected outcomes for relevant standards

The project will produce the first technical guide for the implementation of a thermodynamic temperature scale. The aim is that this will eventually be a EURAMET guide, and it will be developed to fulfil the needs expressed in particular by the EURAMET TC-T but also the CCT. The project will report on its progress to the CCT working group for non-contact thermometry, which oversees the dissemination of the radiation thermometry scale at the highest level.

There are currently no available standards for multi-fixed point techniques beyond the MeP-K, but a standard is in preparation within IEC TC 65/SC 65B/WG 5 sub group RT on radiation thermometer calibrations. The consortium is represented in this committee and will provide input to the preparations. In many applications temperature measurement is a part of the standard, such as ISO 13916:2017, *Welding — Measurement of preheating temperature, interpass temperature and preheat maintenance temperature*, and some of the project outputs could influence future revisions of these. However, the consortium is not represented in any of the relevant standardisation committees at present.

Standards Committee / Technical Committee / Working Group	Participants involved	Likely area of impact / activities undertaken by participants related to standard / committee
CCT-Working Group for Non-Contact Thermometry (CCT WG NCTherm)	**CNAM,** CMI, JV, SMU, TUBITAK	CNAM, with the support of all participants, will prepare and present a report based on the findings of the project related to deliverables D4 (the determination of the thermodynamic temperature of the freezing point of Al and/or Ag, performed by the ratio method relating it to the Cu point) and D5 (the realisation of the radiometric high-temperature scale using multiple fixed points) to the working group on non-contact thermometry of the CCT. If successful, the project will strengthen the evidence that the interpolation scheme is a viable path to realise a thermodynamic temperature scale beyond the highest-ranking institutes. 22RPT03 will provide direct comparisons between different scale implementations, using different radiometers, fixed points and furnaces, and should thus inform the CCT on the robustness of the implementation of the MeP-K technique. The WG meets at least once every 3 years, but not according to a fixed schedule.
EURAMET TC-T	**JV,** CMI, CNAM, DFM, LNE, RISE, SMU, TUBITAK, UL	JV will give an oral (where possible) annual report on MultiFixRad to the EURAMET TC-T. CMI, CNAM, DFM, LNE, RISE, SMU, TUBITAK and UL will provide input to the report. This will brief the whole EURAMET TC-T community on the important developments underway in MultiFixRad and how they will impact the practice of radiation thermometry in the future. The EURAMET TC-T meets annually, usually in the Spring.
EURAMET TC-T, WG best practice	**CMI**, CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK, UL	A new EURAMET guide on implementation of the indirect primary thermometry using radiation thermometry will be written by CMI, with support from CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK, UL, as deliverable D8. TUBITAK and SMU will interact with the TC-T WG best practice to ensure that the guide fulfils its needs. The WG will be asked for input and comment on the draft guide.
International standardisation sub-group on radiation thermometry (IEC TC 65/SC 65B/WG 5 sub group RT)	**CNAM,** CMI, DFM, JV, LNE, RISE, SMU, TUBITAK and UL	The main achievements of the project on the implementation of the multiple fixed point technique for the calibration of radiation thermometers will be presented to the working group by CNAM with the aim of introducing it in the standard about the calibration of radiation thermometers which is in preparation. CMI, DFM, JV, LNE, RISE, SMU, TUBITAK and UL will support CNAM in preparations and with necessary material. The sub-group meets on an ad-hoc basis.

B3.d Projected wider impact of the project

Economic impact:

Improved high temperature reference standards are the foundation for improved temperature measurements in numerous industrial processes. With better temperature control it may be possible to improve end product quality, reduce waste and reduce the energy consumption for a given process output. Improved temperature control may also affect the lifetime of equipment used in the processes by avoiding unnecessarily high temperatures or rates of change. Improved temperature control thus has numerous economic benefits for industry and will also help improve the competitiveness of European industry in diverse fields. Examples include:

- Graphite production involves several stages, some of which takes place at temperatures in excess of 2000 °C. The cooling rate affects the process output via microcracks appearing in the graphite, which in turn affects its suitability in various applications.
- In welding processes, the temperature affects the quality of the weld, for instance by affecting heat induced stress in the vicinity of the weld. Depending on the metals being welded, the temperatures involved can be far above 1000 °C. As there can be issues with free sight, small temperature spots and unknown emissivity, radiation thermometry is often difficult to apply directly, but the traceability route for more specialised thermometry techniques is still via radiation thermometry.
- In several metallurgical processes, for instance Si production, purification processes involve melting and refreezing in a controlled manner. The cooling rate is important for both the product quality and the optimisation of the production process. The temperatures involved depend on the metal but may reach very high temperatures.
- Steam reforming, which is used to produce H_2 from natural gas, require temperatures up to 1100 °C. The temperature of the catalytic tubes inside the reactor chambers has a strong impact on their lifetime, and a modest increase of 15 °C may halve the lifetime.
- Common insulation materials for buildings involve production steps at high temperature, some of them exceeding 2000 °C.
- Combustion processes can involve very high temperatures. Waste incineration, depending on the waste, may reach 1700 °C, large ship engines may operate at similar temperatures. Common to both is that the process efficiency increases with temperature. For combustion engines this has the obvious implication on fuel consumption, while for waste incineration the temperature may have implications for toxic contents in the flue gas, or the available useful heat to be reused in e.g. district heating. However, this must be balanced with safety precautions to avoid exceeding the tolerances of the combustion chamber.

Environmental impact:

The longer term environmental impact of the project is connected to the possible improvements in several key industrial processes. Better building insulation is an important contribution to reduced energy consumption. Heating and cooling of buildings consumes around half of the energy spent in households and business buildings in the EU, which again accounts for around 28 %-35 % [5] of the total energy consumption in the EU. Improved temperature measurements may have an impact on the production of insulation materials, both in terms of product quality and the resources necessary to produce it.

Modern Li-ion batteries rely on graphite as the anode material, and graphite production requires high temperatures. Such batteries are essential in the electrification of transport, but also play a role in energy storage required when intermittent, renewable sources become more widespread. Their production, however, is energy intensive and improved high-temperature standards could help reduce some of this energy demand.

The Si used in solar panels is also based on high temperature processes. The IEA posits that a 24 % annual increase in the photovoltaic energy output is needed for their net zero emissions in 2050 scenario [6]. The high temperature stages of the production are responsible for most of the energy consumption, and better temperature measurements might help optimise the product quality while minimising the energy required in the production.

Social impact:

While there is no direct social impact of this project, as mentioned above a number of key products in a green and sustainable society rely on high-temperature processes. High precision temperature standards are one component in helping European industry optimise, maintain and develop production processes.

B3.e Summary of the project's impact pathway

SPECIFIC NEEDS	EXPECTED RESULTS	DCE MEASURES
What are the specific needs that triggered this project? Many European NMIs, particularly less experienced one, currently lack a primary temperature scale above 1000 °C. There is a growing need for locally accessible and highly accurate thermometry calibration services by industries such as glass and metallurgy in these countries. Meanwhile, the transition to the green economy will further increase the importance of precise high temperature measurements in industry, to reduce waste, improve product quality and optimise processes to conserve energy.	*What do you expect to generate by the end of the project?* Most importantly, **realisations of thermodynamic temperature scales** above 1000 °C in six less experienced NMIs/DIs, including new, documented high temperature measurement capabilities. **Training material** on the temperature scale realisation in ITS-90 and the MeP-K from the initial knowledge transfer workshops, published on the e-learning platform. A **EURAMET best practice guide** for the implementation of the relative primary thermometry interpolation scheme. **Published and documented curve fitting software** for optical measurements on high temperature fixed point cells in Python, LabVIEW, and MATLAB from A3.2.4, shared in a user friendly and extendible form. Results and outcomes from the **high-temperature dissemination trials in industrial environments** Denmark and Türkiye.	*What dissemination, communication and exploitation measures will you apply to the results?* **Communication**: Web page for the project. Workshop for the stakeholders on the project outputs. An open LinkedIn group aimed at stakeholders, but available to a wider audience. Presentations at 15 national and international conferences. Participants will actively share published papers on ResearchGate, Academia.edu or similar platforms. **Dissemination**: Reports to the CCT WG NC-Th and the EURAMET TC-T. A comparison, openly published, which tests the performance of the laboratories after the interpolation temperature scales have been implemented. Peer reviewed papers on the interpolation temperature scale implementations, and on a thermodynamic measurement of the Al freezing temperature. EURAMET best practice guide for the implementation of the interpolation scheme **Exploitation**: Direct in-situ trials of the new dissemination of the temperature scale at industrial stakeholders in Denmark and Türkiye. New temperature calibration services above 1000 °C at the less experienced NMIs.
TARGET GROUPS	**OUTCOMES**	**IMPACTS**
Who will use or further up-take the results of the project? Who will benefit from the results of the project? **End users:** the metrology institutes CMI, DFM, JV, RISE, SMU and UL who are part of the consortium will adopt the new measurement techniques as a service for industries in their respective countries, accredited laboratories, various industrial high temperature applications such as graphite production, metallurgical and welding processes, combustion processes including waste incineration and ships' engines, steam reforming to generate H_2 from CH_4, **Others:** The metrology community, EURAMET TC-T, BIPM CCT.	*What change do you expect to see after successful dissemination and exploitation of project results to the target group(s)?* Improvement of scientific and measurement capabilities in less experienced countries for temperature measurements above 1000 ºC. Trial of the multiple fixed point interpolation scheme from the new *MeP*-K will inform the CCT on the robustness of the technique.	*What are the expected wider scientific, economic and societal effects of the project contributing to the expected impacts outlined in the work programme and call scope?* New or improved CMCs for high temperatures for the less experienced NMIs/DIs. Capacity to participate in cutting-edge research in high temperature metrology. A test case for an interpolation radiometric scale according to the revised *MeP-K* down to the freezing point of Al. A successful trial of the multiple fixed point interpolation scheme from the new *MeP*-K will provide the opportunity for a wider range of NMIs/DIs to implement this technique. Improved high temperature standards will enable better temperature control in many energy-intensive industrial processes. In the longer term the results are expected to help improve the efficiency in various combustion processes (district heating, waste incineration, etc).

B4 The quality and efficiency of the implementation

B4.a <u>Overview of the consortium</u>

The consortium brings together established NMIs and DIs with varying degrees of experience with high temperature radiometric fixed points. LNE, CNAM and TUBITAK represent the experienced NMIs/DIs, which will support six other NMIs/DIs (CMI, DFM, JV, RISE, SMU, UL), and one external, scientific participant (DTU) in their efforts to implement a thermodynamic scale consistent with the new *MeP*-K. The consortium is geographically clustered in two regions, Scandinavia and central Europe.

JV is the Norwegian NMI and coordinates the project. JV currently coordinates two EMPIR projects, 18SIB10 chipS·CALe and 19RPT01 QuantumPower. JV operates a well-equipped thermometry fixed point laboratory, currently up to the Cu point, and has recently extended its capability with new, open cells for the Sn, Zn and Al points. JV also operates a radiation thermometry laboratory and a radiometry laboratory with the ability to characterise spectral response at a high level. JV will participate in all technical work packages.

CMI is the NMI of Czechia. Since 2008 CMI has continuously developed its laboratory facilities within the field of radiation thermometry. Currently, CMI's services cover the temperature range from -30 °C to 1800 °C, and during the project the range will be expanded up to approximately 3000 °C. CMI will lead WP1, construct HTFPs within WP2, establish scale implementations in WP3 and participate in the comparison realised in WP4.

CNAM is the French DI for the units of temperature, length, mass and luminous intensity and has world leading capability in radiation thermometry. The “Thermal Metrology” department, which operates jointly with the French NMI LNE, is responsible for the realisation and the dissemination of the national temperature standards and performs research in the fields of primary thermometry and the realisation of the ITS-90. CNAM is one of the leading contributors to the new definition of the kelvin and is fully involved in the MeP-K with a long experience in the construction and development of HTFPs up to 3000 K. CNAM has participated in several EMRP and EMPIR JRPs related to high temperatures, such as IND01 HiTeMS, SIB01 InK and 18SIB02 Real-K. CNAM participated in the key comparison CCT-K10 and holds a pivotal role in this project by providing the linkage in the comparison performed in WP4. CNAM will lead the WP4 and WP5, and will contribute to all other technical work packages.

DFM is the Danish NMI and maintains high temperature reference standards. DFM has numerous metrological activities within thermal transport, broadband emissivity measurements and non-contact thermometry, and these competences will be used in WP3. DFM has contributed to relevant projects such as EMIRIM, MetroPEMS, 19ENV05 STELLAR, as well as “The Boltzmann project”. DFM is also a member of “Energy Cluster Denmark" which has 400 member companies and distributes more than 100 million euros.

LNE is the French NMI, and at the technical level works in the frame of a Joint Laboratory with CNAM within the “Thermal Metrology” department. LNE has developed competencies and facilities for measuring temperatures at the lowest uncertainty level from primary thermometry to ITS-90 calibration, as well as in design and construction of the thermostats. LNE contributed to the Boltzmann constant determination and to the realisation of primary thermometry for the “*mise en pratique*” of the future definition of the kelvin. LNE is currently involved in the JRP 17FUN05 PhotOQuanT which aims to develop optomechanical and photonic temperature sensors. LNE will work closely with CNAM in this project and will support the less experienced institutes in all work packages.

RISE is the NMI in Sweden responsible for the traceability to the SI for most quantities. The temperature group within RISE realises the international temperature scale ITS-90 between -189 °C and 2600 °C and its research is focussed on improvement of calibration facilities and practical calibration methods. RISE's equipment for non-contact thermometers includes a large number of black-body sources, furnaces, pyrometers, as well as the Ag, Co-C, and Pt-C fixed points that are currently in use for pyrometer calibrations. RISE currently operates a Cu fixed point for radiation thermometry which is used to implement an ITS-90 scale. In this project they will participate in all technical work packages.

