 SMÚ-24L/2024/00031/000031

EUROPEAN PARTNERSHIP Co-funded by the European Union METROLOGY PARTNERSHIP EURAMET

MULTI-BENEFICIARY GRANT AGREEMENT FOR

The European Partnership on Metrology

Project: 23IND11 ThermoSI

PREAMBLE

This **Agreement** ('the Agreement') is **between** the following parties:

on the one part,

EURAMET e.V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority'), under the powers delegated by the European Commission ('European Commission') represented for the purposes of signature of this Agreement by, Partnership Chair, Maguelonne Chambon,

and

on the other part,

1. 'the coordinator':

Teknologisk Institut (DTI), established in Gregersensvej 1, DK-2630, Taastrup, Denmark, VAT no. DK56976116 as 'Designated Institute' (DI)

and the following other beneficiaries, if they sign their 'Accession Form' (see Annex 3 and Article 40):

2. Cesky Metrologicky Institut (CMI), established in Okružní 31, CZ-638 00 Brno, Czechia, VAT no. CZ00177016 as 'National Metrology Institute' (NMI)

3. Physikalisch-Technische Bundesanstalt (PTB), established in Bundesallee 100, DE-38116 Braunschweig, Germany, VAT no. DE811240952 as 'National Metrology Institute' (NMI)

4. Slovenský Metrologický Ústav (SMU), established in Karloveská 63, SK-842 55 Bratislava 4, Slovakia, VAT no. SK2020908230 as 'National Metrology Institute' (NMI)

5. Univerza v Ljubljani (UL), established in Kongresni trg 12, SI-1000 Ljubljana, Slovenia, VAT no. SI54162513 as 'Designated Institute' (DI)

6. Teknologian tutkimuskeskus VTT Oy (VTT), established in Tekniikantie 21, 02150, Espoo, Finland, VAT no. FI26473754 as 'National Metrology Institute' (NMI)

7. Danmarks Tekniske Universitet (DTU), established in Anker Engelunds Vej 1, Bygning 101A, DK-2800 Kongens Lyngby, Denmark, VAT no. DK30060946

8. National Scientific Centre Institute of Metrology (NSC-IM), established in 42 Mironositskaya Str., UA-61002 Kharkov, Ukraine, VAT no. UA025683220315

9. Otto-von-Guericke-Universitaet Magdeburg (OVGU), established in Universitaetsplatz 2, 39106 Magdeburg, Germany, VAT no. DE139238413

10. Babcock & Wilcox Vølund A/S (B&W Volund), established in Falkevej 2, DK-6705, Esbjerg Ø, Denmark, VAT no. DK25053664

11. Beamex Oy Ab (Beamex), established in Ristisuonraitti 10, 68600, Pietarsaari, Finland, VAT no. FI0181602-8

Unless otherwise specified, references to 'beneficiary' or 'beneficiaries' include the coordinator and affiliated entities (if any).

If only one beneficiary signs the grant agreement ('mono-beneficiary grant'), all provisions referring to the 'coordinator' or the 'beneficiaries' will be considered — mutatis mutandis — as referring to the beneficiary.

Having regard to Decision (EU) 2021/2084 of the European Parliament and of the Council of 24 November 2021 on the participation of the Union in the European Partnership on Metrology jointly undertaken by several Member States[1],

The parties referred to above have agreed to enter into the Agreement.

By signing the Agreement and the accession forms, the beneficiaries accept the grant and agree to implement the action under their own responsibility and in accordance with the Agreement, with all the obligations and terms and conditions it sets out.

The Agreement is composed of:

Preamble

Terms and Conditions (including Data Sheet)

Annex 1	Description of the action
Annex 2	Estimated budget for the action
Annex 2a	Additional information on unit costs and contributions
Annex 3	Accession forms
Annex 3a	Declaration on joint and several liability of affiliated entities (if applicable)
Annex 4	Model for the financial statements [2]
Annex 4a	Model for the statement on the use of the previous pre-financing payment (not applicable)
Annex 5	Specific rules
Annex 6	Model for the certificate on the financial statements (CFS) [3]

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1 OJ L 427, 30.11.2021, p. 1 -16

2 Template published on https://metpart.eu/.

3 Template published on https://metpart.eu/.

TERMS AND CONDITIONS

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DATA SHEET

1. General data

Project summary

Project summary

Most industrial processes rely on temperature measurement, which directly influences product quality, energy efficiency, and emissions All conventional temperature sensors exhibit calibration drift leading to inefficiencies Poor surface thermometry causes process control problems in advanced manufacturing Poor gas thermometry causes sub-optimal noxious emissions and reduced efficiency This project will overcome specific process control challenges by implementing embedded traceable thermometry in-situ through driftless practical primary thermometry and self-validation, gas/combustion thermometry, and new traceable surface temperature measurement methods Traceability will be either directly to the redefined SI kelvin, or indirectly via the International Temperature Scale of 1990 (ITS-90)

Keywords Temperature, Johnson noise thermometry, practical primary thermometry, phosphor thermometry, thermal imaging, surface thermometry, gas thermometry, artificial intelligence, process efficiency

Project number 23IND11

Project name Thermometry with embedded SI traceability for industrial applications

Project acronym ThermoSI

Call Industry (2023)

Topic SRT-i17

Type of action Metrology Partnership Research and Innovation actions

Granting authority EURAMET e V

Grant managed through EU Funding & Tenders Portal No

Project starting date 01 September 2024

Project end date 31 August 2027

Project duration 36 months

Consortium agreement Yes

2. Participants

List of participants:

Number	Role	Short name	Legal name	Country	PIC	Total eligible costs	Maximum grant amount	Entry date	Exit date
1	COO	DTI	Teknologisk Institut	Denmark	999460356	400,000 00	400,000 00	01 September 2024	31 August 2027
2	BEN	CMI	Cesky Metrologicky Institut	Czechia	993266033	60,000 00	60,000 00	01 September 2024	31 August 2027

3	BEN	PTB	Physikalisch-Technische Bundesanstalt	Germany	999596544	370,000 00	370,000 00	01 September 2024	31 August 2027
4	BEN	SMU	Slovensky Metrologicky Ustav	Slovakia	994207903	25,000 00	25,000 00	01 September 2024	31 August 2027
5	BEN	UL	Univerza v Ljubljani	Slovenia	999923240	267,500 00	267,500 00	01 September 2024	31 August 2027
6	BEN	VTT	Teknologian tutkimuskeskus VTT Oy	Finland	932760440	79,999 50	79,999 50	01 September 2024	31 August 2027
7	BEN	DTU	Danmarks Tekniske Universitet	Denmark	999990655	160,000 00	160,000 00	01 September 2024	31 August 2027
8	BEN	NSC-IM	National Scientific Centre Institute of Metrology	Ukraine	952600335	60,000 00	60,000 00	01 September 2024	31 August 2027
9	BEN	OVGU	Otto-von-Guericke-Universitaet Magdeburg	Germany	999873285	55,000 00	55,000 00	01 September 2024	31 August 2027
10	BEN	B&W Volund	Babcock & Wilcox Vølund A/S	Denmark	934297308	15,000 00	0 00	01 September 2024	31 August 2027
11	BEN	Beamex	Beamex Oy Ab	Finland	892954938	87,575 00	0 00	01 September 2024	31 August 2027
12	AP	BAE	BAE Systems Marine Ltd	United Kingdom	935453645	0 00	0 00	01 September 2024	31 August 2027
13	AP	CCPI	CCPI Europe Ltd	United Kingdom	937294220	0 00	0 00	01 September 2024	31 August 2027
14	AP	Metrosol	Metrosol Limited	United Kingdom	950225193	0 00	0 00	01 September 2024	31 August 2027
15	AP	NPL	NPL Management Limited	United Kingdom	999920330	0 00	0 00	01 September 2024	31 August 2027
16	AP	STRATH	University of Strathclyde	United Kingdom	999974068	0 00	0 00	01 September 2024	31 August 2027
17	AP	UoM	The University of Manchester	United Kingdom	999903840	0 00	0 00	01 September 2024	31 August 2027

Coordinator:

- DTI from 01 September 2024 to 31 August 2027

3. Grant

Maximum grant amount, total estimated eligible costs and contributions and funding rate:

Total eligible costs (BEN and AE)	Funding rate (%)	Maximum grant amount (Annex 2)	Maximum grant amount (award decision)
1,580,074 50	100	1,477,499 50	1,477,499 50

Grant form: Budget-based

Grant mode: Action grant

Budget categories/activity types:

- A Personnel costs
  - A 1 Employees
  - A 2 Natural persons under direct contract
  - A 3 Seconded persons
  - A 4 SME owners and natural person beneficiaries
- B Subcontracting costs
- C Purchase costs
  - C 1 Travel and subsistence
  - C 2 Equipment
  - C 3 Other goods, works and services
- D Other cost categories
  - D 1 Financial support to third parties
  - D 2 Internally invoiced goods and services
- E Indirect costs

Cost eligibility options:

- In-kind contributions eligible costs
- Parental leave
- Project-based supplementary payments
- Average personnel costs (unit cost according to usual cost accounting practices)
- Limitation for subcontracting
- Travel and subsistence
  - Travel Actual costs
  - Accommodation Actual costs
  - Subsistence Actual costs
- Equipment depreciation only
- Indirect cost flat-rate 25% of the eligible direct costs (categories A-D, except volunteers costs, subcontracting costs, financial support to third parties and exempted specific cost categories, if any)
- VAT Yes
- Other ineligible costs

Budget flexibility Yes (no flexibility cap)

4. Reporting, payments and recoveries

4.1 Obligation to submit reports (art 21 1)

Deliverables: Yes

4.2 Periodic reporting and payments

Reporting and payment schedule (art 21, 22):

Reporting					Payments	
Reporting periods			Type	Deadline	Type	Deadline (time to pay)
RP No	Month from	Month to				
					Initial prefinancing	30 days from entry into force or from receipt of the last signed Accession Forms / 10 days before starting date – whichever is the latest
1	1	18	Periodic report	60 days after end of reporting period	Interim payment	90 days from receiving periodic report
2	19	36	Periodic report	60 days after end of reporting period	Final payment	90 days from receiving periodic report

Prefinancing payments and guarantees:

Prefinancing payments			
Type	Total Amount	Division per participant	
Prefinancing 1 (initial)	886,499 70	01 DTI	240,000 00
		02 CMI	36,000 00
		03 PTB	222,000 00
		04 SMU	15,000 00
		05 UL	160,500 00
		06 VTT	47,999 70
		07 DTU	96,000 00
		08 NSC-IM	36,000 00
		09 OVGU	33,000 00
		10 B&W Volund	0 00
		11 Beamex	0 00
		12 BAE	0 00
		13 CCPI	0 00
		14 Metrosol	0 00

		15 NPL	0 00
		16 STRATH	0 00
		17 UoM	0 00

Reporting and payment modalities (art 21, 22):

Mutual Insurance Mechanism (MIM) Yes

MIM contribution 5% of the maximum grant amount 73,874 98 retained from the initial prefinancing as follows

5 % MIM Contribution per beneficiary

	Division per participant	Net initial payment
01 DTI	20,000 00	220,000 00
02 CMI	3,000 00	33,000 00
03 PTB	18,500 00	203,500 00
04 SMU	1,250 00	13,750 00
05 UL	13,375 00	147,125 00
06 VTT	3,999 98	43,999 73
07 DTU	8,000 00	88,000 00
08 NSC-IM	3,000 00	33,000 00
09 OVGU	2,750 00	30,250 00
10 B&W Volund	0 00	0 00
11 Beamex	0 00	0 00
12 BAE	0 00	0 00
13 CCPI	0 00	0 00
14 Metrosol	0 00	0 00
15 NPL	0 00	0 00
16 STRATH	0 00	0 00
17 UoM	0 00	0 00

Interim payment ceiling (if any) 90% of the maximum grant amount

Exception for revenues No

No-profit rule Yes

Late payment interest ECB + 3 5 %

Bank accounts of the beneficiaries for payments

Conversion into euros Double conversion

Reporting language Language of the Agreement

4.3 Certificates (art 24)

Certificates on the financial statements (CFS)

Conditions

Schedule only at final payment, if threshold is reached

Standard threshold (beneficiary level)

- financial statement requested European Partnership on Metrology contribution to costs ≥ EUR 430 000

Special threshold for beneficiaries with a systems and process audit (see Article 24) financial statement requested European Partnership on Metrology contribution to costs ≥ EUR 725 000

4.4 Recoveries (art 22)

First-line liability for recoveries:

Beneficiary termination Beneficiary concerned

Final payment Each beneficiary for their own debt

After final payment Beneficiary concerned

Joint and several liability for enforced recoveries (in case of non-payment):

Individual financial responsibility Each beneficiary is liable only for its own debts (and those of its affiliated entities, if any)

Joint and several liability of affiliated entities — N/A

5. Consequences of non-compliance, applicable law & dispute settlement forum

Suspension and termination:

Additional suspension grounds (art 31)

Additional termination grounds (art 32)

Applicable law (art 43):

Standard applicable law regime EU law + national law of the Member State of the granting authority

Dispute settlement forum (art 43):

Standard dispute settlement forum competent national courts of the Member State of the granting authority

6. Other

Specific rules (Annex 5): Yes

- Sensitive information with security recommendation
- EU classified information
- Ethics and research integrity
- Gender mainstreaming
- IPR, results and background, access rights and rights of use (Horizon Europe)
- Communication, dissemination, open science and visibility (Horizon Europe)
- Specific rules for carrying out the action
  - Implementation in case of restrictions due to strategic assets, interests, autonomy or security of the EU and its Member States
  - Recruitment and working conditions for researchers
  - Specific rules for PCP and PPI procurements

Standard time-limits after project end:

Confidentiality (for X years after final payment) 5

Record-keeping (for X years after final payment) 5 (or 3 for grants of not more than EUR 60 000)

Reviews (up to X years after final payment) 2

Audits (up to X years after final payment) 2

Extension of findings from other grants to this grant (no later than X years after final payment) 2

Impact evaluation (up to X years after final payment) 5 (or 3 for grants of not more than EUR 60 000)

CHAPTER 1 GENERAL

ARTICLE 1 — SUBJECT OF THE AGREEMENT

This Agreement sets out the rights and obligations and terms and conditions applicable to the grant awarded for the implementation of the action set out in Chapter 2

ARTICLE 2 — DEFINITIONS

For the purpose of this Agreement, the following definitions apply

Action — The project which is being funded in the context of this Agreement

Grant — The grant awarded in the context of this Agreement

EU grants — Grants awarded by EU institutions, bodies, offices or agencies (including EU executive agencies, EU regulatory agencies, EDA, joint undertakings, etc)

Metrology Partnership contribution - aggregate amount of the financial resources committed and paid by EURAMET in the framework of the Metrology Partnership to beneficiaries and affiliated entities,

Participants — Entities participating in the action as beneficiaries, affiliated entities, associated partners, third parties giving in-kind contributions, subcontractors or recipients of financial support to third parties

Beneficiaries (BEN) — The signatories of this Agreement (either directly or through an accession form)

Affiliated entities (AE) — Entities affiliated to a beneficiary within the meaning of Article 187 of EU Financial Regulation 2018/1046[4] which participate in the action with similar rights and obligations as the beneficiaries (obligation to implement action tasks and right to charge costs and claim contributions)

Associated partners (AP) — Entities which participate in the action, but without the right to charge costs or claim contributions

Purchases — Contracts for goods, works or services needed to carry out the action (e g equipment, consumables and supplies) but which are not part of the action tasks (see Annex 1)

Subcontracting — Contracts for goods, works or services that are part of the action tasks (see Annex 1)

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[4] For the definition, see Article 187 Regulation (EU, Euratom) 2018/1046 of the European Parliament and of the Council of 18 July 2018 on the financial rules applicable to the general budget of the Union, amending Regulations (EU) No 1296/2013, (EU) No 1301/2013, (EU) No 1303/2013, (EU) No 1304/2013, (EU) No 1309/2013, (EU) No 1316/2013, (EU) No 223/2014, (EU) No 283/2014, and Decision No 541/2014/EU and repealing Regulation (EU, Euratom) No 966/2012 ('EU Financial Regulation') (OJ L 193, 30 7 2018, p 1) "**affiliated entities** [are]

(a) entities that form a sole beneficiary [(i e where an entity is formed of several entities that satisfy the criteria for being awarded a grant, including where the entity is specifically established for the purpose of implementing an action to be financed by a grant)],

(b) entities that satisfy the eligibility criteria and that do not fall within one of the situations referred to in Article 136(1) and 141(1) and that have a link with the beneficiary, in particular a legal or capital link, which is neither limited to the action nor established for the sole purpose of its implementation"

In-kind contributions — In-kind contributions within the meaning of Article 2(36) of EU Financial Regulation 2018/1046, i e non-financial resources made available free of charge by third parties

Fraud — Fraud within the meaning of Article 3 of EU Directive 2017/1371[5] and Article 1 of the Convention on the protection of the European Communities' financial interests, drawn up by the Council Act of 26 July 1995[6], as well as any other wrongful or criminal deception intended to result in financial or personal gain

Irregularities — Any type of breach (regulatory or contractual) which could impact the EU financial interests, including irregularities within the meaning of Article 1(2) of EU Regulation 2988/95[7]

Grave professional misconduct — Any type of unacceptable or improper behaviour in exercising one's profession, especially by employees, including grave professional misconduct within the meaning of Article 136(1)(c) of EU Financial Regulation 2018/1046