SMU is the Slovak national metrology institute and has experienced metrological experts in thermometry. SMU currently operates non-contact fixed points at the In, Sn, Zn, Al and Ag points. Furthermore, the laboratory has multiple furnaces and black body sources designed for non-contact thermometry that are capable of operating at temperatures up to 1600 °C. SMU has participated in temperature related EMRP and EMPIR projects IND01 HITEMS, 15SIB02 InK 2 or 18SIB02 Real-K. SMU will lead WP2 and participate in all other work packages.

TUBITAK is the Scientific and Technological Research Council of Türkiye. TUBITAK UME is the Turkish NMI and has leading capability for performing low uncertainty temperature measurements up to 3000 K. The group has well-established experience in the design, construction and characterisation of low- and medium-temperature range pyrometers for use in harsh environments, and several high-temperature furnaces reaching

3500 K - including those for the filling of HTFPs. TUBITAK has participated in previous EMRP and EMPIR projects, e.g. IND01 InK1, 15SIB02 InK 2, 17IND04 EMPRESS2 and 18SIB02 Real-K. TUBITAK will lead WP3, and contribute to the other work packages as an experienced NMI.

UL Laboratory of Metrology and Quality (LMK) at the Faculty of Electrical Engineering (FE), University of Ljubljana is the DI for thermometry and humidity in Slovenia. UL currently realises the ITS-90 from the triple point of Ar to the melting point of Pd, and brings experience in high temperature measurements. Within the project UL will construct their first interpolating radiometric scale. UL will participate in all technical WPs.

DTU is the Danish Technical University. The division of Chemical Engineering has expertise in industrial processes separation processes, reaction engineering, heat transmission, fluid mechanics and applied thermodynamics, calibration of IR instruments and non-contact temperature measurements of gas and surfaces based on spectroscopy. In this project they are an external beneficiary, but will collaborate closely with DFM and Danish industrial stakeholders to demonstrate an in-situ dissemination of the improved temperature scale that DFM will build during the course of the project. DTU will primarily participate in WP2 and WP5, but also in WP1.

Section C: Detailed project plans by work package

C1 WP1: Establishing the required basic competence on the realisation of the temperature scale and the MeP-K at the less experienced institutes

The aims of this work package are (i) to provide knowledge transfer on realisation of the kelvin at high temperatures (i.e. above around 1000 °C where ITS-90 changes from contact thermometry to the radiometric scale), (ii) to map the current capabilities of CMI, DFM, JV, SMU, RISE, UL and DTU, including equipment inventories, and to explore potential synergies and opportunities for smart specialisation, and (iii) to document and follow up on the progress of development of capabilities during the lifetime of the project. The current status of the less experienced laboratories varies from no scale realisation above 1100 °C to an ITS-90 based realisation at higher temperatures. The training sessions in Task 1.1 will ensure that all less experienced laboratories are at broadly the same level before embarking on the cell construction and scale implementations in WP2 and WP3. Task 1.2 will map the current capabilities of the less developed NMIs/DIs related to the realisation of the temperature scale and MeP-K and future needs. Task 1.3 will include work to ensure enhanced regional collaboration and smart specialisation and will assess the progress on developing capability.

C1.a <u>Task 1.1: Training workshops on the realisation of the scale and MeP-K at high temperatures</u>

The aim of this task is to organise and deliver training workshops on the realisation of the scale and MeP K at high temperatures. The training workshops will bring together staff from less experienced institutes (CMI, DFM, JV, SMU, RISE, UL and DTU) with experts from experienced NMIs/DIs (LNE, CNAM, TUBITAK). The training will cover the construction, characterisation, maintenance and use of high temperature fixed points; interpolation between known temperatures and extrapolation from known temperatures as prescribed in the ITS-90; data analysis (curve fitting and uncertainty evaluation); and finally, radiometer characterisation.

Activity number	**Activity description**	**Participants (Lead in bold)**
A1.1.1 M01	CMI, together with CNAM and LNE, will prepare the agenda and detailed content of the training workshop on temperature scale realisation in ITS-90, including radiometer characterisation. The preparations will also identify practical exercises that could be undertaken either at CMI or when the participants return to their own laboratories.	**CMI**, CNAM, LNE
A1.1.2 M01	TUBITAK, together with CMI, CNAM and LNE, will prepare the agenda and detailed content of the training workshop on the MeP-K interpolation schemes, which will include the construction, characterisation and usage of high temperature fixed points, and curve fitting and interpolation techniques to create a continuous scale. The preparations will also identify practical exercises that could be undertaken either at CMI or when the participants return to their own laboratories.	**TUBITAK**, CMI, CNAM, LNE
A1.1.3 M02	The two workshops on scale realisation and the MeP-K based on the training material prepared in A1.1.1 and A1.1.2 will be delivered by CNAM, LNE and TUBITAK at CMI. The workshops will be held in conjunction with the kick-off meeting. The duration of the workshops will be 0.5-1 day each depending on the content deemed suitable for each workshop, whether laboratory activities are included, and the availability of the relevant participants. It is expected that at least one expert from each less experienced institute i.e. CMI, DFM, JV, RISE, SMU, UL and DTU, will attend.	**CMI**, CNAM, DFM, JV, LNE, RISE, SMU, UL, TUBITAK, DTU
A1.1.4 M04	CMI and TUBITAK, with input from CNAM, DFM, JV, LNE, RISE, SMU, UL and DTU, will prepare a report on the workshops held in A1.1.3. In addition, one of the workshop outputs will be the preparation of training materials suitable for use at other training or workshops.	**CMI**, CNAM, DFM, JV, LNE, RISE, SMU, UL, TUBITAK, DTU
A1.1.5 M15	Once the training materials from A1.1.4 has been agreed by the consortium, the coordinator on behalf of CMI, CNAM, DFM, JV, LNE, RISE, SMU, UL, TUBITAK, DTU will then submit them to EURAMET as **D1**; "*Training materials on the temperature scale realisation in ITS-90 and the MeP-K for use in the radiation thermometry community for later training*". In addition, the training materials will be submitted to the relevant staff in EURAMET for publication on the e-learning training platform under an open license.	**CMI**, CNAM, DFM, JV, LNE, RISE, SMU, UL, TUBITAK, DTU

C1.b Task 1.2: Mapping the current capabilities related to the realisation of the temperature scale and the MeP-K and future needs

The aim of this task is to survey the current capabilities of the less experienced participants (CMI, DFM, JV, SMU, RISE, UL and DTU), their needs and targets for future development, and to identify possible regional synergies in Scandinavia and central Europe, respectively.

Activity number	Activity description	Participants (Lead in bold)
A1.2.1 M02	CMI will develop a survey to collect information on the current capabilities related to the realisation of the temperature scale and the MeP K and future targets for the less experienced laboratories. CMI will circulate the survey and the responses from CMI, DFM, JV, RISE, SMU, UL and DTU will be collected and stored by CMI.	**CMI**, DFM, JV, RISE, SMU, UL, DTU
A1.2.2 M03	Based on part the survey responses obtained in A1.2.1, CMI will compile an overview of existing capabilities in relevant characterisation measurements, for instance SSE, linearity and spectral response of radiometers (note A1.2.2 addresses radiometers and hence has a narrower scope than the full survey). This information on the existing capabilities will be summarised in a single report by CMI. The overview and report will be reviewed by DFM, JV, RISE, SMU and UL.	**CMI**, DFM, JV, RISE, SMU, UL
A1.2.3 M12	The results and overview of existing capabilities from A1.2.1-A1.2.2 will be used to identify candidate areas for smart specialisation in the realisation of the temperature scale and the MeP K. DFM, JV, RISE and DTU will identify relevant laboratory services that may serve the entire Scandinavian region, for instance specialisations in temperature ranges or advanced characterisation equipment. In addition, DFM, JV, RISE and DTU will identify other services where future regional collaboration is beneficial. CMI, SMU and UL will perform a similar analysis for the central European region. UL will summarise the suggestions for smart specialisation for both the Scandinavian and the central European regions in a report. This information will be used as input to the development of the Dissemination, communication and exploitation plan in Task 5.2.	**UL**, CMI, DFM, JV, RISE, SMU, DTU

C1.c Task 1.3: Documentation of the progress on the realisation of the scale and MeP-K in less experienced NMIs/DIs

The aim of this task is to document progress of the less experienced NMIs/DIs (CMI, DFM, JV, SMU, RISE, UL) in developing capability related to the realisation of the temperature scale and MeP-K at temperatures above 961.78 °C during the project. Information from the final report on progress on realising the temperature scale will help less experienced NMIs/DIs to propagate their new developed abilities, not only within their local areas but also on the international scene.

Activity number	Activity description	Participants (Lead in bold)
A1.3.1 M04	Based on the survey of existing capabilities from A1.2.1 and the report from A1.2.2, all less experienced NMIs/DIs, CMI, DFM, JV, RISE, SMU, UL, will prepare their detailed plan for the development of capabilities.	**UL**, CMI, DFM, JV, RISE, SMU
A1.3.2 M06	CNAM and LNE will review and revise the development plans prepared in A1.3.1 and will identify any possible problems. Where necessary, CNAM and LNE, in consultation with CMI, DFM, JV, RISE, SMU and UL, will propose updates to the prepared development plans.	**CNAM**, CMI, DFM, JV, LNE, RISE, SMU, UL
A1.3.3 M18	Taking into account the development plans finalised in A1.3.2, the less experienced NMIs/DIs, CMI, DFM, JV, RISE, SMU and UL, will prepare progress reports detailing the state of the developments of capability at their organisation. This information will provide input to the midterm review reporting regarding reducing the capability gap.	**UL**, CMI, DFM, JV, RISE, SMU

A1.3.4 M35	UL with input from the other less experienced NMIs/DIs CMI, DFM, JV, RISE, and SMU, will prepare a final report describing their developments on the realisation of the scale and MeP-K during the project (this will incorporate information from WP1-WP4). This includes a summary of the new capabilities in the individual, less experienced NMIs/DIs, but also a summary of the regional capacity resulting from the project. The final status will be compared with information on existing capability and options for smart specialisation in A1.2.2-A1.2.3 and the initial development plans from A1.3.2	**UL**, CMI, DFM, JV, RISE, SMU
A1.3.5 M36	Once the report detailing the progress made in developing capability in the temperature scale realisation within in ITS-90 and the MeP-K from A1.3.4 has been agreed by the consortium, the coordinator on behalf of CMI, DFM, JV, RISE, SMU and UL will then submit it to EURAMET as **D2**; "*Report detailing the progress made by the less experienced NMIs/DIs during the project in developing capability in the temperature scale realisation within ITS-90 and the MeP-K at higher temperatures*".	**UL**, CMI, DFM, JV, RISE, SMU

C2 WP2: Realisation of medium and high temperature fixed points

The aim of this work package is to construct and characterise the fixed point cells (FPCs) that each of the less experienced NMIs/DIs will use to realise the radiometric temperature scale.

Task 2.1 entails a series of intertwined actions to define the cell geometry, carbon purity and metal purity, and to purchase the materials and mechanical machining required. The training from WP1 will be completed with a laboratory visit to CNAM/LNE, where staff from CMI, DFM, JV, RISE, SMU, UL and DTU will learn practical skills for cell production. In Task 2.2 CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU, will construct their new cells: the specific fixed points that will be constructed as part of this work package are Al (660.323 °C), Ag (961.78 °C), Cu (1084.62 °C), Fe-C (1154 °C), Co-C (1324.24 °C), Pd-C (1492 °C), Pt-C (1738.28 °C) and Re-C (2474.69 °C). The selected cells either have an assigned thermodynamic temperature or are in the process of obtaining one. Finally, in Task 2.3 the new cells will be characterised using techniques learnt in WP1. The aim is that each laboratory succeeds in constructing cells with an uncertainty in the practical realisation of the transition temperature of less than 0.6 °C (k=2). In addition, the determination of the thermodynamic temperature of the Al and Ag fixed points will be improved.

C2.a Task 2.1: Preparations for fixed point cell construction

The aim of this task is to complete the necessary preparations for the construction of the fixed-point cells. The activities build on the training undertaken in WP1 and will augment that training with laboratory visits to the experienced NMIs, CNAM/LNE, in order for staff at the less experienced institutes to gain practical experience. Furthermore, the task will also prepare for the purchase of the necessary materials, both high purity metals for the fixed-point and graphite for the crucibles. Finally, this task will ensure that participants have the necessary mechanical fittings to enable reliable mounting of the fixed-point cells in the furnaces.

Activity number	Activity description	Participants (Lead in bold)
A2.1.1 M04	CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU, with support from CNAM and LNE will identify possible suppliers of filling materials (pure metals and carbon) for fixed point cells with the best possible purity, not lower than 99.99 % for each element (if available). The fixed points to be produced by each participant were decided prior to the project and are as follows: • CMI (Co-C, Pd-C and Re-C) • DFM (Pd-C) • DTU (Co-C) • JV (Al, Ag, Cu, Fe-C, Co-C, Pd-C and Pt-C) • RISE (Ag, Cu, Fe-C, Co-C, Pd-C and Re-C) • SMU (Cu and Co-C) • TUBITAK (Fe-C, Co-C, Pd-C, and Re-C) • UL (Cu, Fe-C, Co-C, and Pd-C)	**SMU**, CMI, CNAM, DFM, JV, LNE, RISE, TUBITAK, UL, DTU

A2.1.2 M04	CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU, with support from CNAM and LNE will identify possible suppliers of carbon crucible material for the fixed point cells with the best possible purity (better than 99.95 %).	**SMU**, CMI, CNAM, DFM, JV, LNE, RISE, TUBITAK, UL, DTU
A2.1.3 M06	Based on the knowledge gained from A1.1.3 and A2.1.1-A2.1.2, CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU, will determine the dimensions of and construction plan for their future radiation thermometry fixed points. The dimensions of the cell housings will depend in part on the size of the fixed-point melting cavity and the size of the furnace. Suppliers of machining services will be identified, and preparations made to manufacture the cell housings and crucibles.	**SMU**, CMI, DFM, JV, RISE, TUBITAK, UL, DTU
A2.1.4 M07	Based on information from A2.1.1-A2.1.3, SMU, CMI, DFM, JV, RISE, TUBITAK, UL and DTU will select the suppliers of the material for the construction of the fixed-point cells.	**SMU,** CMI, DFM, JV, RISE, TUBITAK, UL, DTU
A2.1.5 M07	CNAM will analyse the plans created in A2.1.3 for their plausibility of realisation based on the equipment capabilities of CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU and their selected fixed-point cells.	**CNAM**, CMI, DFM, JV, RISE, SMU, TUBITAK, UL, DTU
A2.1.6 M08	Based on the analysis of the plans in A2.1.5, CNAM and LNE will organise and provide practical training at CNAM on the realisation and implementation of high-temperature fixed points for staff of CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU. The practical training is likely to have a duration of 4-5 days, but this will be determined during the initial planning phase. The aim is to enable the participants to gain the necessary practical experience in the filling process for fixed point cells.	**CNAM**, CMI, DFM, JV, LNE, RISE, SMU, TUBITAK, UL, DTU

C2.b Task 2.2 Construction of fixed-point cells

The aim of this task is for the participants CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU to complete the construction of the fixed-point cells at their own laboratories. TUBITAK, LNE and CNAM will assist participants remotely. At least 28 cells will be constructed in total.

Activity number	Activity description	Participants (Lead in bold)
A2.2.1 M10	Based on the evaluation in A2.1.3 and A2.1.5 CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU will acquire the cell housings and graphite crucibles. The high purity materials for filling the fixed-point cells will be obtained / purchased from outside of the project (in a few cases participants already have some materials).	**SMU,** CMI, DFM, JV, RISE, TUBITAK, UL, DTU
A2.2.2 M12	Using the cell housings and crucibles acquired in A2.2.1, together with the filling materials, CMI, with remote assistance from CNAM, LNE and TUBITAK, will construct at least 1 Co-C, 1 Pd-C and 1 Re-C fixed point cells.	**CMI**, CNAM, LNE, TUBITAK
A2.2.3 M12	Using the cell housings and crucibles acquired in A2.2.1, together with the filling materials, DFM, with remote assistance from CNAM, LNE and TUBITAK, will construct at least 1 Pd-C fixed point cell.	**DFM**, CNAM, LNE, TUBITAK
A2.2.4 M12	Using the cell housings and crucibles acquired in A2.2.1, together with the filling materials, DTU, with remote assistance from CNAM, LNE and TUBITAK, will construct at least 1 Co-C fixed point cell.	**DTU**, CNAM, LNE, TUBITAK
A2.2.5 M12	Using the cell housings and crucibles acquired in A2.2.1, together with the filling materials, JV, with remote assistance from CNAM, LNE and TUBITAK, will construct at least 1 Al, 1 Ag, 1 Cu, 1 Fe-C, 1 Co-C, 1 Pd-C and 1 Pt-C fixed point cells.	**JV**, CNAM, LNE, TUBITAK
A2.2.6 M12	Using the cell housings and crucibles acquired in A2.2.1, together with the filling materials, RISE, with remote assistance from CNAM, LNE and TUBITAK, will construct at least 1 Ag, 1 Cu, 1 Fe-C, 1 Co-C, 1 Pd-C and 1 Re-C fixed point cells.	**RISE**, CNAM, LNE, TUBITAK
A2.2.7 M12	Using the cell housings and crucibles acquired in A2.2.1, together with the filling materials, SMU, with remote assistance from CNAM, LNE and TUBITAK, will construct at least 1 Cu and 1 Co-C fixed point cells.	**SMU**, CNAM, LNE, TUBITAK
A2.2.8 M12	Using the cell housings and crucibles acquired in A2.2.1, together with the filling materials, TUBITAK will construct at least 1 Fe-C, 1 Co-C, 1 Pd-C, and 1 Re-C fixed point cells.	**TUBITAK**

A2.2.9 M12	Using the cell housings and crucibles acquired in A2.2.1, together with the filling materials, UL, with remote assistance from CNAM, LNE, and TUBITAK, will construct at least 1 Cu, 1 Fe-C, 1 Co-C, and 1 Pd-C fixed point cells.	**UL**, CNAM, LNE, TUBITAK

C2.c Task 2.3: Characterisation of fixed-point cells and optimisation of the phase transition realisations

The aim of this task is to characterise and document the performance of the radiation thermometry fixed point cells constructed in Task 2.2, and to optimise the realisations of the phase transition. The characteristics of interest are the phase transition duration, stability, repeatability and slope of phase transition. This characterisation is essential for the determination of the contribution of individual cells to the overall uncertainty budget.

Activity number	Activity description	Participants (Lead in bold)
A2.3.1 M13	CMI, JV, RISE, SMU, TUBITAK and UL will measure the freezing and melting curves of the fixed-point cells constructed in A2.2.2, A2.2.5-A2.2.9 using their respective radiation thermometers. DFM and DTU will use DFM's pyrometer to measure the freezing and melting curves of the cells constructed in A2.2.3-A2.2.4. A minimum of 5 freezing and melting cycles will be measured for each of the constructed cells. Early feedback from A2.3.2 on the optimised processes for the fixed-point realisations will be adopted.	**SMU**, CMI, DFM, JV, RISE, TUBITAK, UL, DTU
A2.3.2 M13	CMI, DFM, DTU, JV, RISE, SMU, TUBITAK and UL will analyse the initial measurements from A2.3.1 and based on the results will perform an optimisation process of the fixed-point realisations. This will include the alteration of furnace setpoints for melting and freezing cycles and the furnace uniformity. The parameters that will be used for the assessment of the process will be the phase transition stability, duration, repeatability and slope. Information on the optimised process will be fed back to A2.3.1.	**SMU**, CMI, DFM, JV, RISE, TUBITAK, UL, DTU
A2.3.3 M14	CMI, DFM, DTU, JV, RISE, SMU, TUBITAK and UL will summarise the results of the optimisations undertaken in A2.3.2 in internal reports or other documents. This information will be used in the development of the uncertainty budgets in A2.3.4, and in the report produced in A2.3.5	**SMU**, CMI, DFM, JV, RISE, TUBITAK, UL, DTU
A2.3.4 M15	Based on the results from A2.3.1, A2.3.2 and A2.3.3, CMI, DFM, DTU, JV, RISE, SMU, and UL will develop uncertainty budgets for the fixed points, with assistance from TUBITAK and LNE.	**SMU**, CMI, DFM, JV, LNE, RISE, TUBITAK, UL, DTU
A2.3.5 M18	RISE will collect the results of all characterisation measurements performed on the new fixed-point cells in A2.3.1 by the less experienced institutes. The information on the development of the fixed-point cells in A2.2.2-A2.2.9, their characterisation, and the optimisation process in A2.3.2-A2.3.3 will be collated and summarised in a report. CMI, DFM, JV, SMU, TUBITAK, UL and DTU will assist RISE in the data collection and collation, and in writing the report.	**RISE,** CMI, DFM, JV, SMU, TUBITAK, UL, DTU
A2.3.6 M20	Once the report detailing the development, characterisation and optimisation of the new fixed point cells from A2.3.5 has been agreed by the consortium, the coordinator on behalf of CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU will then submit it to EURAMET as **D3**; "*Report describing the fixed-point cells (Al (660.323 °C), Ag (961.78 °C), Cu (1084.62 °C), Fe-C (1154 °C), Co-C (1324.24 °C), Pd C (1492 °C), Pt-C (1738.28 °C) and Re-C (2474.69 °C)) constructed in the project, with the results of the characterisation measurements and a summary of the optimisation processes. The target uncertainty in the practical realisation of the transition temperatures is less than 0.6 °C (k=2)*".	**RISE**, CMI, DFM, JV, SMU, TUBITAK, UL, DTU
A2.3.7 M29	CMI JV, CNAM and LNE will perform relative radiometric measurements of the temperature of the freezing points of Al and/or Ag. The reference point will be the Cu freezing point. The aim of the measurements is to improve the determination of the thermodynamic temperature of these fixed points, which is important for improved precision of the interpolation scale from Al and up. The results will be presented in a peer reviewed paper.	**LNE**, CMI, CNAM, JV

A2.3.8 M30	Once the paper on the determination of the thermodynamic temperature of the freezing point of Al and/or Ag from A2.3.7 has been agreed by the consortium, the coordinator on behalf of CMI, CNAM, JV and LNE will then submit it to EURAMET as **D4**; "*Publication on the determination of the thermodynamic temperature of the freezing point of Al and/or Ag, performed by the ratio method relating it to the Cu point*". The paper will be submitted to a peer-reviewed journal.	**LNE**, CMI, CNAM, JV
A2.3.9 M30	JV, CMI, SMU, UL, DFM, TUBITAK and RISE will characterise the emissivity of the fixed-point cells developed in A2.2.2-A2.2.9, characterised in A2.3.1 and optimised in A2.3.2. LNE and CNAM will assist the participants with radiometric calculations and simulations. The information will be used to refine the uncertainty budgets developed in A2.3.4.	**SMU**, CMI, CNAM, DFM, JV, LNE, RISE, TUBITAK, UL

C3 WP3: Establishing scale implementations using the multi–fixed point scheme

The aim of this work package is to establish relative primary radiometric temperature scales at the less experienced NMIs/DIs with uncertainties less than 0.6 °C at 1500 °C and 1 °C at 2000 °C. In Task 3.1, three institutes (JV, DFM and TUBITAK) will construct suitable radiation thermometers to be used as interpolating instruments. In addition, appropriate characterisation tools will be established, in particular to measure the SSE property of the radiometers. Task 3.2 will develop the computational tools and implement the actual improved radiometric high-temperature scale above the silver point (961.78 °C) by performing calibration experiments using the fixed-point cells constructed in Task 2.2 and reporting the results in a peer reviewed paper. Task 3.3 will compare the interpolation scales established in Task 3.2 to realisations of the ITS-90.

C3.a Task 3.1: Characterisation and construction of interpolation instruments

The aim of this task is twofold. Firstly, the task aims to characterise the interpolating instruments that will be used by the less experienced institutes to realise the new scale. Emphasis will be placed on the proper measurement of the SSE, but linearity and spectral characterisation will also be considered. Some of the characterisation setups could be shared between several institutes and serve as a suitable candidate(s) for regional specialisation.

The second aim of this task is to design, construct (or modify), characterise and validate the metrological performance of reliable and accurate pyrometers, capable of operating from about 650 °C to 2500 °C. Three institutes (DFM, JV and TUBITAK) will construct low-cost and relatively simple instruments from commercially available components. These instruments will be traceable to the SI- kelvin, with the uncertainty level fulfilling the requirements in the less experienced NMI/DIs' countries in the temperature range of 650 °C to 2500 °C. The "in use" uncertainty of each interpolation instrument will be retrieved by metrologically valid characterisation of the main parameters (SSE, impact of the ambient temperature, nonlinearity). CMI, DFM, JV, RISE, SMU, UL and DTU, with support from CNAM, LNE and TUBITAK will develop realistic budgets for the determination of the uncertainty in the detection of the Planck radiation using the specific pyrometer(s) each laboratory will use.

Activity number	**Activity description**	**Participants (Lead in bold)**
A3.1.1 M10	DFM, JV, RISE, SMU and UL, will establish characterisation setups for radiometers. Each participant will establish a reliable SSE characterisation set up suitable for the wavelengths to be used with their radiometer, and with sufficiently small object aperture diameters.	**SMU**, DFM, JV, RISE, UL
A3.1.2 M12	DFM, DTU, JV and TUBITAK, with support from CNAM, LNE and SMU, will perform literature surveys to identify pyrometer designs suitable for the temperature scale implementation. Based on the results from the literature survey, JV will construct a dual detector instrument with exchangeable optical filters, capable of covering the temperature range from 650 °C to 1800 °C. TUBITAK will construct an instrument with an operating range from 650 °C up to 2500 °C. TUBITAK's instrument will be available earlier than M12, allowing time for its stability to be assessed in A3.1.3. DFM, with support from DTU, will implement a camera system which will cover the entire temperature range up to 1500 °C. The target uncertainty for individual pixels is 5 °C at 1200 °C. The camera's uniformity, linearity, and stability will be characterised, as well as its imaging	**JV**, CNAM, DFM, DTU, LNE, SMU, TUBITAK

	performance (crosstalk, aberrations and SSE for pixels). The camera will also be used in conjunction with a dissemination demonstration at an industrial stakeholder in A5.2.4.	
A3.1.3 M15	DFM, JV and TUBITAK will characterise the instruments developed in A3.1.2 using the setups established in A3.1.1. The characterisation will include SSE, linearity and influence of environmental conditions. TUBITAK will assess the drift of its instrument from the measurements of certain fixed points, separated by 6 to 10 months and compare the results with the ITS-90 scale at TUBITAK established with a more advanced radiation thermometer, an IKE LP5.	**TUBITAK**, DFM, JV
A3.1.4 M15	CMI, DFM, RISE, SMU and UL will characterise their existing interpolation instruments and establish the SSE curves, the linearity and spectral response. The results from the characterisations will be documented and made available in accordance with the DMP.	**RISE**, CMI, SMU, UL, DFM
A3.1.5 M18	Taking into account information from A3.1.1-A3.1.4, CMI, DFM, JV, RISE, SMU, UL and DTU will develop realistic uncertainty budgets for the detection of the Planck radiation, applicable to the pyrometer each laboratory uses. CNAM, LNE, and TUBITAK will assist the less experienced institutes to ensure that all necessary contributions are properly accounted for and quantified. The participants will also expand the budgets with appropriate components for the uncertainty in use, for instance accounting for changes in environmental conditions and changes in the size of the source.	**CNAM**, CMI, DFM, JV, LNE, RISE, SMU, TUBITAK, UL, DTU
A3.1.6 M24	Based on the results of A3.1.1-A3.1.5, CMI, CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK, UL and DTU will write an internal report describing the technical performance of the interpolation instruments and the metrological results achieved. The document will be shared with the consortium. The report will provide inputs to the “Best practice guide / EURAMET guide for indirect primary thermometry using HTFPs” which will be produced in A5.2.3.	**CMI**, CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK, UL, DTU

C3.b Task 3.2: Implementation of an improved radiometric high-temperature scale

The aim of this task is to establish an improved radiometric high-temperature scale above the silver point (961.78 °C) at less experienced NMIs/DIs. This will be achieved by means of relative primary radiometric thermometry for realising the thermodynamic temperature by interpolation between three or more high temperature fixed-points (HTFPs) on the basis of Planck’s law. The target uncertainties for the implementation of the scale are less than 0.6 °C at 1500 °C and 1 °C at 2000 °C. This task is strongly correlated with the Task 2.2, as the type and number of fixed points constructed play a key role in the selection of a certain interpolation scheme. CMI, JV, RISE, TUBITAK, and UL, will have more than 3 fixed point cells available and will implement a curve fitting scheme for interpolation. DFM, SMU, and DTU will have 3 available fixed points and will implement an exact fit interpolation scheme. All participants will evaluate the interpolation and extrapolation uncertainty.