Applicable EU, international and national law — Any legal acts or other (binding or non-binding) rules and guidance in the area concerned

Portal — EU Funding & Tenders Portal, electronic portal and exchange system managed by the European Commission and used by itself and other EU institutions, bodies, offices or agencies for the management of their funding programmes (grants, procurements, prizes, etc)

CHAPTER 2 ACTION

ARTICLE 3 — ACTION

The grant is awarded for the action **23IND11 ThermoSI** ('action'), as described in Annex 1

ARTICLE 4 — DURATION AND STARTING DATE

The duration and the starting date of the action are set out in the Data Sheet (see Point 1)

CHAPTER 3 GRANT

ARTICLE 5 — GRANT

5.1 Form of grant

The grant is an action grant[8] which takes the form of a budget-based mixed actual cost grant (i e a grant based on actual costs incurred, but which may also include other forms of funding, such as unit costs or contributions, flat-rate costs or contributions, lump sum costs or contributions or financing not linked to costs)

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5 Directive (EU) 2017/1371 of the European Parliament and of the Council of 5 July 2017 on the fight against fraud to the Union's financial interests by means of criminal law (OJ L 198, 28 7 2017, p 29)

6 OJ C 316, 27 11 1995, p 48

7 Council Regulation (EC, Euratom) No 2988/95 of 18 December 1995 on the protection of the European Communities financial interests (OJ L 312, 23 12 1995, p 1)

8 For the definition, see Article 180(2)(a) EU Financial Regulation 2018/1046 '**action grant**' means an EU grant to finance "an action intended to help achieve a Union policy objective"

5.2 Maximum grant amount

The maximum grant amount is set out in the Data Sheet (see Point 3) and in the estimated budget (Annex 2)

5.3 Funding rate

The funding rate for costs is **100 %** of the action's eligible costs

Contributions are not subject to any funding rate

5.4 Estimated budget, budget categories and forms of funding

The estimated budget for the action is set out in Annex 2

It contains the estimated eligible costs and contributions for the action, broken down by participant and budget category

Annex 2 also shows the types of costs and contributions (forms of funding)[9] to be used for each budget category

If unit costs or contributions are used, the details on the calculation will be explained in Annex 2a

5.5 Budget flexibility

The budget breakdown may be adjusted — without an amendment (see Article 39) — by transfers (between participants and budget categories), as long as this does not imply any substantive or important change to the description of the action in Annex 1

However

- changes to budget categories with lump sums costs or contributions (if used, including financing not linked to costs) always require an amendment
- addition of amounts for subcontracts not provided for in Annex 1 either require an amendment or simplified approval in accordance with Article 6 2
- other changes require an amendment or simplified approval, if specifically provided for in Article 6 2

ARTICLE 6 — ELIGIBLE AND INELIGIBLE COSTS AND CONTRIBUTIONS

In order to be eligible, costs and contributions must meet the **eligibility** conditions set out in this Article

6.1 General eligibility conditions

The **general eligibility conditions** are the following

(a) for actual costs

(i) they must be actually incurred by the beneficiary

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9 *See Article 125 EU Financial Regulation 2018/1046*

(ii) they must be incurred in the period set out in Article 4 (with the exception of costs relating to the submission of the final periodic report, which may be incurred afterwards, see Article 21)

(iii) they must be declared under one of the budget categories set out in Article 6 2 and Annex 2

(iv) they must be incurred in connection with the action as described in Annex 1 and necessary for its implementation

(v) they must be identifiable and verifiable, in particular recorded in the beneficiary's accounts in accordance with the accounting standards applicable in the country where the beneficiary is established and with the beneficiary's usual cost accounting practices

(vi) they must comply with the applicable national law on taxes, labour and social security and

(vii) they must be reasonable, justified and must comply with the principle of sound financial management, in particular regarding economy and efficiency

(b) for unit costs or contributions (if any)

(i) they must be declared under one of the budget categories set out in Article 6 2 and Annex 2

(ii) the units must

- be actually used or produced by the beneficiary in the period set out in Article 4 (with the exception of units relating to the submission of the final periodic report, which may be used or produced afterwards, see Article 21)

- be necessary for the implementation of the action and

(iii) the number of units must be identifiable and verifiable, in particular supported by records and documentation (see Article 20)

(c) for flat-rate costs or contributions (if any)

(i) they must be declared under one of the budget categories set out in Article 6 2 and Annex 2

(ii) the costs or contributions to which the flat-rate is applied must

- be eligible

- relate to the period set out in Article 4 (with the exception of costs or contributions relating to the submission of the final periodic report, which may be incurred afterwards, see Article 21)

(d) for lump sum costs or contributions (if any)

(i) they must be declared under one of the budget categories set out in Article 6 2 and Annex 2

(ii) the work must be properly implemented by the beneficiary in accordance with Annex 1

(iii) the deliverables/outputs must be achieved in the period set out in Article 4 (with the exception of deliverables/outputs relating to the submission of the final periodic report, which may be achieved afterwards, see Article 21)

(e) for unit, flat-rate or lump sum costs or contributions according to usual cost accounting practices (if any)

(i) they must fulfil the general eligibility conditions for the type of cost concerned

(ii) the cost accounting practices must be applied in a consistent manner, based on objective criteria, regardless of the source of funding

(f) for financing not linked to costs (if any) the results must be achieved or the conditions must be fulfilled as described in Annex 1

In addition, for direct cost categories (e g personnel, travel & subsistence, subcontracting and other direct costs) only costs that are *directly* linked to the action implementation and can therefore be attributed to it *directly* are eligible They must not include any *indirect* costs (i e costs that are only indirectly linked to the action, e g via cost drivers)

In-kind contributions provided by third parties free of charge may be declared as eligible direct costs by the beneficiaries which use them (under the same conditions as if they were their own, provided that they concern only direct costs and that the third parties and their in-kind contributions are set out in Annex 1 (or approved ex post in the periodic report, if their use does not entail changes to the Agreement which would call into question the decision awarding the grant or breach the principle of equal treatment of applicants, 'simplified approval procedure')

6.2 Specific eligibility conditions for each budget category

For each budget category, the **specific eligibility conditions** are as follows

Direct costs

A. Personnel costs

A.1 Costs for employees (or equivalent) are eligible as personnel costs if they fulfil the general eligibility conditions and are related to personnel working for the beneficiary under an employment contract (or equivalent appointing act) and assigned to the action

They must be limited to salaries (including net payments during parental leave), social security contributions, taxes and other costs linked to the remuneration, if they arise from national law or the employment contract (or equivalent appointing act) and be calculated on the basis of the costs actually incurred, in accordance with the following method

{daily rate for the person multiplied by number of day-equivalents worked on the action (rounded up or down to the nearest half-day)}

The daily rate must be calculated as

{annual personnel costs for the person divided by 215}

The number of day-equivalents declared for a person must be identifiable and verifiable (see Article 20)

The actual time spent on parental leave by a person assigned to the action may be deducted from the 215 days indicated in the above formula

The total number of day-equivalents declared in EU grants, for a person for a year, cannot be higher than 215 minus time spent on parental leave (if any)

For personnel which receives supplementary payments for work in projects (project-based remuneration), the personnel costs must be calculated at a rate which

- corresponds to the actual remuneration costs paid by the beneficiary for the time worked by the person in the action over the reporting period

- does not exceed the remuneration costs paid by the beneficiary for work in similar projects funded by national schemes ('national projects reference')

- is defined based on objective criteria allowing to determine the amount to which the person is entitled

  and

- reflects the usual practice of the beneficiary to pay consistently bonuses or supplementary payments for work in projects funded by national schemes

The national projects reference is the remuneration defined in national law, collective labour agreement or written internal rules of the beneficiary applicable to work in projects funded by national schemes

If there is no such national law, collective labour agreement or written internal rules or if the project-based remuneration is not based on objective criteria, the national project reference will be the average remuneration of the person in the last full calendar year covered by the reporting period, excluding remuneration paid for work in EU actions

If the beneficiary uses average personnel costs (unit cost according to usual cost accounting practices), the personnel costs must fulfil the general eligibility conditions for such unit costs and the daily rate must be calculated

- using the actual personnel costs recorded in the beneficiary's accounts and excluding any costs which are ineligible or already included in other budget categories, the actual personnel costs may be adjusted on the basis of budgeted or estimated elements, if they are relevant for calculating the personnel costs, reasonable and correspond to objective and verifiable information

  and

- according to usual cost accounting practices which are applied in a consistent manner, based on objective criteria, regardless of the source of funding

A.2 and **A.3 Costs for natural persons working under a direct contract** other than an employment contract and costs for **seconded persons by a third party against payment** are also eligible as personnel costs, if they are assigned to the action, fulfil the general eligibility conditions and

(a) work under conditions similar to those of an employee (in particular regarding the way the work is organised, the tasks that are performed and the premises where they are performed) and