Activity number	Activity description	Participants (Lead in bold)
A3.2.1 M10	CMI, DFM, JV, RISE, SMU, TUBITAK, UL and DTU, will implement computational tools to fit calibration data (optical measurements on fixed-point cells) to the Sakuma-Hattori equation or another suitable interpolation equation. It shall be possible to relate the equation coefficients to the spectral response of the pyrometer. Each participant will apply its own model for data interpolation and uncertainty evaluation. CNAM and LNE will provide test data from actual measurements, which the less experienced institutes can use to test their computations. JV will provide a suite of theoretical test data to enable a further validation, in particular evaluation of the uncertainty of the interpolation.	**CNAM**, CMI, DFM, JV, LNE, RISE, SMU, TUBITAK, UL, DTU
A3.2.2 M18	The less experienced institutes, CMI, DFM (working closely with DTU), JV, RISE, SMU, TUBITAK and UL, will calibrate their interpolating instruments characterised in A3.1.3-A3.1.4, using the fixed-point cells produced and characterised in A2.2.2-A2.2.9 and A2.3.1-A2.3.4. Employing the tools acquired in A3.2.1 CMI, DFM, DTU, JV, RISE, SMU, TUBITAK and UL will fit the calibration data. The uncertainty in the calibration points will be computed using the uncertainty budgets for the fixed-point temperatures developed in A2.3.4 and for the light detection in A3.1.5. These uncertainties will be fed to the curve fitting procedures to produce the interpolation uncertainty. The participants will then compare their interpolation uncertainties with those of the other participants in the activity.	**RISE**, CMI, DFM, DTU, JV, RISE, SMU, TUBITAK, UL

A3.2.3 M32	CNAM, JV, and LNE, with input from CMI, DFM, RISE, SMU, TUBITAK, UL and DTU, will prepare and submit a peer-reviewed paper on the practical implementation of the multi-fixed-point technique, and the performance of the temperature scale realisations at different institutes. Using information from earlier in activity, SMU and UL will prepare and provide input material to the "Best practice guide / EURAMET guide for indirect primary thermometry using HTFPs" in A5.2.3.	**JV**, CMI, CNAM, DFM, LNE, RISE, SMU, TUBITAK, UL, DTU
A3.2.4 M36	Based on output from A3.2.1, TUBITAK will develop code in Python and LabVIEW for the curve fitting procedure for optical measurements on high temperature fixed point cells. The code will be tested and validated and made public in accordance with the DMP. Similarly, JV and RISE will validate, share, and publish code for curve fitting developed in Matlab. The aim of this activity is to create code that is in a user-friendly format, sharable and publicly available.	**TUBITAK**, JV, RISE
A3.2.5 M36	Once the paper on the practical implementation of the multi-fixed point technique, and the performance of the temperature scale realisations at different institutes from A3.2.3 has been agreed by the consortium, the coordinator on behalf of CMI, CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK, UL and DTU will then submit it to EURAMET as **D5**; "*Publication on the realisation of the radiometric high-temperature scale using multiple fixed points, the associated uncertainties and the characteristics of each participants' scheme. The target uncertainties for the implementation of the scale are less than 0.6 °C at 1500 °C and 1 °C at 2000 °C*". The paper will be submitted to a peer-reviewed journal.	**JV**, CMI, CNAM, DFM, LNE, RISE, SMU, TUBITAK, UL, DTU

C3.c Task 3.3: Comparison of the newly developed temperature scale realisations according to the MeP-K against ITS-90

The aim of this task is to directly compare the newly developed temperature scale realisations according to the MeP-K in less experienced NMIs/DIs with the ITS-90. Above the freezing point of silver (961.78 °C) the ITS-90 is realised using Planck's law in the ratio form, using a blackbody at the freezing point of pure Ag, Au or Cu as its reference temperature, i.e. it prescribes an extrapolation from a single fixed point. As a consequence, ITS-90 requires detailed knowledge of the extrapolation pyrometer, in particular its linearity, and only a few of the participants currently have suitable equipment. Less experienced NMIs/DIs who do not have the ITS-90 scale realisation capability, will work with project participants that employ existing pyrometric implementations of the ITS-90. The comparison will be performed from 960 °C to 2500 °C, but with specific ranges for each participant as detailed in the activity descriptions.

Activity number	Activity description	Participants (Lead in bold)
A3.3.1 M26	TUBITAK will compare its own interpolation instrument calibrated in A3.2.2 according to the procedure developed in-house for the ITS-90 scale realisation. The results will be compared directly with the laboratory's ITS-90 scale from 960 °C to 2500 °C which is established using an LP5 linear pyrometer.	**TUBITAK**
A3.3.2 M26	DTU/DFM, JV and RISE will compare their calibrated interpolating instruments calibrated in A3.2.2 with the ITS-90 scale realised at RISE. JV and DFM will take their calibrated interpolation instruments to RISE and a direct comparison with RISE's LP5 pyrometer will be carried out. The comparison will cover 960 °C to 1800 °C.	**RISE**, DFM, DTU, JV
A3.3.3 M26	SMU will compare the calibration of its interpolating instrument calibrated in A3.2.2 with the ITS-90 scale realised at LNE from 1000 °C to 1400 °C. UL will calibrate its interpolation instruments characterised in A3.2.2 in accordance with the ITS-90 scale realisation traceable to the SMU Radiation Temperature Laboratory from 1000 °C to the Pd-C transition at 1600 °C.	**SMU**, LNE, UL
A3.3.4 M30	RISE will collect the results from the ITS-90 comparisons in A3.3.1-A3.3.3 and analyse them. Based on this information, RISE with input from DTU, DFM, JV, LNE, SMU, TUBITAK, and UL will write a report summarising the findings of the comparisons of the newly developed temperature scale realisations against ITS-90. The report will be shared with all participants. The report will provide inputs to the "Best practice guide / EURAMET guide for indirect primary thermometry using HTFPs" which will be produced in A5.2.3.	**RISE**, DTU, DFM, JV, LNE, SMU, TUBITAK, UL

A3.3.5 M36	Once the report detailing the findings of the comparisons of the newly developed temperature scale realisations against ITS-90 from A3.3.4 has been agreed by the consortium, the coordinator on behalf of DTU, DFM, JV, LNE, RISE, SMU, TUBITAK and UL, will submit it to EURAMET as **D6** "*Report on the comparisons of the newly developed temperature scale realisations against ITS-90 over the range 1000* °C *to 2500* °C ".	**RISE**, DTU, DFM, JV, LNE, SMU, TUBITAK, UL

C4 WP4: Comparison with potential linkage to the CCT-K10 key comparison

The aim of this work package is to validate the skills of the less experienced laboratories (CMI, JV, RISE, SMU, UL) and TUBITAK in performing the *mise-en-pratique* of the kelvin (MeP-K) by their participation in a regional comparison, where the aim is to link to the Key Comparison CCT-K10 'Realisations of the ITS-90 between 960 °C and 3000 °C'. The pilot laboratory for the regional comparison, CNAM, participated in CCT-K10. Successful participation in the regional comparison will enable the participating laboratories to demonstrate their Calibration Measurement Capabilities (CMC), and then be able to respond directly to requests from industry for advice or services, strengthening the link between the NMIs/DIs and manufacturers. Task 4.1 will undertake the preparations for the comparison, whilst Task 4.2 will involve the comparison measurements, analysis, and reporting.

C4.a Task 4.1: Preparation of the regional comparison

The aim of this task is to prepare the regional comparison of the *mise-en-pratique* of the kelvin, from 1000 °C to 2500 °C, but with a participant specific upper temperature limited by the highest fixed point that the participants have access to. This will involve writing and approving the comparison protocol, circulation scheme and schedule, and characterising and calibrating at least one travelling standard used for the comparison. Pyrometers are susceptible to drift when shipped around in a comparison, which is why substantial effort will be invested in ensuring that a stable travelling standard is selected and a way to verify its stability during the circulation.

Activity number	Activity description	Participants (Lead in bold)
A4.1.1 M6	CNAM and LNE, together with CMI, JV, RISE, SMU, TUBITAK and UL will identify a stable and robust radiation thermometer (pyrometer) to be used as a travelling standard for the comparison. The pyrometer will be selected from pyrometers available at the participants' laboratories. In addition, CNAM will provide at least one Cu fixed point cell and a suitable furnace (Chino IR-R0A) as a way of checking the drift of the pyrometer during the circulation. Only one Cu fixed point will be included in the travelling standard package, but a second one may be selected as a backup.	**CNAM**, CMI, JV, LNE, RISE, SMU, TUBITAK, UL
A4.1.2 M8	LNE and CNAM, the latter which will act as the pilot laboratory, will draft the circulation scheme and schedule, which will be discussed with CMI, JV, RISE, SMU, TUBITAK and UL. Feedback from the participants will be taken into account and any necessary changes made.	**CNAM**, CMI, JV, LNE, RISE, SMU, TUBITAK, UL
A4.1.3 M9	CNAM will characterise the travelling standard pyrometer selected in A4.1.1 in terms of its stability and SSE.	**CNAM**
A4.1.4 M9	CNAM will characterise the Cu fixed point(s) provided in A4.1.1 in terms of stability, plateau duration, furnace effect and its temperature difference to the national standard.	**CNAM**
A4.1.5 M12	CNAM will calibrate the travelling standard pyrometer against the various fixed points that will be included in the comparison.	**CNAM**
A4.1.6 M12	As early as possible LNE/CNAM will announce the comparison to the EURAMET TC-T. Taking into account the responses from TC-T members and information from A4.1.1-A4.1.5, CNAM will draft the protocol for the comparison with input from CMI, JV, RISE, SMU, TUBITAK and UL. Once the protocol is agreed by the participants, CNAM, on behalf of the consortium, will seek approval from the CCT WGKC and register the comparison in the KCDB at BIPM's webpages.	**CNAM**, CMI, JV, LNE, RISE, SMU, TUBITAK, UL
A4.1.7 M15	CMI, CNAM, LNE, JV, RISE, SMU, TUBITAK and UL will confirm the definitive circulation scheme and the schedule proposed in A4.1.2, taking into account any revisions necessary due to information from A4.1.1-A4.1.6.	**CNAM**, CMI, LNE, JV, RISE, SMU, TUBITAK, UL

C4.b Task 4.2: Conducting the regional comparison

The aim of this task is to conduct the regional comparison planned in Task 4.1, whilst minimising the risks of any break of traceability throughout the comparison.

From an experimental point of view, and due to feedback from the CCT-K10, the first part of the task will be to ensure that the travelling standard instrument which will be circulated amongst participants remains as stable as possible during the transfer. This key aspect will be validated by following the stability of the travelling standard instrument using a transportable Cu fixed point of high reproducibility. A calibration in situ of the travelling standard instrument will be performed in each laboratory, firstly when the instrument is delivered and again, prior to the shipment to the next laboratory. The output from the task will be to prepare and submit the Draft A to EURAMET TC-T.

Activity number	Activity description	Participants (Lead in bold)
A4.2.1 M18	CNAM will re-calibrate the pyrometer against the various fixed points within the temperature range of the comparison in order to estimate its long-term stability over the 6 months period following its calibration in A4.1.5. CNAM will then start the comparison by the calibration of the pyrometer from 962 °C (Ag fixed point) to 2500 °C.	**CNAM**
A4.2.2 M30	CNAM will circulate the pyrometer travelling standard package calibrated in A4.2.1 to the first participant in the comparison. The pyrometer travelling standard package will then be circulated in turn to CMI, JV, RISE, SMU, TUBITAK and UL in the order in the schedule agreed in A4.1.7. CMI, JV, RISE, SMU, TUBITAK and UL will each perform the measurements in accordance with the protocol agreed in A4.1.6. LNE and CNAM will oversee the circulation of pyrometer travelling standard package.	**CNAM**, CMI, JV, LNE, RISE, SMU, TUBITAK, UL
A4.2.3 M31	Once CMI, JV, RISE, SMU, TUBITAK and UL have completed their measurements and performed any necessary checks, they will each send their results to LNE. CNAM will calibrate the pyrometer once again against the transfer fixed points to estimate its stability over the duration of the circulation.	**CNAM**, CMI, JV, LNE, RISE, SMU, TUBITAK, UL
A4.2.4 M34	LNE and CNAM will analyse the results from A4.2.3 and will prepare the Draft A of the report on the comparison of the *mise en pratique* of the kelvin. CMI, JV, RISE, SMU, TUBITAK and UL will review the report.	**CNAM**, CMI, JV, LNE, RISE, SMU, TUBITAK, UL
A4.2.5 M36	Once the report on the comparison from A4.2.4 has been agreed by the consortium, the coordinator on behalf of CMI, CNAM, LNE, JV, RISE, SMU, TUBITAK and UL will then submit it to EURAMET as **D7**; "*Draft A report on the comparison of the mise en pratique of the kelvin over the range 1000 °C to 2500 °C*". The Draft A of the report will also be sent to EURAMET TC-T.	**CNAM**, CMI, LNE, JV, RISE, SMU, TUBITAK, UL

C5 WP5: Creating impact

The aims of this work package are to ensure that the knowledge developed during this project and in previous projects related to this topic is transferred to the user community, in particular the national metrology institutes seeking innovative methods for the realisation of the new definition of the kelvin at high temperatures through the schemes allowed by *mise-en-pratique* of this new definition. The consortium will work to establish the best means of communication to the stakeholders for example, the EURAMET TC-T, the CCT and the RMOs. The wider scientific community will be made aware of this research through refereed papers and conference presentations.

Training sessions are planned in the early steps of the project to ensure a homogeneous level of information and skills for the members of the consortium. A final workshop will be devoted to the presentation of the methods and techniques developed and tested in this project. Communication will take place via a number of routes including scientific symposiums to university lectures. Early exploitation will be encouraged through collaborations with less experienced and experienced NMIs in the fields of high-temperatures and radiation thermometry and possibly with industrial users and manufacturers of fixed point cells and furnaces.

C5.a Task 5.1 Dissemination and communication

Within the consortium many project participants are well placed to interact with key stakeholders since they participate within the CCT, CCT working groups and task groups as well as EURAMET TC-T. The consortium will therefore be able to communicate the results and the findings of this project to the relevant working groups and will provide feedback to the EURAMET TC-T during the annual general assemblies. The consortium will not establish a stakeholder committee but will utilise the CCT working / task groups and EURAMET TC-T for this purpose. Stakeholder interaction will primarily be social media based, in particular via the LinkedIn group for stakeholders established in A5.1.6.

In addition, several members of the consortium are experienced conference speakers and have published widely in the scientific literature. This experience will be used to ensure that the project outcomes are disseminated as widely as possible to the most relevant communities during conferences and through scientific publications.

Activity number	Activity description	Participants (Lead in bold)
A5.1.1 M18, M30	CMI, CNAM, JV, LNE, SMU and TUBITAK will work with and within the CIPM Consultative Committee of Thermometry (CCT) including consortium members participating in the WG Non-contact Thermometry (NCTh). Annual reports will be supplied to the CCT-WG NCTh. The project will deliver valuable contributions to the practical implementation of the mise-en-pratique (D3, D4, D5 and D8) and will help refine the *MeP*-K-19 which is the authoritative guide to the realisation of the new kelvin. Information on the project's research results and progress will be disseminated to standards bodies, technical committees and working groups, and feedback sought (see table in Section B3.c).	**CNAM**, CMI, JV, LNE, SMU, TUBITAK
A5.1.2 M7, M19, M31	All NMI/DI members of the consortium, CMI, CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK and UL, will interact with the EURAMET Technical Committee for Thermometry (TC-T) and the relevant working groups, namely, Strategy and Best Practice. An oral presentation (where possible) on the project progress will be given at the annual TC-T meetings by the project coordinator.	**CNAM**, CMI, DFM, JV, LNE, RISE, SMU, TUBITAK, UL
A5.1.3 M36	The participants will give at least 15 presentations in international conferences such as: • International Metrology Congress, CIM 2025, France • Tempmeko 2025, France 2025 • IMEKO World Congress, Hamburg, Germany, August 2024 • 22nd Symposium on thermophysical properties, USA, June 2024 • European Conference on Thermophysical Properties, location not yet known, autumn 2025 • NEWRAD, location not yet known, autumn 2025 Further relevant conferences may be identified during the project.	**CNAM**, all participants
A5.1.4 M36	The participants will submit at least 5 papers to peer-reviewed journals during the project. Target journals include: • Metrologia • Measurement Science and Technology • International Journal of Thermophysics • Measurement The expectations are that 5 of the 5 open access publications will be the result of a collaborative effort from participants from different countries. The authors of the open access peer-reviewed papers will clearly acknowledge the financial support provided through the Partnership as required by EURAMET in accordance with Article 17, Article 18, and Annex 5 of the Grant Agreement with the following text: "The project (22RPT03 MultiFixRad) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States." The authors will ensure that the following meta data is submitted and included for each paper:	**CNAM**, all participants

<table>
<tr><th>Activity number</th><th>Activity description</th><th>Participants (Lead in bold)</th></tr>
<tr><td></td><td>

Funder name: European Partnership on Metrology
Funder ID: 10.13039/100019599
Grant number: 22RPT03 MultiFixRad

</td><td></td></tr>
<tr><td>A5.1.5
M3, M10, M19, M28, M36</td><td>A project website will be set up by CNAM within three months from the project start. The website will be used by the consortium to communicate with the wider community detailing for e.g. events, presentations, reports and recent developments. The website will be updated at least every nine months after the reporting periods.
The project website will clearly acknowledge, in a prominent position on the homepage (e.g. in the header, footer or centre and in a readable size), the Metrology Partnership. This will be done by including either i) the Partnership project website header/footer badge and acknowledgement text (this text can be anywhere on homepage) or ii) the Partnership acknowledgement badge.</td><td>CNAM, all participants</td></tr>
<tr><td>A5.1.6
M1, M10, M19, M28, M36</td><td>At the start of the project a LinkedIn group will be established, and all stakeholders will be invited to join. All major achievements will be posted there, along with workshop announcements and links to deliverables when they are ready. The project participants will regularly post small updates on their progress to keep the stakeholder community informed. Every 9 months the project will publish a news post summarising the progress to date.
The consortium will tag EURAMET on Twitter and LinkedIn with '@EURAMET' 'and @EURAMET' - The European Association of National Metrology Institutes' respectively so that EURAMET can share if appropriate. Also, hashtags such as #measurementscience, #metrology, #EUfunded, #EUPartnership should be used if possible.</td><td>CNAM, all participants</td></tr>
<tr><td>A5.1.7
M36</td><td>Information on the results of the project will be disseminated to a range of standards bodies and committees and feedback sought (see details below and in the table in Section B3.c).
<table>
<tr><th>Standards Committee / Technical Committee / Working Group</th><th>Participants involved</th><th>Likely area of impact / activities undertaken by participants related to standard / committee</th></tr>
<tr><td>CCT-Working Group for Non-Contact Thermometry
(CCT WG NCTherm)</td><td>CNAM, CMI, JV, SMU, TUBITAK</td><td>CNAM, with the support of all participants, will prepare and present a report based on the findings of the project related to deliverables D4 (the determination of the thermodynamic temperature of the freezing point of Al and/or Ag, performed by the ratio method relating it to the Cu point) and D5 (the realisation of the radiometric high-temperature scale using multiple fixed points) to the working group on non-contact thermometry of the CCT. If successful, the project will strengthen the evidence that the interpolation scheme is a viable path to realise a thermodynamic temperature scale beyond the highest-ranking institutes. 22RPT03 will provide direct comparisons between different scale implementations, using different radiometers, fixed points and furnaces, and should thus inform the CCT on the robustness of the implementation of the MeP-K technique. The WG meets at least once every 3 years, but not according to a fixed schedule.</td></tr>
<tr><td>EURAMET TC-T</td><td>JV, CMI, CNAM, DFM, LNE, RISE, SMU, TUBITAK, UL</td><td>JV will give an oral (where possible) annual report on MultiFixRad to the EURAMET TC-T (where possible). CMI, CNAM, DFM, LNE, RISE, SMU, TUBITAK and UL will provide input to the report. This will brief the whole EURAMET TC-T community on the important developments underway in MultiFixRad and how they will impact the practice of radiation thermometry in the future. The EURAMET TCT meets annually, usually in the Spring.</td></tr>
</table>
</td><td>CNAM, all participants</td></tr>
</table>

<table>
<tr><th>Activity number</th><th>Activity description</th><th>Participants (Lead in bold)</th></tr>
<tr><td></td><td>
<table>
<tr><td>EURAMET TC-T, WG best practice</td><td>TUBITAK, CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK, UL</td><td>A new EURAMET guide on implementation of the indirect primary thermometry using radiation thermometry will be written by CMI, with support from CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK, UL, as deliverable D8. TUBITAK and SMU will interact with the TC-T WG best practice to ensure that the guide fulfils its needs. The WG will be asked for input and comment on the draft guide.</td></tr>
<tr><td>International standardisation sub-group on radiation thermometry (IEC TC 65/SC 65B/WG 5 sub group RT)</td><td>CNAM, CMI, DFM, JV, LNE, RISE, SMU, TUBITAK and UL</td><td>The main achievements of the project on the implementation of the multiple fixed point technique for the calibration of radiation thermometers will be presented to the working group by CNAM with the aim of introducing it in the standard about the calibration of radiation thermometers which is in preparation. CMI, DFM, JV, LNE, RISE, SMU, TUBITAK and UL will support CNAM in preparations and with necessary material. The sub-group meets on an ad-hoc basis.</td></tr>
</table>
</td><td></td></tr>
<tr><td>A5.1.8
M36</td><td>At least 4 laboratory visits will take place during the MultiFixRad project. These are important to facilitate the exchange of experience and information and to build staff capability.</td><td>CNAM, all participants</td></tr>
<tr><td>A5.1.9
M36</td><td>A 0.5 day workshop for stakeholders from industry, other NMIs/DIs and calibration laboratories will be organised at the final meeting at RISE. The industry stakeholders are expected to come from high-temperature process manufacturing and device manufacturing. The target number of attendees will be 20-50. This workshop will summarise the findings of the project and prepare possible future collaborative projects. The format will be determined during organisation of the event but will be chosen to maximise the impact.</td><td>RISE, all participants</td></tr>
</table>

C5.b Task 5.2 Exploitation and uptake

The results of the technical work packages will be exploited and illustrated through several reports and papers provided to the EURAMET TC-T and CCT WGs, for potential inclusion in future developments related to the realisation of thermodynamic temperature scale and with a possible impact on the revision of the *MeP*-K after 2026.

Uptake of the project outputs will take place through demonstrations and dissemination trials with end-users in industry.

<table>
<tr><th>Activity number</th><th>Activity description</th><th>Participants (Lead in bold)</th></tr>
<tr><td>A5.2.1
M36</td><td>A dissemination, communication and exploitation plan (DCE) will be created at the beginning of the project with support from all participants and submitted to EURAMET at M6. It will be reviewed and updated at least at each project meeting.
The DCE plan will provide further details on the following high-level expected results:

Expected result 1: Training material on the temperature scale realisation in ITS-90 and the MeP-K from the initial knowledge transfer workshops, published on the e-learning platform.
Expected result 2: EURAMET best practice guide on the practical implementation of relative primary thermometry based on the multi high temperature fixed point technique and radiation thermometry.
Expected result 3: Published and documented curve fitting software for optical measurements on high temperature fixed point cells in Python, LabVIEW, and MATLAB from A3.2.4, shared in a user friendly and extendible form.
Expected result 4: New, documented high temperature measurement capabilities at the less experienced institutes. The documentation arises from the cross-comparisons between the ITS-90 and the new implemented realisations of primary temperature scales.
Expected result 5: Results and outcomes from the high-temperature dissemination trials in industrial environments Denmark and Türkiye

It may also contain further planned dissemination activities.</td><td>CNAM, all participants</td></tr>
</table>

A5.2.2 M36	Training material developed in A1.1.1-A1.1.4 during the early stages of the project for the knowledge transfer will be made available on the project website and on BIPM's e-learning platform (deliverable D1).	**CNAM,** all participants
A5.2.3 M36	A best-practice guide on indirect primary thermometry using high temperature fixed-points (HTFPs) by CMI with input from all participants. will be prepared. The guide will incorporate input from A3.1.6, A3.2.3 and A3.3.4. Once the best-practice guide has been agreed by the consortium, the coordinator on behalf of CMI, CNAM, DFM, JV, LNE, RISE, SMU, TUBITAK, UL and DTU, will then submit it to EURAMET as **D8**; "*Best practice guide / EURAMET guide on indirect primary thermometry using high temperature fixed points (HTFPs)*". The guide will be submitted to the EURAMET TC-T working group "Best Practices" for comments and adoption as a EURAMET guide.	**CMI,** all participants
A5.2.4 M36	DTU with assistance from DFM will develop a transfer cavity for in-situ use in high temperature industry cases at two collaborators' facilities in Denmark. These trials using the transfer cavity will allow a practical test of the new capabilities developed at DFM and DTU, including the camera system from A3.1.2, and the use of transfer high-temperature fixed points in-situ.	**DFM,** DTU
A5.2.5 M36	TUBITAK will perform a traceability trial at a collaborator's facility in Türkiye and assess the effect of using the multiple fixed points for dissemination.	**TUBITAK**
A5.2.6 M18, M36	The consortium will identify measures that they will use to demonstrate that the project has narrowed the gap between the capabilities of their consortium and other NMIs/DIs in Europe. Summaries will be produced at months 18 and 36, demonstrating how the project helped less experienced NMIs in the consortium to develop their capabilities. Where appropriate this improvement will be quantified. Information from A1.3.3 and A1.3.5, plus other activities, will provide input. All participants will provide input to these summaries and the coordinator will provide this information demonstrating the narrowing of the capability gap at the mid-term review and at the end of the project.	**JV**, CMI, CNAM, DFM, DTU, LNE, RISE, SMU, TUBITAK, UL

All IP and potential licencing/exploitation will be handled in accordance with the Grant Agreement and Consortium Agreement.