(b) the result of the work belongs to the beneficiary (unless agreed otherwise)

They must be calculated on the basis of a rate which corresponds to the costs actually incurred for the direct contract or secondment and must not be significantly different from those for personnel performing similar tasks under an employment contract with the beneficiary

A.4 The work of **SME owners** for the action (i e owners of beneficiaries that are small and medium-sized enterprises[10] not receiving a salary) or **natural person beneficiaries** (i e beneficiaries that are natural persons not receiving a salary) may be declared as personnel costs, if they fulfil the general eligibility conditions and are calculated as unit costs in accordance with the method set out in Annex 2a

B. Subcontracting costs

Subcontracting costs for the action (including related duties, taxes and charges, such as non-deductible or non-refundable value added tax (VAT)) are eligible, if they are calculated on the basis of the costs actually incurred, fulfil the general eligibility conditions and are awarded using the beneficiary's usual purchasing practices — provided these ensure subcontracts with best value for money (or if appropriate the lowest price) and that there is no conflict of interests (see Article 12)

Beneficiaries that are 'contracting authorities/entities' within the meaning of the EU Directives on public procurement must also comply with the applicable national law on public procurement

Subcontracting may cover only a limited part of the action

The tasks to be subcontracted and the estimated cost for each subcontract must be set out in Annex 1 and the total estimated costs of subcontracting per beneficiary must be set out in Annex 2 (or may be approved ex post in the periodic report, if the use of subcontracting does not entail changes to the Agreement which would call into question the decision awarding the grant or breach the principle of equal treatment of applicants, 'simplified approval procedure')

C. Purchase costs

Purchase costs for the action (including related duties, taxes and charges, such as non-deductible or non-refundable value added tax (VAT)) are eligible if they fulfil the general eligibility conditions and are bought using the beneficiary's usual purchasing practices — provided these ensure purchases with best value for money (or if appropriate the lowest price) and that there is no conflict of interests (see Article 12)

Beneficiaries that are 'contracting authorities/entities' within the meaning of the EU Directives on public procurement must also comply with the applicable national law on public procurement

C.1 Travel and subsistence

Purchases for **travel, accommodation** and **subsistence** must be calculated as follows

- travel on the basis of the costs actually incurred and in line with the beneficiary's usual practices on travel
- accommodation on the basis of the costs actually incurred and in line with the beneficiary's usual practices on travel

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[10] For the definition, see Commission Recommendation 2003/361/EC micro, small or medium-sized enterprise (SME) are enterprises
- engaged in an economic activity, irrespective of their legal form (including, in particular, self- employed persons and family businesses engaged in craft or other activities, and partnerships or associations regularly engaged in an economic activity) and
- employing fewer than 250 persons (expressed in 'annual working units' as defined in Article 5 of the Recommendation) and which have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million

- subsistence on the basis of the costs actually incurred and in line with the beneficiary's usual practices on travel

C.2 Equipment

Purchases of **equipment, infrastructure or other assets** used for the action must be declared as depreciation costs, calculated on the basis of the costs actually incurred and written off in accordance with international accounting standards and the beneficiary's usual accounting practices

Only the portion of the costs that corresponds to the rate of actual use for the action during the action duration can be taken into account

Costs for **renting or leasing** equipment, infrastructure or other assets are also eligible, if they do not exceed the depreciation costs of similar equipment, infrastructure or assets and do not include any financing fees

C.3 Other goods, works and services

Purchases of **other goods, works and services** must be calculated on the basis of the costs actually incurred

Such goods, works and services include, for instance, consumables and supplies, promotion, dissemination, protection of results, translations, publications, certificates and financial guarantees, if required under the Agreement

D. Other cost categories

D.1 Financial support to third parties

Not applicable

D.2 Internally invoiced goods and services

Costs for internally invoiced goods and services directly used for the action may be declared as unit cost according to usual cost accounting practices, if and as declared eligible in the call conditions, if they fulfil the general eligibility conditions for such unit costs and the amount per unit is calculated

- using the actual costs for the good or service recorded in the beneficiary's accounts, attributed either by direct measurement or on the basis of cost drivers, and excluding any cost which are ineligible or already included in other budget categories, the actual costs may be adjusted on the basis of budgeted or estimated elements, if they are relevant for calculating the costs, reasonable and correspond to objective and verifiable information

  and

- according to usual cost accounting practices which are applied in a consistent manner, based on objective criteria, regardless of the source of funding

'Internally invoiced goods and services' means goods or services which are provided within the beneficiary's organisation directly for the action and which the beneficiary values on the basis of its usual cost accounting practices

This cost will not be taken into account for the indirect cost flat-rate

D.5 PCP/PPI procurement costs

Not applicable

Indirect costs

E. Indirect costs

Indirect costs will be reimbursed at the flat-rate of 25% of the eligible direct costs (categories A-D, except volunteers costs, subcontracting costs, financial support to third parties and exempted specific cost categories, if any)

Contributions

Not applicable

6.3 Ineligible costs and contributions

The following costs or contributions are **ineligible**

(a) costs or contributions that do not comply with the conditions set out above (Article 6 1 and 6 2), in particular

(i) costs related to return on capital and dividends paid by a beneficiary

(ii) debt and debt service charges

(iii) provisions for future losses or debts

(iv) interest owed

(v) currency exchange losses

(vi) bank costs charged by the beneficiary's bank for transfers from the granting authority

(vii) excessive or reckless expenditure

(viii) deductible or refundable VAT (including VAT paid by public bodies acting as public authority)

(ix) costs incurred or contributions for activities implemented during grant agreement suspension (see Article 32)

(x) in-kind contributions by third parties Not applicable

(b) costs or contributions declared under other EU grants (or grants awarded by an EU Member State, non-EU country or other body implementing the EU budget), except for the following cases

(i) Synergy actions Not applicable

(ii) if the action grant is combined with an operating grant[11] running during the same period and the beneficiary can demonstrate that the operating grant does not cover any (direct or indirect) costs of the action grant

[11] For the definition, see Article 180(2)(b) EU Financial Regulation 2018/1046 '**operating grant**' means an EU grant to finance "the functioning of a body which has an objective forming part of and supporting an EU policy"

(c) costs or contributions for staff of a national (or regional/local) administration, for activities that are part of the administration's normal activities (i e not undertaken only because of the grant)

(d) costs or contributions (especially travel and subsistence) for staff or representatives of EU institutions, bodies or agencies

(e) other

(i) country restrictions for eligible costs Not applicable

(ii) costs or contributions declared specifically ineligible in the call conditions

6.4 Consequences of non-compliance

If a beneficiary declares costs or contributions that are ineligible, they will be rejected (see Article 27)

This may also lead to other measures described in Chapter 5

CHAPTER 4 GRANT IMPLEMENTATION

SECTION 1 CONSORTIUM: BENEFICIARIES, AFFILIATED ENTITIES AND OTHER PARTICIPANTS

ARTICLE 7 — BENEFICIARIES

The beneficiaries, as signatories of the Agreement, are fully responsible towards the granting authority for implementing it and for complying with all its obligations

They must implement the Agreement to their best abilities, in good faith and in accordance with all the obligations and terms and conditions it sets out

They must have the appropriate resources to implement the action and implement the action under their own responsibility and in accordance with Article 11 If they rely on affiliated entities or other participants (see Articles 8 and 9), they retain sole responsibility towards the granting authority and the other beneficiaries

They are jointly responsible for the *technical* implementation of the action If one of the beneficiaries fails to implement their part of the action, the other beneficiaries must ensure that this part is implemented by someone else (without being entitled to an increase of the maximum grant amount and subject to an amendment, see Article 39) The *financial* responsibility of each beneficiary in case of recoveries is governed by Article 22

The beneficiaries (and their action) must remain eligible under the EU programme funding the grant for the entire duration of the action Costs and contributions will be eligible only as long as the beneficiary and the action are eligible

The **internal roles and responsibilities** of the beneficiaries are divided as follows

(a) Each beneficiary must

(i) keep information stored in the Portal Participant Register up to date (see Article 19)

(ii) inform the granting authority (and the other beneficiaries) immediately of any events or circumstances likely to affect significantly or delay the implementation of the action (see Article 19)

(iii) submit to the coordinator in good time

- the prefinancing guarantees (if required, see Article 23)
- the financial statements and certificates on the financial statements (CFS) (if required, see Articles 21 and 24 2 and Data Sheet, Point 4 3)
- the contribution to the deliverables and technical reports (see Article 21)
- any other documents or information required by the granting authority under the Agreement

(iv) submit via the Portal data and information related to the participation of their affiliated entities

(b) The coordinator must

(i) monitor that the action is implemented properly (see Article 11)

(ii) act as the intermediary for all communications between the consortium and the granting authority, unless the Agreement or granting authority specifies otherwise, and in particular

- submit the prefinancing guarantees to the granting authority (if any)
- request and review any documents or information required and verify their quality and completeness before passing them on to the granting authority
- submit the deliverables and reports to the granting authority

The coordinator may not delegate or subcontract the above-mentioned tasks to any other beneficiary or third party (including affiliated entities)

However, coordinators which are public bodies may delegate the tasks set out in Point (b)(ii) last indent above to entities with 'authorisation to administer' which they have created or which are controlled by or affiliated to them In this case, the coordinator retains sole responsibility for compliance with the obligations under the Agreement

Moreover, coordinators which are 'sole beneficiaries'[12] (or similar, such as European research infrastructure consortia (ERICs)) may delegate the tasks set out in Point (b)(i) to (ii) above to one of their members The coordinator retains sole responsibility for compliance with the obligations under the Agreement

The beneficiaries must have **internal arrangements** regarding their operation and co-ordination, to ensure that the action is implemented properly

If required by the granting authority (see Data Sheet, Point 1), these arrangements must be set out in a written **consortium agreement** between the beneficiaries, covering for instance

- the internal organisation of the consortium
- the management of access to the Portal

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[12] For the definition, see Article 187(2) EU Financial Regulation 2018/1046 "Where several entities satisfy the criteria for being awarded a grant and together form one entity, that entity may be treated as the **sole beneficiary**, including where it is specifically established for the purpose of implementing the action financed by the grant "

- different distribution keys for the payments and financial responsibilities in case of recoveries (if any)
- additional rules on rights and obligations related to background and results (see Article 16)
- settlement of internal disputes
- liability, indemnification and confidentiality arrangements between the beneficiaries

The internal arrangements must not contain any provision contrary to this Agreement

ARTICLE 8 — AFFILIATED ENTITIES

Not applicable

ARTICLE 9 — OTHER PARTICIPANTS INVOLVED IN THE ACTION

9.1 Associated partners

The following entities which cooperate with a beneficiary will participate in the action as 'associated partners'

- BAE Systems Marine Ltd (BAE), PIC no 935453645, associated partner of Teknologisk Institut (DTI), Cesky Metrologicky Institut (CMI), Physikalisch-Technische Bundesanstalt (PTB), Slovenský Metrologický Ústav (SMU), Univerza v Ljubljani (UL), Teknologian tutkimuskeskus VTT Oy (VTT), Danmarks Tekniske Universitet (DTU), National Scientific Centre Institute of Metrology (NSC-IM), Otto-von-Guericke-Universitaet Magdeburg (OVGU), Babcock & Wilcox Vølund A/S (B&W Volund), Beamex Oy Ab (Beamex)

- CCPI Europe Ltd (CCPI), PIC no 937294220, associated partner of Teknologisk Institut (DTI), Cesky Metrologicky Institut (CMI), Physikalisch-Technische Bundesanstalt (PTB), Slovenský Metrologický Ústav (SMU), Univerza v Ljubljani (UL), Teknologian tutkimuskeskus VTT Oy (VTT), Danmarks Tekniske Universitet (DTU), National Scientific Centre Institute of Metrology (NSC-IM), Otto-von-Guericke-Universitaet Magdeburg (OVGU), Babcock & Wilcox Vølund A/S (B&W Volund), Beamex Oy Ab (Beamex)

- Metrosol Limited (Metrosol), PIC no 950225193, associated partner of Teknologisk Institut (DTI), Cesky Metrologicky Institut (CMI), Physikalisch-Technische Bundesanstalt (PTB), Slovenský Metrologický Ústav (SMU), Univerza v Ljubljani (UL), Teknologian tutkimuskeskus VTT Oy (VTT), Danmarks Tekniske Universitet (DTU), National Scientific Centre Institute of Metrology (NSC-IM), Otto-von-Guericke-Universitaet Magdeburg (OVGU), Babcock & Wilcox Vølund A/S (B&W Volund), Beamex Oy Ab (Beamex)

- NPL Management Limited (NPL), PIC no 999920330, associated partner of Teknologisk Institut (DTI), Cesky Metrologicky Institut (CMI), Physikalisch-Technische Bundesanstalt (PTB), Slovenský Metrologický Ústav (SMU), Univerza v Ljubljani (UL), Teknologian tutkimuskeskus VTT Oy (VTT), Danmarks Tekniske Universitet (DTU), National Scientific Centre Institute of Metrology (NSC-IM), Otto-von-Guericke-Universitaet Magdeburg (OVGU), Babcock & Wilcox Vølund A/S (B&W Volund), Beamex Oy Ab (Beamex)

- University of Strathclyde (STRATH), PIC no 999974068, associated partner of Teknologisk Institut (DTI), Cesky Metrologicky Institut (CMI), Physikalisch-Technische

Bundesanstalt (PTB), Slovenský Metrologický Ústav (SMU), Univerza v Ljubljani (UL), Teknologian tutkimuskeskus VTT Oy (VTT), Danmarks Tekniske Universitet (DTU), National Scientific Centre Institute of Metrology (NSC-IM), Otto-von-Guericke-Universitaet Magdeburg (OVGU), Babcock & Wilcox Vølund A/S (B&W Volund), Beamex Oy Ab (Beamex)

- The University of Manchester (UoM), PIC no 999903840, associated partner of Teknologisk Institut (DTI), Cesky Metrologicky Institut (CMI), Physikalisch-Technische Bundesanstalt (PTB), Slovenský Metrologický Ústav (SMU), Univerza v Ljubljani (UL), Teknologian tutkimuskeskus VTT Oy (VTT), Danmarks Tekniske Universitet (DTU), National Scientific Centre Institute of Metrology (NSC-IM), Otto-von-Guericke-Universitaet Magdeburg (OVGU), Babcock & Wilcox Vølund A/S (B&W Volund), Beamex Oy Ab (Beamex)

Associated partners must implement the action tasks attributed to them in Annex 1 in accordance with Article 11 They may not charge costs or contributions to the action and the costs for their tasks are not eligible

The tasks must be set out in Annex 1

The beneficiaries must ensure that their contractual obligations under Articles 11 (proper implementation), 12 (conflict of interests), 13 (confidentiality and security), 14 (ethics), 17 2 (visibility), 18 (specific rules for carrying out action), 19 (information) and 20 (record-keeping) also apply to the associated partners

The beneficiaries must ensure that the bodies mentioned in Article 25 (e g granting authority, OLAF, Court of Auditors (ECA), etc) can exercise their rights also towards the associated partners

9.2 Third parties giving in-kind contributions to the action

Other third parties may give in-kind contributions to the action (i e personnel, equipment, other goods, works and services, etc which are free-of-charge) if necessary for the implementation

Third parties giving in-kind contributions do not implement any action tasks They may not charge costs or contributions to the action, but the costs for the in-kind contributions are eligible and may be charged by the beneficiaries which use them, under the conditions set out in Article 6 The costs will be included in Annex 2 as part of the beneficiaries' costs

The third parties and their in-kind contributions should be set out in Annex 1

The beneficiaries must ensure that the bodies mentioned in Article 25 (e g granting authority, OLAF, Court of Auditors (ECA), etc) can exercise their rights also towards the third parties giving in-kind contributions

9.3 Subcontractors

Subcontractors may participate in the action, if necessary for the implementation

Subcontractors must implement their action tasks in accordance with Article 11 The costs for the subcontracted tasks (invoiced price from the subcontractor) are eligible and may be charged by the beneficiaries, under the conditions set out in Article 6 The costs will be included in Annex 2 as part of the beneficiaries' costs

The beneficiaries must ensure that their contractual obligations under Articles 11 (proper implementation), 12 (conflict of interest), 13 (confidentiality and security), 14 (ethics), 17 2 (visibility), 18 (specific rules for carrying out action), 19 (information) and 20 (record-keeping) also apply to the subcontractors

The beneficiaries must ensure that the bodies mentioned in Article 25 (e g granting authority, OLAF, Court of Auditors (ECA), etc) can exercise their rights also towards the subcontractors

9.4 Recipients of financial support to third parties

If the action includes providing financial support to third parties (e g grants, prizes or similar forms of support), the beneficiaries must ensure that their contractual obligations under Articles 12 (conflict of interest), 13 (confidentiality and security), 14 (ethics), 17 2 (visibility), 18 (specific rules for carrying out action), 19 (information) and 20 (record-keeping) also apply to the third parties receiving the support (recipients)

The beneficiaries must also ensure that the bodies mentioned in Article 25 (e g granting authority, OLAF, Court of Auditors (ECA), etc) can exercise their rights also towards the recipients

ARTICLE 10 — PARTICIPANTS WITH SPECIAL STATUS

10.1 Non-EU participants

Participants which are established in a non-EU country (if any) undertake to comply with their obligations under the Agreement and