C6 WP6: Management and coordination

C6.a Task 6.1: Project management

Activity number	Activity description	Participants (Lead in bold)
A6.1.1 M36	The project will be managed by the coordinator from JV, who will be supported by the project management board consisting of one member from each participant. The members of the project management board will guide the project, attend the project meetings, help organise the progress meetings and call additional meetings if needed to ensure the overall project's success. The project management board will monitor project activities, to facilitate the completion of deliverables by set deadlines and to take responsibility for frequent communication between the participants.	**JV**, all participants
A6.1.2 M36	LNE will set up, host and manage a MS Teams or SharePoint site for internal sharing of data, documents and work in progress.	**LNE,** all participants
A6.1.3 M36	The work package leaders will report regularly to the coordinator on the progress of the work packages. The reporting will be undertaken by email and video conferences.	**JV**, CMI, CNAM, LNE, SMU, TUBITAK
A6.1.4 M36	The coordinator, with support from the participants, will manage the project's risks to ensure timely and effective delivery of the scientific and technical objectives and deliverables.	**JV**, all participants
A6.1.5 M36	The consortium will ensure that any ethics issues identified are addressed.	**JV**, all participants

C6.b Task 6.2: Project meetings

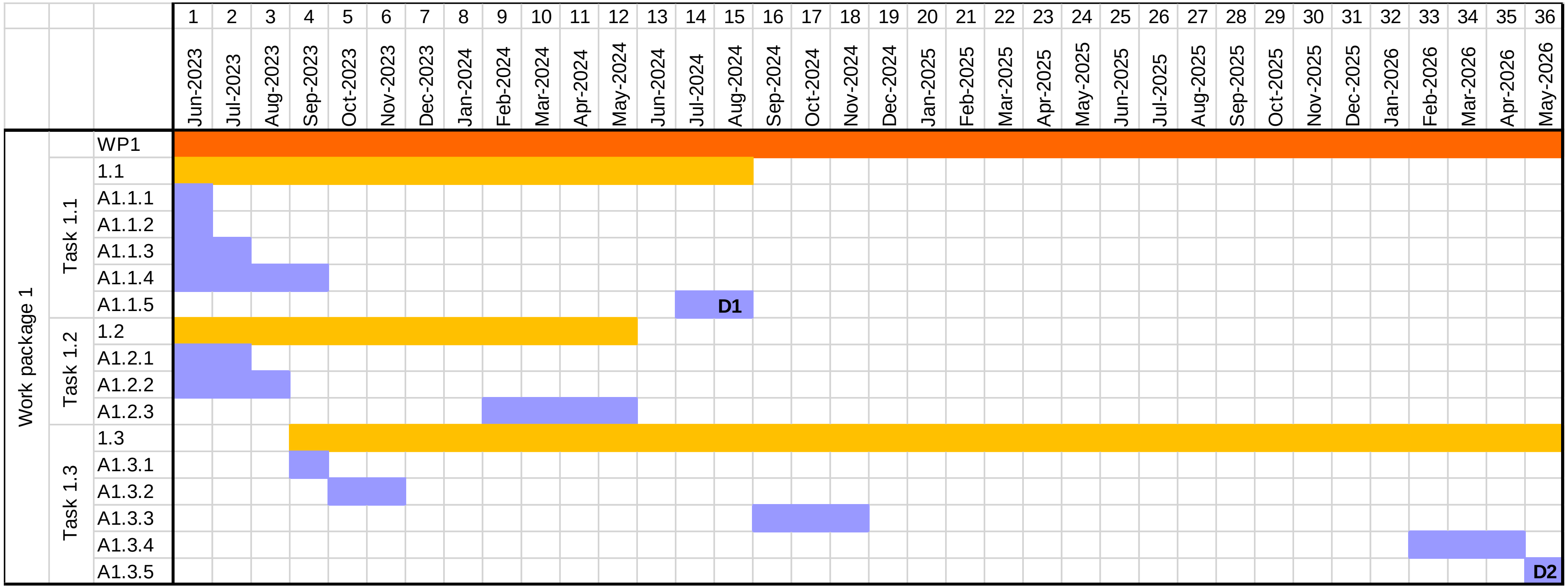
Activity number	Activity description	Participants (Lead in bold)
A6.2.1 M02	The kickoff meeting involving all participants will be held at CMI in M02 (July 2023). This meeting will be held in conjunction with the knowledge transfer workshop / training sessions in A1.1.3.	**CMI**, all participants
A6.2.2 M36	There will be 5 formal meetings in the project. These include the kick-off (A5.2.1), midterm (round M18) and the final meetings, all of which will be held face-to-face. The kickoff meeting will be organised by CMI, the midterm meeting by LNE and the final project meeting by RISE. In addition, there will be 2 shorter video conferences project meetings held around M9 and M27. The meetings will review progress and will be used to ensure participants are clear as to their role for the next period.	**JV**, all participants
A6.2.3 M36	In addition to the formal project meetings, technical meetings will be held as needed. These may involve the entire consortium or only parts of it. Some meetings may involve only the regional participants where the meetings relate to the planning of regional smart specialisation.	**JV**, all participants

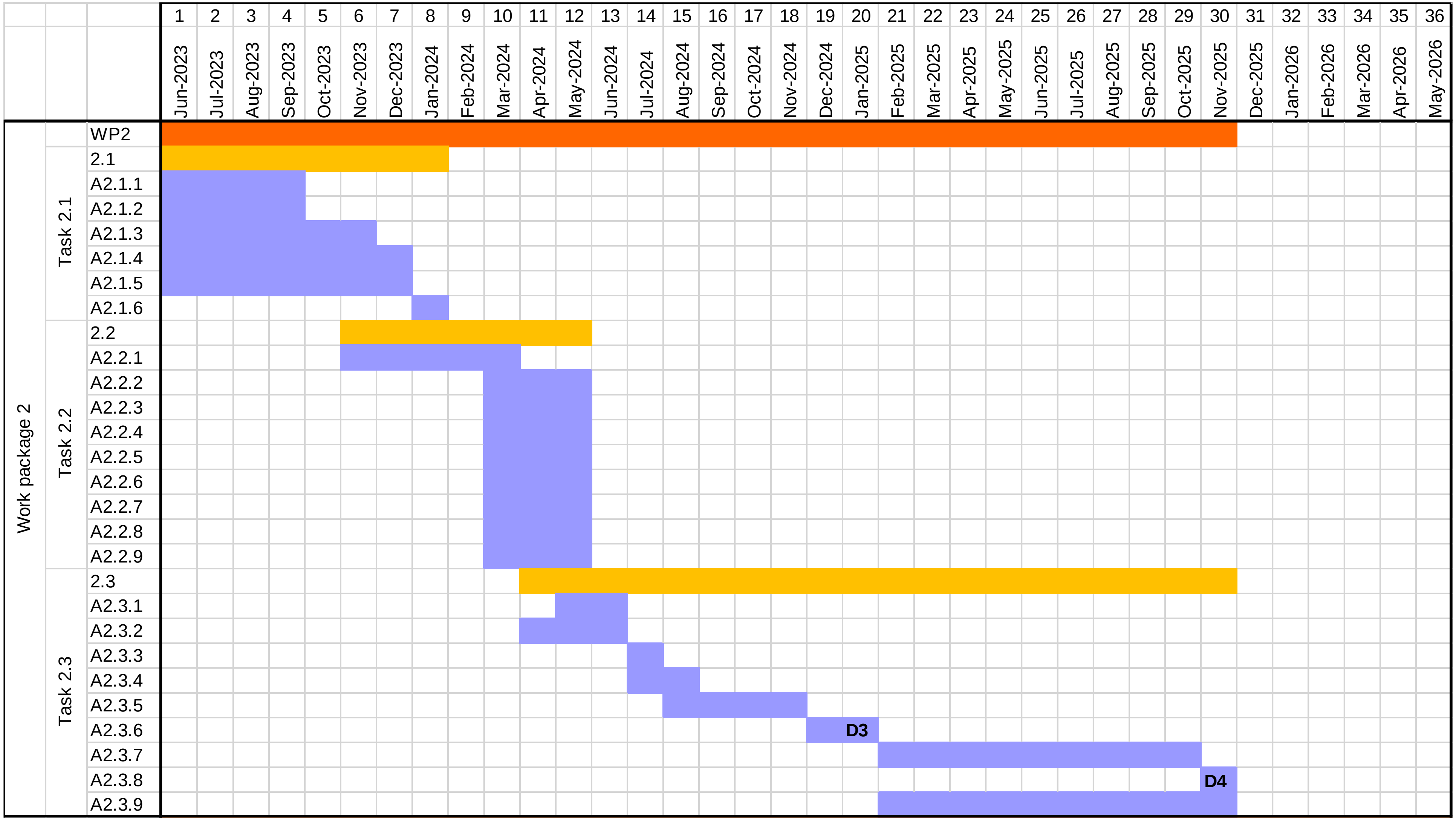
C6.c Task 6.3: Project reporting

Activity number	Activity description	Participants (Lead in bold)
A6.3.1 M01	One month after the start of the project a publishable summary will be produced and submitted to EURAMET.	**JV**
A6.3.2 M06	Six months after the start of the project a data management plan (DMP) and a dissemination, communication and exploitation plan (DCE) will be produced and submitted to EURAMET.	**JV**, all participants
A6.3.3 M36	Following Articles 19 and 21 and the data sheet of the grant agreement, information will be submitted to EURAMET, in accordance with the procedures issued by them to enable EURAMET to comply with its obligations to report on the programme to the European Commission. • Progress reports will be submitted at months 9, 27 (February 2024, August 2025 + 45 days), 18, 36 (November 2024, May 2026 + 60 days). • Impact/Output reports and updated publishable summaries will be submitted at the same times. All participants will provide input to these reports and the coordinator will provide these and updated publishable summaries to EURAMET. Where necessary, additional reports and / or information may be requested to enable EURAMET to comply with its obligations to the European Commission.	**JV**, all participants
A6.3.4 M18 (+60 days)	Periodic reports (including financial reports, updated data management plan, and updated dissemination, communication and exploitation plan) will be delivered at months 18 (November 2024 + 60 days) and 36 (May 2026 + 60 days) in accordance with Articles 19 and 21 and the data sheet of the grant agreement. All participants will provide input to these reports and the coordinator will provide these to EURAMET	**JV**, all participants
A6.3.5 M36 (+60 days)	Final report will be delivered at month 36 (May 2026 + 60 days) in accordance with Articles 19 and 21 and the data sheet of the grant agreement. All participants will provide input to these reports and the coordinator will provide these to EURAMET	**JV**, all participants
A6.3.6 M22	The project will be subject to a midterm review in Spring 2025. Reports (project self-assessment, updated publishable summary and presentation) will be delivered prior to the midterm reviews for Cal 2022, following the schedule detailed by EURAMET for the specific review. All participants will provide input to these reporting documents and the coordinator will provide the documents to EURAMET.	**JV**, all participants

Formal reporting will be in line with EURAMET's requirements and will be submitted in accordance with the Reporting Guidelines.