- to respect general principles (including fundamental rights, values and ethical principles, environmental and labour standards, rules on classified information, intellectual property rights, visibility of funding and protection of personal data)
- for the submission of certificates under Article 24 to use qualified external auditors which are independent and comply with comparable standards as those set out in EU Directive 2006/43/EC[13]
- for the controls under Article 25 to allow for checks, reviews, audits and investigations (including on-the-spot checks, visits and inspections) by the bodies mentioned in that Article (e g granting authority, OLAF, Court of Auditors (ECA), etc)

Special rules on dispute settlement apply (see Data Sheet, Point 5)

10.2 Participants which are international organisations

Participants which are international organisations (IOs, if any) undertake to comply with their obligations under the Agreement and

- to respect general principles (including fundamental rights, values and ethical principles, environmental and labour standards, rules on classified information, intellectual property rights, visibility of funding and protection of personal data)
- for the submission of certificates under Article 24 to use either independent public officers or external auditors which comply with comparable standards as those set out in EU Directive 2006/43/EC
- for the controls under Article 25 to allow for the checks, reviews, audits and investigations by the bodies mentioned in that Article, taking into account the specific agreements concluded by them and the EU (if any)

For such participants, nothing in the Agreement will be interpreted as a waiver of their privileges or immunities, as accorded by their constituent documents or international law

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[13] Directive 2006/43/EC of the European Parliament and of the Council of 17 May 2006 on statutory audits of annual accounts and consolidated accounts or similar national regulations (OJ L 157, 9 6 2006, p 87)

Special rules on applicable law and dispute settlement apply (see Article 43 and Data Sheet, Point 5)

10.3 Pillar-assessed participants

Pillar-assessed participants (if any) may rely on their own systems, rules and procedures, in so far as they have been positively assessed and do not call into question the decision awarding the grant or breach the principle of equal treatment of applicants or beneficiaries

'Pillar-assessment' means a review by the European Commission on the systems, rules and procedures which participants use for managing EU grants (in particular internal control system, accounting system, external audits, financing of third parties, rules on recovery and exclusion, information on recipients and protection of personal data, see Article 154 EU Financial Regulation 2018/1046)

Participants with a positive pillar assessment may rely on their own systems, rules and procedures, in particular for

- record-keeping (Article 20) may be done in accordance with internal standards, rules and procedures
- currency conversion for financial statements (Article 21) may be done in accordance with usual accounting practices
- guarantees (Article 23) for public law bodies, prefinancing guarantees are not needed
- certificates (Article 24)
    - certificates on the financial statements (CFS) may be provided by their regular internal or external auditors and in accordance with their internal financial regulations and procedures
    - certificates on usual accounting practices (CoMUC) are not needed if those practices are covered by an ex-ante assessment

and use the following specific rules, for

- recoveries (Article 22) in case of financial support to third parties, there will be no recovery if the participant has done everything possible to retrieve the undue amounts from the third party receiving the support (including legal proceedings) and non-recovery is not due to an error or negligence on its part
- checks, reviews, audits and investigations by the EU (Article 25) will be conducted taking into account the rules and procedures specifically agreed between them and the framework agreement (if any)
- impact evaluation (Article 26) will be conducted in accordance with the participant's internal rules and procedures and the framework agreement (if any)
- grant agreement suspension (Article 31) certain costs incurred during grant suspension are eligible (notably, minimum costs necessary for a possible resumption of the action and costs relating to contracts which were entered into

before the pre-information letter was received and which could not reasonably be suspended, reallocated or terminated on legal grounds)

- grant agreement termination (Article 32) the final grant amount and final payment will be calculated taking into account also costs relating to contracts due for execution only after termination takes effect, if the contract was entered into before the pre-information letter was received and could not reasonably be terminated on legal grounds

- liability for damages (Article 33 2) the granting authority must be compensated for damage it sustains as a result of the implementation of the action or because the action was not implemented in full compliance with the Agreement only if the damage is due to an infringement of the participant's internal rules and procedures or due to a violation of third parties' rights by the participant or one of its employees or individual for whom the employees are responsible

Participants whose pillar assessment covers procurement and granting procedures may also do purchases, subcontracting and financial support to third parties (Article 6 2) in accordance with their internal rules and procedures for purchases, subcontracting and financial support

Participants whose pillar assessment covers data protection rules may rely on their internal standards, rules and procedures for data protection (Article 15)

The participants may however not rely on provisions which would breach the principle of equal treatment of applicants or beneficiaries or call into question the decision awarding the grant, such as in particular

- eligibility (Article 6)

- consortium roles and set-up (Articles 7-9)

- security and ethics (Articles 13, 14)

- IPR (including background and results, access rights and rights of use), communication, dissemination and visibility (Articles 16 and 17)

- information obligation (Article 19)

- payment, reporting and amendments (Articles 21, 22 and 39)

- rejections, reductions, suspensions and terminations (Articles 27, 28, 29-32)

If the pillar assessment was subject to remedial measures, reliance on the internal systems, rules and procedures is subject to compliance with those remedial measures

Participants whose assessment has not yet been updated to cover (the new rules on) data protection may rely on their internal systems, rules and procedures, provided that they ensure that personal data is

- processed lawfully, fairly and in a transparent manner in relation to the data subject

- collected for specified, explicit and legitimate purposes and not further processed in a manner that is incompatible with those purposes

- adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed
- accurate and, where necessary, kept up to date
- kept in a form which permits identification of data subjects for no longer than is necessary for the purposes for which the data is processed and
- processed in a manner that ensures appropriate security of the personal data

Participants must inform the coordinator without delay of any changes to the systems, rules and procedures that were part of the pillar assessment The coordinator must immediately inform the granting authority

Pillar-assessed participants that have also concluded a framework agreement with the EU, may moreover — under the same conditions as those above (i e not call into question the decision awarding the grant or breach the principle of equal treatment of applicants or beneficiaries) — rely on the provisions set out in that framework agreement

SECTION 2 RULES FOR CARRYING OUT THE ACTION

ARTICLE 11 — PROPER IMPLEMENTATION OF THE ACTION

11.1 Obligation to properly implement the action

The beneficiaries must implement the action as described in Annex 1 and in compliance with the provisions of the Agreement, the call conditions and all legal obligations under applicable EU, international and national law

11.2 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 28)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 12 — CONFLICT OF INTERESTS

12.1 Conflict of interests

The beneficiaries must take all measures to prevent any situation where the impartial and objective implementation of the Agreement could be compromised for reasons involving family, emotional life, political or national affinity, economic interest or any other direct or indirect interest ('conflict of interests')

They must formally notify the granting authority without delay of any situation constituting or likely to lead to a conflict of interests and immediately take all the necessary steps to rectify this situation

The granting authority may verify that the measures taken are appropriate and may require additional measures to be taken by a specified deadline

12.2 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 28) and the grant or the beneficiary may be terminated (see Article 32)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 13 — CONFIDENTIALITY AND SECURITY

13.1 Sensitive information

The parties must keep confidential any data, documents or other material (in any form) that is identified as sensitive in writing ('sensitive information') — during the implementation of the action and for at least until the time-limit set out in the Data Sheet (see Point 6)

If a beneficiary requests, the granting authority may agree to keep such information confidential for a longer period

Unless otherwise agreed between the parties, they may use sensitive information only to implement the Agreement

The beneficiaries may disclose sensitive information to their personnel or other participants involved in the action only if they

(a) need to know it in order to implement the Agreement and

(b) are bound by an obligation of confidentiality

The granting authority may disclose sensitive information to its staff and to other EU institutions and bodies

It may moreover disclose sensitive information to third parties, if

(a) this is necessary to implement the Agreement or safeguard the EU financial interests and

(b) the recipients of the information are bound by an obligation of confidentiality

The confidentiality obligations no longer apply if

(a) the disclosing party agrees to release the other party

(b) the information becomes publicly available, without breaching any confidentiality obligation

(c) the disclosure of the sensitive information is required by EU, international or national law

Specific confidentiality rules (if any) are set out in Annex 5

13.2 Classified information

The parties must handle classified information in accordance with the applicable EU, international or national law on classified information (in particular, Decision 2015/444[14] and its implementing rules)

Deliverables which contain classified information must be submitted according to special procedures agreed with the granting authority

Action tasks involving classified information may be subcontracted only after explicit approval (in writing) from the granting authority

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[14] Commission Decision 2015/444/EC, Euratom of 13 March 2015 on the security rules for protecting EU classified information (OJ L 72, 17 3 2015, p 53)

Classified information may not be disclosed to any third party (including participants involved in the action implementation) without prior explicit written approval from the granting authority

Specific security rules (if any) are set out in Annex 5

13.3 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 28)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 14 — ETHICS AND VALUES

14.1 Ethics

The action must be carried out in line with the highest ethical standards and the applicable EU, international and national law on ethical principles

Specific ethics rules (if any) are set out in Annex 5

14.2 Values

The beneficiaries must commit to and ensure the respect of basic EU values (such as respect for human dignity, freedom, democracy, equality, the rule of law and human rights, including the rights of minorities)