C7 Gantt chart

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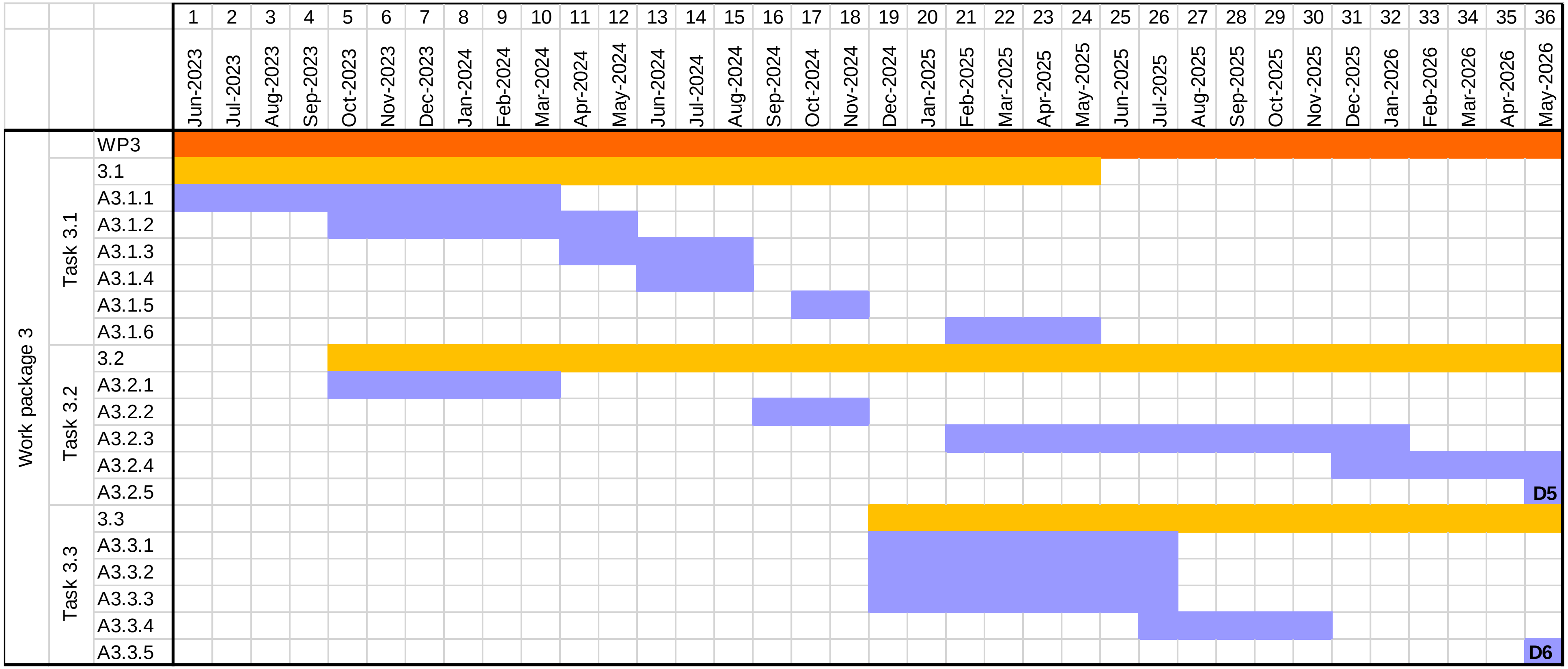
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Work package 3
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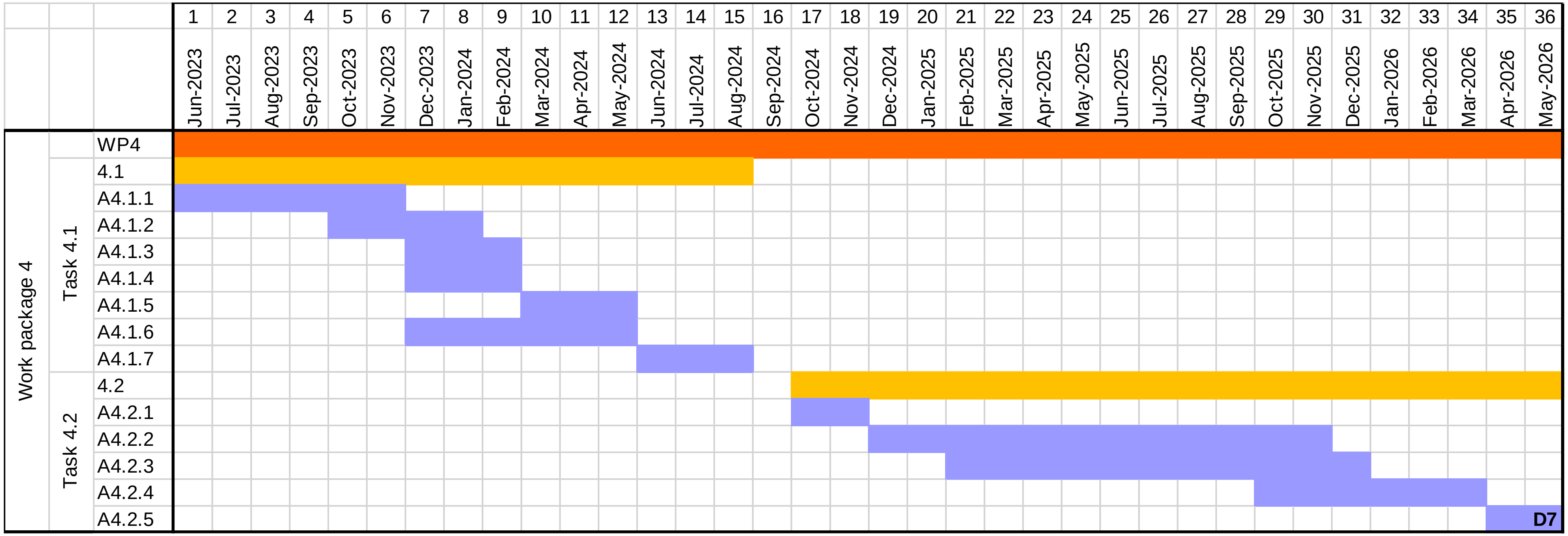
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Work package 4
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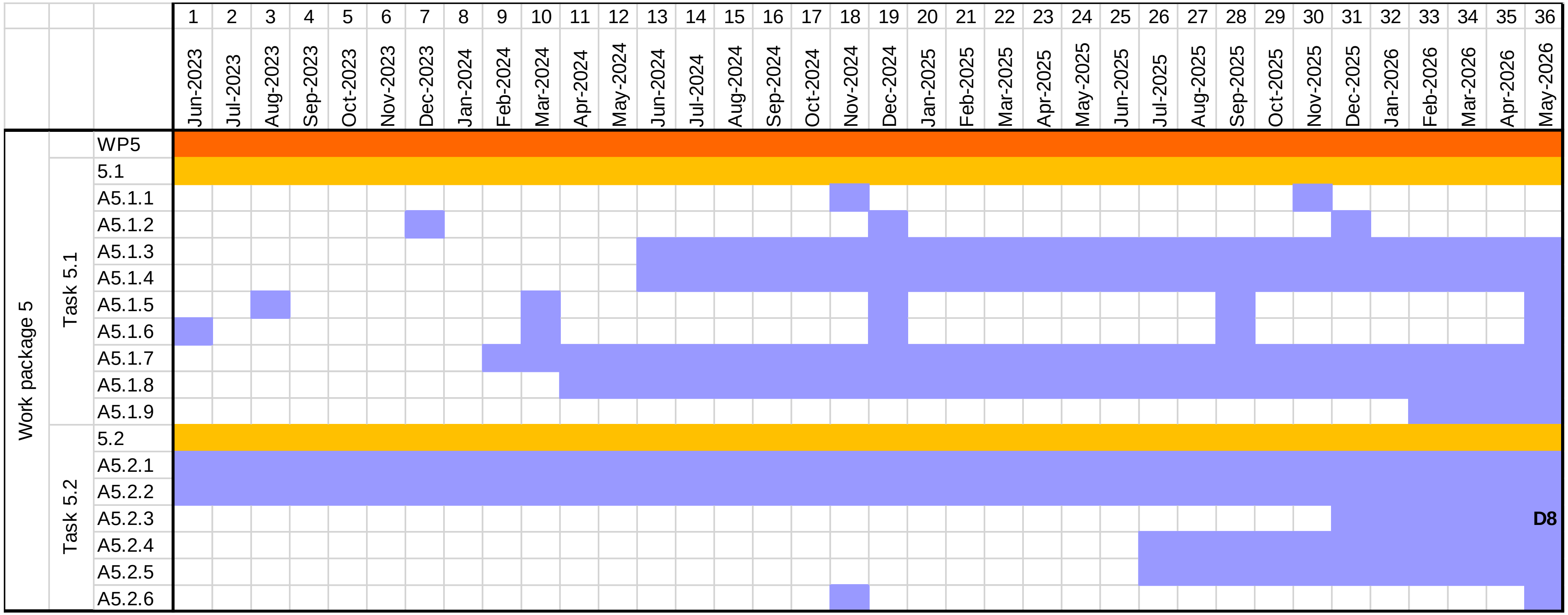
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Work package 5
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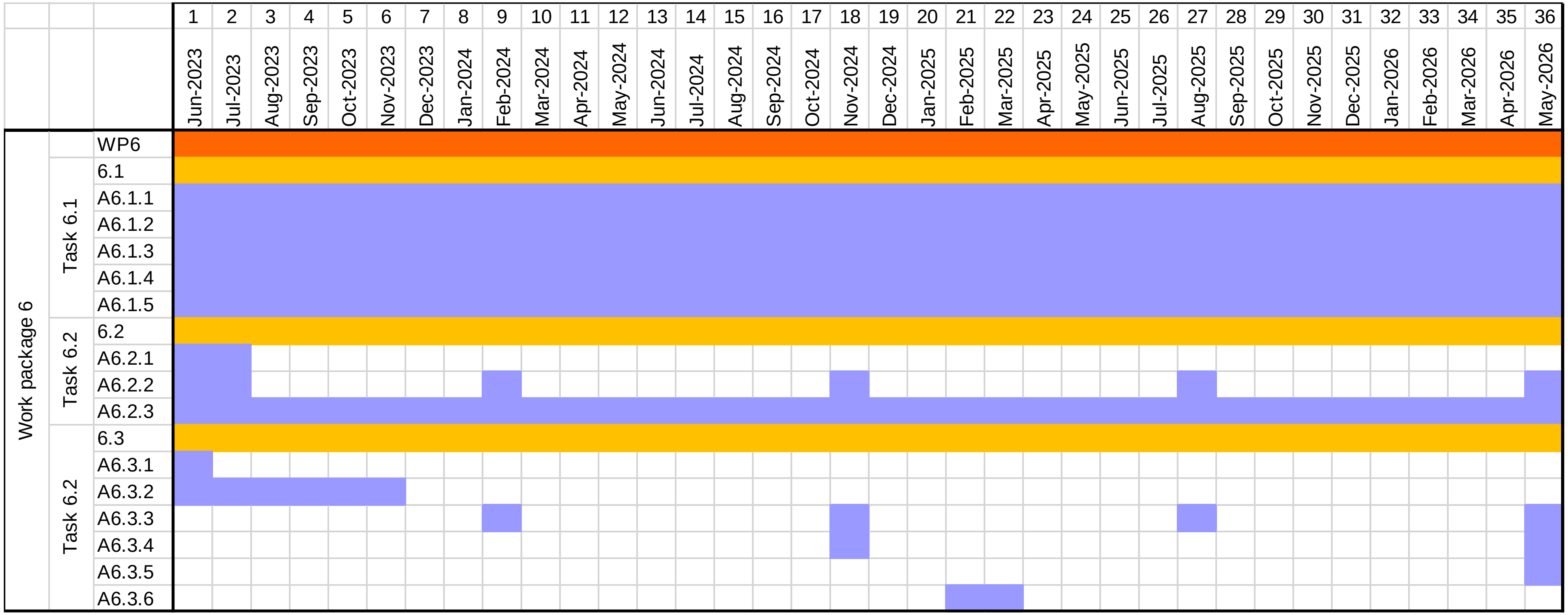
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Work package 6
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Section D: Risk and risk mitigation

D1 Scientific/technical risks

Risk (description)	**Likelihood, impact and severity of occurrence**	**Mitigation** i.e. what the consortium will do to decrease the likelihood of the risk occurring	**Contingency** i.e. what the consortium will do if despite the mitigation the risk still occurs
Task 1.1 The workshops cannot be organised as planned either because CMI encounters unexpected difficulties in hosting them, or some of the project participants are unable to attend	Likelihood after mitigation: Low Impact: The less experienced NMIs will not receive the intended training and will be less qualified to start the practical work of creating fixed point cells and radiometer characterisations. Level of severity: High	The kickoff meeting and the training workshops are planned to take place early in the project and all participants know the relevant times even before the project starts.	In the event the training sessions cannot be held as planned, they will be held online as soon as all participants are ready.
Task 1.2 The results from the survey of current capabilities are inadequate, not coherent, or conclusive	Likelihood after mitigation: Low Impact: It might be difficult to identify suitable areas for smart specialisation, or some of the fixed point cell construction activities could become harder to complete. Level of severity: Low	All participants are NMIs or DIs and have a good overview of their own laboratory capabilities. The survey will be carried out early in the project, with time to resolve any issues with the results.	The consortium will go ahead with fixed point construction as planned, despite lacking a coherent overview of the capabilities in the consortium.
Task 1.2 It is not possible to identify suitable candidate areas for smart specialisation	Likelihood after mitigation: Low Impact: The project will not be able to deliver a smart specialisation plan in A1.2.3. Level of severity: Medium	The consortium will start the process early in the project and will work continuously to identify suitable areas for specialisation. The emphasis will be on identifying the cases where there is a clear mutual benefit.	The project will continue with the rest of the activities as planned, since no activities explicitly depend on the outcome of Task 1.2.
Task 1.3 The analysis of the survey results is not available on time	Likelihood after mitigation: Low Impact: The consortium will lack an overview of the capabilities, which will make it harder to identify areas for smart specialisation and to write sensible development plans. Level of severity: Low	The survey will be carried out early in the project. If the responsible participant cannot carry out the analysis there is time for other participants to take over.	The survey results are not critical for the other activities in the project, such as the construction of fixed points or the implementation of the temperature scales. The project will therefore continue, despite losing one important outcome.
Task 2.1: High purity metals for the fixed-point cells are unavailable or have long lead times	Likelihood after mitigation: Low Impact: Construction of the best possible fixed-point cells will not be possible within the timeframe of the project. Level of severity: High	The acquisition of metals will be highest priority from the start of the project. The lead times and availability of the metals will be investigated even prior to the start of the project. Alternative sources will also be identified where possible. In addition, some participants have raw materials available that could be of use from previous defective fixed-point cells (for Ag, Au and Cu), which could be chemically analysed for purity assessment and possibly reused.	The consortium will consider using lower purity metal in order to gain experience with construction of the cells. If it turns out that there is a similar problem with the availability / lead time of the lower purity metals, then a subset of the cells will be constructed instead based on the metals available.

Risk (description)	**Likelihood, impact and severity of occurrence**	**Mitigation** i.e. what the consortium will do to decrease the likelihood of the risk occurring	**Contingency** i.e. what the consortium will do if despite the mitigation the risk still occurs
Task 2.2: Some or all of the less experienced participants do not master the construction of the cells within the timeframe of the project	Likelihood after mitigation: Low Impact: One or more participant will not be able to implement a multiple fixed point interpolation scale within the timeframe of the project. Level of severity: Medium	The less experienced institutes will be thoroughly trained early in the project and will visit the experienced institutes to gain practical experience. The less experienced institutes will consult the experienced institutes as soon as possible when issues occur.	If necessary, participants will exchange cells, or construct cells jointly. This will leverage the skills of the most less experienced institutes for the benefit of the project and will increase the probability that enough cells are available before the comparison starts.
Task 2.2: Failure of high-temperature furnaces used to fill the fixed-point cells. The highest temperatures targeted in the project lead to more wear on equipment.	Likelihood after mitigation: Low Impact: One or more participant fails to reach the upper temperature limit planned. Level of severity: Medium	The consortium has access to a backup furnace that can be used, providing some redundancy.	The project will proceed with a restricted temperature range.
Task 2.3 Unable to obtain repeatable, stable, and uniform phase transitions in the newly constructed fixed-point cells	Likelihood after mitigation: Low Impact: The consortium will not be able to establish temperature scales with satisfactory precision. Level of severity: High	The less experienced NMIs/DIs will actively seek support and assistance from the experienced NMIs/DIs. Since the scales are constructed independently at several institutes it is unlikely that all will fail.	The project will proceed with less precise and reliable scales. The experience will still be valuable input to the CCT WG NcTh and the EURAMET TC-T.
Task 3.1 One or more participants encounter problems with important characterisation equipment and fails to properly characterise SSE, linearity or spectral properties of the pyrometer	Likelihood after mitigation: Low Impact: Important inputs in the uncertainty evaluation will be lacking. Level of severity: High	Most participants are experienced in operating the necessary equipment. They will make every effort to ensure that the equipment is available and operational in time.	Characterisation of the instruments will be carried out only once in the project at one of the participants with operational equipment. A larger uncertainty will be accepted if required.
Task 3.2: One or more participants is unable to obtain and characterise a pyrometer of sufficient reliability and quality	Likelihood after mitigation: Low Impact: One or more participant fails to implement the temperature scale. Level of severity: High	The consortium includes participants with previous experience in the construction and operation of radiometers. It is likely that any issues arising can be solved either with the expertise of the experienced NMIs/DIs, or the combined efforts of all participants.	Any laboratory which is unable to acquire a suitable pyrometer will take their cells to a different project participant and perform a calibration using the host institute’s pyrometer, in order to validate their cells. The institute will not participate in the comparison within the project, but will obtain linkage at a later stage.
Task 3.3 Facilities for the ITS-90 calibration of the interpolation instrument are not available at the host institute due to unforeseen reasons	Likelihood after mitigation: Low Impact: The participant affected will not be able to calibrate their interpolation instrument or at least not on time. Delay in A3.3.4. Level of severity: Low	The consortium includes more than one institute capable of providing ITS-90 traceability in pyrometry. The activities A3.3.1-A3.3.4 will be redistributed amongst the participants accordingly.	It is very unlikely that the consortium is not able to provide the ITS-90 traceable calibration service. In the worst case, participants will be redirected to NMIs (having ITS-90 capabilities) outside the consortium.

Risk (description)	**Likelihood, impact and severity of occurrence**	**Mitigation** i.e. what the consortium will do to decrease the likelihood of the risk occurring	**Contingency** i.e. what the consortium will do if despite the mitigation the risk still occurs
WP1-WP3 The relevant work in WP1-WP3 required in preparation for WP4 takes longer to complete than expected	Likelihood after mitigation: Medium Impact: WP4 cannot start until all laboratories have successfully established their scale. Level of severity: High	The project has a challenging timeline initially, and WP1-3 must be completed before WP4 can start. On the other hand, during the comparison most laboratories will have time available for other tasks since only one laboratory will perform measurements at a time. Therefore, as many non-experimental activities e.g. reporting activities as possible are deferred to the second half of the project.	The comparison will be started, but not finished by the end of the project. The work will continue, however, and a draft A report will be produced.
Task 4.1: The consortium is unable to find a suitable travelling standard device in time for the start of the circulation of the instrument for the comparison	Likelihood after mitigation: Low Impact: The comparison cannot be carried out within the timeframe of the project. Level of severity: High	Both the experienced institutes and some of the less experienced NMIs/DIs already possess suitable instruments. The planning of the comparison will start early, which increases the likelihood that a suitable device is obtained before the planned start of the comparison.	The consortium will define a different comparison scheme within the project. Two options will be considered which would provide useful results but have some drawbacks: (i) circulate fixed points rather than a furnace and radiometer however this would not align with the approach for CCT-K10, or (ii) visits to two laboratories where each participant brings their own calibrated radiometer, however this has some cost and availability implications.
Task 4.1: Unexpected difficulties in approval of the protocol by TC-T or CCT and registration in the KCDB	Likelihood after mitigation: Low Impact: The comparison cannot be carried out within the timeframe of the project. Level of severity: Medium	The planning of the comparison will start early. One of the consortium participants, CNAM, participated in the CCT-K10 and will start work early in the project on an adapted protocol.	The comparison will have to start later than planned. If it cannot be started within the project timeframe, a simpler comparison will be carried out within the consortium, but potentially without the ability to link to CCT-K10 or registration as a EURAMET comparison.
Task 4.2: Travelling standards damaged during shipment in the comparison	Likelihood after mitigation: Low Impact: The comparison cannot be carried out within the timeframe of the project. Analysis of the results will be complicated. Level of severity: Medium	The containers will be equipped with accelerometers. Transporters will be informed of the fragility of the material.	The standards will be characterised prior to the circulation against the reference Cu fixed-point cells. The traceability will be then ensured in case of irreversible damage.
Task 4.2: Issues arising during the circulation of the travelling standards (e.g. customs issues, breakdown of participants' reference instruments)	Likelihood after mitigation: Medium Impact: Delay in the comparison which may extend beyond the timeframe of the project. Level of severity: Low	The comparison will be planned to minimise the circulation time. The participants will have prepared their setups as part of the project prior to the start of the comparison. While shipping instruments care will be taken to reduce possible customs issues.	The consortium will deal with delays as they arise, and the exact remedial action will depend on the issue arising. It may be possible to reschedule the circulation of the travelling standards, replace broken units, or include a participant after the project ends if the participant is unable to carry out measurements in time.

Risk (description)	Likelihood, impact and severity of occurrence	Mitigation i.e. what the consortium will do to decrease the likelihood of the risk occurring	Contingency i.e. what the consortium will do if despite the mitigation the risk still occurs
Task 5.2: Locations for industrial trials are unavailable, either due to operational or administrative issues	Likelihood after mitigation: Low Impact: One of more of the industrial on-site demonstrations cannot be completed within the project lifetime. Level of severity: Low	The consortium plans to create a stakeholder group on LinkedIn and interact closely with it. The consortium should therefore be warned and informed early on of any unforeseen issues. Alternative test sites will then be searched for.	It is expected that the industrial stakeholders will be interested in the demonstrations as soon as practically possible after the project ends, and the likely worst case outcome is that the demonstrations happen after the project ends.

D2 Management risks

Risk (description)	Likelihood, impact and severity of occurrence	Mitigation i.e. what the consortium will do to decrease the likelihood of the risk occurring	Contingency i.e. what the consortium will do if despite the mitigation the risk still occurs
Key personnel are lost to the project through staff changes, illness, or other absence during the project timeframe	Likelihood after mitigation: Low Impact: Loss of key staff may delay tasks or make them impossible to complete within the project. Level of severity: High	The grouping of experts within the consortium should minimise the areas where knowledge is held by a single person. Participants will involve at least two staff members in the activities. All the participants will identify backups for key workers wherever possible to reduce the overall risk to the project. Project plans will be shared within the consortium and results and methodology will be documented. The consortium will assist participants that need additional training due to staff changes.	If a key member leaves the project, then the participant concerned will be responsible for appointing a replacement. The remaining participants will carry out their activities as planned. If the participant affected cannot carry out activities which other participants depend on, the remaining participants will assist each other to ensure the necessary activities are completed. However, this may still lead to a delay in delivery.
Insufficient funding for purchasing high-purity metals outside of the project for fixed-point cells at one or more participants due to changing priorities at their organisations or by their national governments	Likelihood after mitigation: Low Impact: Affected participants will not be able to construct all their planned fixed points due to a lack of material, and therefore will be unable to implement the interpolation scale. Level of severity: Low	The consortium cannot mitigate risks that involve decisions at higher level. However, each participant requiring high-purity metals will liaise with the senior management as far as possible with the aim of minimising the risk and changes in priorities.	Participants will, within reasonable limits, try to help each other with access to materials.
Inter-dependencies between technical activities and tasks are too complex	Likelihood after mitigation: Low Impact: Tasks are delayed, or it is not possible to deliver them. Level of severity: High	Technical meetings run by WP leaders have been scheduled to ensure proper sharing of knowledge. The interdependencies between tasks will be considered at meetings to ensure that this is addressed properly in the planning of the work. The technical WPs will be closely managed by their WP leaders to ensure that they deliver their own outputs.	In most cases, activities on the critical path have some overlap in time and thus a delay in the output of one deliverable does not necessarily cause an immediate delay in another.

Risk (description)	**Likelihood, impact and severity of occurrence**	**Mitigation** i.e. what the consortium will do to decrease the likelihood of the risk occurring	**Contingency** i.e. what the consortium will do if despite the mitigation the risk still occurs
Project management becomes ineffective due to poor communication	Likelihood after mitigation: Medium Impact: Lack of focus and coherence will lead to duplication of effort or to important tasks being neglected. Level of severity: Medium	In addition to the formal project meetings, technical meetings will be held as needed. These may involve the entire consortium or only parts of it. Some meetings may involve only the regional participants where the meetings relate to the planning of regional smart specialisation. Full use will be made of teleconferencing facilities to allow maximum participation at project meetings. It is expected that following the Covid pandemic the participants have adequate systems and experience with remote interactions.	Increased management resources will be devoted to improving communication.
Problems dealing with Intellectual Property (IP) ownership and/or exploitation might occur and could be a source of potential conflict	Likelihood after mitigation: Low Impact: Disagreement between the participants could delay the project (in implementing the work and publishing results). Level of severity: Medium	All beneficiaries will sign the grant agreement and all participants will sign the consortium agreement, which includes IP clauses.	Independent arbitrators will be used in the event of disagreement between participants.
The onsite facilities of participants, and/or access to public/commercial services or sites is restricted for a period of time during the project due to an extraordinary event or situation that is beyond the participants' control e.g. COVID-19	Likelihood after mitigation: Low Impact: Activities and deliverables are delayed, or no longer able to be completed. Level of severity: Medium	In most cases, activities on the critical path are independently carried out and can be completed at one participant despite issues arising at a different participant (e.g. construction of fixed points). There are some exceptions, such as CNAM which must be available during the comparison, and RISE, SMU and TUBITAK which must be available for the ITS-90 comparisons (Task 3.3).	Where possible, work will be reassigned to an alternative participant, or rephased, therefore minimising delays and technical deviations that would have a negative impact on the project. If necessary, the consortium will contact EURAMET to discuss options according to the grant agreement.
Organisation of workshops, training and joint demonstrator activities in a post- or trans-COVID world	Likelihood after mitigation: Low Impact: Failure to show the outputs at workshops or through demonstrator activities risks reducing the knowledge transfer and impact from the project. Level of severity: Medium	Although most COVID travel restrictions have been removed, there is the possibility that some restrictions may be re-introduced nationally or internationally, or organisations may apply their own restrictions. Some flexibility is built into the tasks and activities with nominal locations and dates, but these will be reviewed nearer the time and the consortium will decide on the appropriate locations of such activities e.g. to take advantage of/cope with moved external events.	Alternatives such as webinars or online meetings can be used.
Environmental and Health and Safety: Staff involved in the project do not follow the relevant H&S procedures in particular related to the use of high temperature environments	Likelihood after mitigation: Low Impact: Staff may become injured. Level of severity: High	All participants are experienced in these types of tests and are aware of the health and safety procedures to follow. In case of doubt, the staff will revise these procedures before initiating the work.	The participants will discuss the possibility of reallocating work within the consortium. If necessary, parts of the work will be re-scoped in agreement with EURAMET.

D3 Ethics

The Partnership Ethics Review 2022 has given JRP 22RPT03 MuliFixRad “Ethics clearance”.

Data protection

By signing or acceding to this grant agreement and / or consortium agreement each participant asserts that the requirements of the General Data Protection Regulation (GDPR) 2016/679 which entered into force on 25 May 2018 will be met. Under the regulation, the data controllers and processors are fully accountable for the data processing operations. Any violation of the data subject rights may lead to sanctions as described in Chapter VIII, art.77-84 of the GDPR.

If personal data are transferred from the EU to a non-EU country or international organisation, such transfers will be in accordance with Chapter V of the GDPR 2016/679. If personal data are transferred from a non-EU country to the EU (or another third state), such transfers will comply with the laws of the country in which the data was collected.

Non-EU countries

The consortium will ensure that participants and collaborators, including those from non-EU countries, fully adhere to Horizon Europe ethics standards and guidelines, no matter where the research or activities are carried out and that research or activities performed outside the European Union are compatible with EU, national and international legislation and can be legally conducted in one of the EU Member States. If applicable, details on the material, samples and/or equipment which will be imported to/exported from EU must be provided and the adequate authorisations granted by the relevant authorities have been or will be obtained and kept on file by the consortium. The consortium will also, in the case of dual use applications, clarify whether any export licence is required for the transfer of knowledge, equipment or material.

Ethical integrity

The participants will ensure that all ethics issues related to activities in the project are addressed in compliance with ethical principles (including the highest standards of research integrity as set out in the ALLEA European Code of Conduct for Research Integrity https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/european-code-of-conduct-for-research-integrity_horizon_en.pdf), the applicable international and national law, and the provisions set out in the grant agreement. This includes the ethics issues identified in the ethics screening and the submitted documents, and any additional ethics issues that may emerge in the course of the project. In the case where any substantial new ethics issues arise, participants will inform the granting authority EURAMET e.V, and for each ethics issue applicable, participants will follow the guidance provided in the Horizon Europe *'How to complete your ethics self-assessment' guide*’.

The consortium will ensure that appropriate procedures, policies and structures (https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/guideline-for-promoting-research-integrity-in-research-performing-organisations_horizon_en.pdf) are in place to foster responsible research practices, to prevent questionable research practices and research misconduct, and to handle allegations of breaches of the principles and standards in the Code of Conduct.

Section E: References

[1] CCT, "The Mise-en-Pratique for the kelvin," BIPM, https://www.bipm.org/documents/20126/41489682/SI-App2-kelvin.pdf/cd36cb68-3f00-05fd-339e-452df0b6215e?version=1.5&t=1637237805352&download=true (Accessed sept 2022), 2019.

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