Specific rules on values (if any) are set out in Annex 5

14.3 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 28)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 15 — DATA PROTECTION

15.1 Data processing by the granting authority

Any personal data under the Agreement will be processed under the responsibility of the granting authority in accordance with the applicable data protection legislation, in particular Regulation 2016/679[15] and related national data protection acts and for the purposes set out in the Privacy Statement

15.2 Data processing by the beneficiaries

The beneficiaries must process personal data under the Agreement in compliance with the applicable EU, international and national law on data protection (in particular, Regulation 2016/679[16])

They must ensure that personal data is

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[15] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC ('GDPR') (OJ L 119, 4 5 2016, p 1)

[16] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC ('GDPR') (OJ L 119, 4 5 2016, p 1)

- processed lawfully, fairly and in a transparent manner in relation to the data subjects
- collected for specified, explicit and legitimate purposes and not further processed in a manner that is incompatible with those purposes
- adequate, relevant and limited to what is necessary in relation to the purposes for which they are processed
- accurate and, where necessary, kept up to date
- kept in a form which permits identification of data subjects for no longer than is necessary for the purposes for which the data is processed and
- processed in a manner that ensures appropriate security of the data

The beneficiaries may grant their personnel access to personal data only if it is strictly necessary for implementing, managing and monitoring the Agreement The beneficiaries must ensure that the personnel is under a confidentiality obligation

The beneficiaries must inform the persons whose data are transferred to the granting authority and provide them with a Privacy Statement

15.3 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 28)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 16 — INTELLECTUAL PROPERTY RIGHTS (IPR) — BACKGROUND AND RESULTS — ACCESS RIGHTS AND RIGHTS OF USE

16.1 Background and access rights to background

The beneficiaries must give each other and the other participants access to the background identified as needed for implementing the action, subject to any specific rules in Annex 5

'Background' means any data, know-how or information — whatever its form or nature (tangible or intangible), including any rights such as intellectual property rights — that is

(a) held by the beneficiaries before they acceded to the Agreement and

(b) needed to implement the action or exploit the results

If background is subject to rights of a third party, the beneficiary concerned must ensure that it is able to comply with its obligations under the Agreement

16.2 Ownership of results

The granting authority does not obtain ownership of the results produced under the action

'Results' means any tangible or intangible effect of the action, such as data, know-how or information, whatever its form or nature, whether or not it can be protected, as well as any rights attached to it, including intellectual property rights

16.3 Rights of use of the granting authority and European Commission on materials, documents and information received for policy, information, communication, dissemination and publicity purposes

The granting authority and the European Commission have the right to use non-sensitive information relating to the action and materials and documents received from the beneficiaries (notably summaries for publication, deliverables, as well as any other material, such as pictures or audio-visual material, in paper or electronic form) for policy, information, communication, dissemination and publicity purposes — during the action or afterwards

The right to use the beneficiaries' materials, documents and information is granted in the form of a royalty-free, non-exclusive and irrevocable licence, which includes the following rights

(a) **use for their own purposes** (in particular, making them available to persons working for them or any other Member State or EU service (including institutions, bodies, offices, agencies, etc) or institution or body from another Member State, copying or reproducing them in whole or in part, in unlimited numbers, and communication through press information services)

(b) **distribution to the public** (in particular, publication as hard copies and in electronic or digital format, publication on the internet, as a downloadable or non-downloadable file, broadcasting by any channel, public display or presentation, communicating through press information services, or inclusion in widely accessible databases or indexes)

(c) **editing or redrafting** (including shortening, summarising, inserting other elements (e g meta-data, legends, other graphic, visual, audio or text elements), extracting parts (e g audio or video files), dividing into parts, use in a compilation)

(d) **translation**

(e) **storage** in paper, electronic or other form

(f) **archiving**, in line with applicable document-management rules

(g) the right to authorise **third parties** to act on its behalf or sub-license to third parties the modes of use set out in Points (b), (c), (d) and (f), if needed for the information, communication and publicity activity of the granting authority and

(h) **processing**, analysing, aggregating the materials, documents and information received and **producing derivative works**

The rights of use are granted for the whole duration of the industrial or intellectual property rights concerned

If materials or documents are subject to moral rights or third party rights (including intellectual property rights or rights of natural persons on their image and voice), the beneficiaries must ensure that they comply with their obligations under this Agreement (in particular, by obtaining the necessary licences and authorisations from the rights holders concerned)

Where applicable, the [granting authority] [European Commission] will insert the following information

"© – [year] – [name of the copyright owner] All rights reserved Licensed to the [name of granting authority] [European Commission] under conditions "

16.4 Specific rules on IPR, results and background

Specific rules regarding intellectual property rights, results and background (if any) are set out in Annex 5

16.5 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 28).

Such a breach may also lead to other measures described in Chapter 5.

ARTICLE 17 — COMMUNICATION, DISSEMINATION AND VISIBILITY

17.1 Communication — Dissemination — Promoting the action

Unless otherwise agreed with the granting authority, the beneficiaries must promote the action and its results by providing targeted information to multiple audiences (including the media and the public), in accordance with Annex 1 and in a strategic, coherent and effective manner.

Before engaging in a communication or dissemination activity expected to have a major media impact, the beneficiaries must inform the granting authority.

17.2 Visibility — European flag and funding statement

Unless otherwise agreed with the granting authority, communication activities of the beneficiaries related to the action (including media relations, conferences, seminars, information material, such as brochures, leaflets, posters, presentations, etc., in electronic form, via traditional or social media, etc.), dissemination activities and any infrastructure, equipment, vehicles, supplies or major result funded by the grant must acknowledge EU support and display the European flag (emblem) and funding statement (translated into local languages, where appropriate):

Funded by the
European Union

Co-funded by the
European Union

Co-funded by the
European Union

Funded by the
European Union

The emblem must remain distinct and separate and cannot be modified by adding other visual marks, brands or text.

Apart from the emblem, no other visual identity or logo may be used to highlight the EU support

When displayed in association with other logos (e g of beneficiaries or sponsors), the emblem must be displayed at least as prominently and visibly as the other logos

For the purposes of their obligations under this Article, the beneficiaries may use the emblem without first obtaining approval from the granting authority or the European Commission This does not, however, give them the right to exclusive use Moreover, they may not appropriate the emblem or any similar trademark or logo, either by registration or by any other means

17.3 Quality of information — Disclaimer

Any communication or dissemination activity related to the action must use factually accurate information

Moreover, it must indicate the following disclaimer (translated into local languages where appropriate)

> "Funded by the European Union Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or [name of the granting authority] Neither the European Union nor the granting authority can be held responsible for them "

17.4 Specific communication, dissemination and visibility rules

Specific communication, dissemination and visibility rules (if any) are set out in Annex 5

17.5 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 28)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 18 — SPECIFIC RULES FOR CARRYING OUT THE ACTION

18.1 Specific rules for carrying out the action

Specific rules for implementing the action (if any) are set out in Annex 5

18.2 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 28)

Such a breach may also lead to other measures described in Chapter 5

SECTION 3 GRANT ADMINISTRATION

ARTICLE 19 — GENERAL INFORMATION OBLIGATIONS

19.1 Information requests

The beneficiaries must provide — during the action or afterwards and in accordance with Article 7 — any information requested in order to verify eligibility of the costs or contributions declared, proper implementation of the action and compliance with the other obligations under the Agreement

The information provided must be accurate, precise and complete and in the format requested, including electronic format

19.2 Participant data updates

The beneficiaries must provide — at all times, during the action or afterwards — their information up to date, in particular, their name, address, legal representatives, legal form and organisation type

19.3 **Information** about events and circumstances which impact the action

The beneficiaries must immediately inform the coordinator, which must immediately inform the granting authority (and the other beneficiaries) of any of the following

(a) **events** which are likely to affect or delay the implementation of the action or affect the EU's financial interests, in particular

  (i) changes in their legal, financial, technical, organisational or ownership situation (including changes linked to one of the exclusion grounds listed in the declaration of honour signed before grant signature)

  (ii) linked action information Not applicable

(b) **circumstances** affecting

  (i) the decision to award the grant or

  (ii) compliance with requirements under the Agreement

19.4 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 28)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 20 — RECORD-KEEPING

20.1 Keeping records and supporting documents

The beneficiaries must — at least until the time-limit set out in the Data Sheet (see Point 6) — keep records and other supporting documents to prove the proper implementation of the action in line with the accepted standards in the respective field (if any)

In addition, the beneficiaries must — for the same period — keep the following to justify the amounts declared

(a) for actual costs adequate records and supporting documents to prove the costs declared (such as contracts, subcontracts, invoices and accounting records), in addition, the beneficiaries' usual accounting and internal control procedures must enable direct reconciliation between the amounts declared, the amounts recorded in their accounts and the amounts stated in the supporting documents

(b) for flat-rate costs and contributions (if any) adequate records and supporting documents to prove the eligibility of the costs or contributions to which the flat-rate is applied

(c) for the following simplified costs and contributions the beneficiaries do not need to keep specific records on the actual costs incurred, but must keep

  (i) for unit costs and contributions (if any) adequate records and supporting documents to prove the number of units declared

(ii) for lump sum costs and contributions (if any) adequate records and supporting documents to prove proper implementation of the work as described in Annex 1

(iii) for financing not linked to costs (if any) adequate records and supporting documents to prove the achievement of the results or the fulfilment of the conditions as described in Annex 1

(d) for unit, flat-rate and lump sum costs and contributions according to usual cost accounting practices (if any) the beneficiaries must keep any adequate records and supporting documents to prove that their cost accounting practices have been applied in a consistent manner, based on objective criteria, regardless of the source of funding, and that they comply with the eligibility conditions set out in Articles 6 1 and 6 2

Moreover, the following is needed for specific budget categories

(e) for personnel costs time worked for the beneficiary under the action must be supported by declarations signed monthly by the person and their supervisor, unless another reliable time-record system is in place, the granting authority may accept alternative evidence supporting the time worked for the action declared, if it considers that it offers an adequate level of assurance

(f) additional record-keeping rules Not applicable

The records and supporting documents must be made available upon request (see Article 19) or in the context of checks, reviews, audits or investigations (see Article 25)

If there are on-going checks, reviews, audits, investigations, litigation or other pursuits of claims under the Agreement, the beneficiaries must keep these records and other supporting documentation until the end of these procedures

The beneficiaries must keep the original documents Digital and digitalised documents are considered originals if they are authorised by the applicable national law The granting authority may accept non-original documents if they offer a comparable level of assurance

20.2 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, costs or contributions insufficiently substantiated will be ineligible (see Article 6) and will be rejected (see Article 27), and the grant may be reduced (see Article 28)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 21 — REPORTING

21.1 Obligation to submit reports

The coordinator must submit the **deliverables** identified in Annex 1, in accordance with the timing and conditions set out in the Annex

The coordinator must submit to EURAMET (see Article 36) the technical and financial reports set out in this Article The financial reports must be drawn up using the forms and templates provided in Annex 4 and 6 These reports include the requests for payment The technical reports must be drawn up using the forms and templates provided by EURAMET

In addition, whenever necessary, EURAMET may request additional reports

21.2 Periodic reporting: Technical reports and financial statements

In addition, the beneficiaries must provide reports to request payments, in accordance with the schedule and modalities set out in the Data Sheet (see Point 4 2)

- for additional prefinancings (if any) an **additional prefinancing report**
- for interim payments (if any) and the final payment a **periodic report**

The prefinancing and periodic reports include a technical and financial part

The technical part includes an overview of the action implementation It must be prepared using the template provided by the granting authority

The financial part of the additional prefinancing report includes

- a statement on the use of the previous prefinancing payment (any request for additional pre-financing payment must be submitted only once 70% of the previous pre-financing payment has been used
- a description of the method for allocating the amount to be paid to each beneficiary (see Article 22(1))

The financial part of the periodic report includes

- the financial statements (individual and consolidated, for all beneficiaries/affiliated entities)
- the explanation on the use of resources (or detailed cost reporting table, if required)
- the certificates on the financial statements (CFS) (if required, see Article 24 2 and Data Sheet, Point 4 3)

The **financial statements** must detail the eligible costs and contributions for each budget category and, for the final payment, also the revenues for the action (see Articles 6 and 22)

All eligible costs and contributions incurred should be declared, even if they exceed the amounts indicated in the estimated budget (see Annex 2) Amounts that are not declared in the individual financial statements will not be taken into account by the granting authority

Beneficiaries will have to submit also the financial statements of their affiliated entities (if any) In case of recoveries (see Article 22), beneficiaries will be held responsible also for the financial statements of their affiliated entities

The coordinator must submit a periodic report within 60 days following the end of each reporting period

The **periodic report** must include the following

(a) a periodic technical report containing

(i) an explanation of the activities carried out by the beneficiaries and an overview of the progress towards the objectives of the action, including deliverables identified in Annex 1

This report must use the output and results indicators set out in Annex 1 and include explanations justifying the differences between the activities planned to be carried out and the expected outcomes in accordance with Annex 1 and those actually carried out or obtained

(ii) copies of the material and visuals used which have not been already forwarded to the granting authority

(b) a **periodic financial report** containing

(i) an individual financial statement (see Annex 4) from each beneficiary for the reporting period concerned

The individual financial statement must detail the eligible costs (actual costs, and flat-rate costs, see Article 6) for each budget category (see Annex 2)

The beneficiaries must declare all eligible costs, even if — for actual costs, and flat-rate costs — they exceed the amounts indicated in the estimated budget (see Annex 2) Amounts which are not declared in the individual financial statement will not be taken into account by the granting authority

If an individual financial statement is not submitted for a reporting period, it may be included in the periodic financial report for the next reporting period

Each beneficiary must certify that

- the information provided is full, reliable and true
- the costs declared are eligible (see Article 6)
- the costs can be substantiated by adequate records and supporting documentation (see Article 20) that will be produced upon request (see Article 19) or in the context of checks, audits and investigations (see Article 25) and
- for the last reporting period that all the receipts have been declared (see Article 22)

(ii) a periodic summary financial statement consolidating the individual financial statements for the reporting period concerned and including — except for the last reporting period — the **request for interim payment**

(iii) a certificate on the financial statements (drawn up in accordance with international audit standards and supported by the audit report and in accordance with Annex 6) for each beneficiary, if

- the maximum Metrology Partnership contribution indicated, for that beneficiary, in the estimated budget (see Annex 2) as reimbursement of eligible costs is EUR 430 000 or more

For the last reporting period, the coordinator must submit the periodic report and the final report within 60 days following the end of the last reporting period

The **final report** must include the following

(a) *a final technical report containing*

(i) an overview of the activities carried out and the achieved outcome of the action using, in particular, the impact indicators set out in Annex 1

(ii) a summary for publication

(b) a final financial report containing a final summary financial statement consolidating the individual financial statements for all reporting periods and including the request for payment of the balance

21.3 Currency for financial statements and conversion into euros

The financial statements must be drafted in euro

Beneficiaries with general accounts established in a currency other than the euro must convert the costs recorded in their accounts into euro, at the average of the daily exchange rates published in the C series of the *Official Journal of the European Union* (ECB website), calculated over the corresponding reporting period

If no daily euro exchange rate is published in the *Official Journal* for the currency in question, they must be converted at the average of the monthly accounting exchange rates published on the European Commission website (InforEuro), calculated over the corresponding reporting period

Beneficiaries with general accounts in euro must convert costs incurred in another currency into euro according to their usual accounting practices

21.4 Reporting language

The reporting must be in the language of the Agreement, unless otherwise agreed with the granting authority (see Data Sheet, Point 4 2)

21.5 Consequences of non-compliance

If a report submitted does not comply with this Article, the granting authority may suspend the payment deadline (see Article 29) and apply other measures described in Chapter 5

If the coordinator breaches its reporting obligations, the granting authority may terminate the grant or the coordinator's participation (see Article 32) or apply other measures described in Chapter 5

ARTICLE 22 — PAYMENTS AND RECOVERIES — CALCULATION OF AMOUNTS DUE

22.1 Payments and payment arrangements

Payments will be made in accordance with the schedule and modalities set out in the Data Sheet (see Point 4 2)

They will be made in euro to the bank account indicated by each beneficiary (restrictions may apply to distribution of the initial prefinancing payment, see Data Sheet, Point 4 2)

Payments to this bank account will discharge the granting authority from its payment obligation

The cost of payment transfers will be borne as follows

- the granting authority bears the cost of transfers charged by its bank
- the beneficiary bears the cost of transfers charged by its bank
- the party causing a repetition of a transfer bears all costs of the repeated transfer

Payments by the granting authority will be considered to have been carried out on the date when they are debited to its account

The amount due as [first] pre-financing payment will be allocated to each beneficiary according to its pro rata share of the estimated eligible costs as defined in the estimated budget breakdown indicated in Annex 2

The amount due as [second [and third] pre-financing payment][,]interim payment and payment of the balance will be allocated to each beneficiary according to the allocation method provided by the coordinator together with the request for payment Payments to the beneficiaries according to this method will discharge the granting authority from its payment obligation

22.2 Recoveries

Recoveries will be made, if — at beneficiary termination, final payment or afterwards — it turns out that the granting authority has paid too much and needs to recover the amounts undue

Each beneficiary's financial responsibility in case of recovery is in principle limited to their own debt and undue amounts of their affiliated entities

In case of enforced recoveries (see Article 22 4), affiliated entities will be held liable for repaying debts of their beneficiaries, if required by the granting authority (see Data Sheet, Point 4 4)

22.3 Amounts due

22.3.1 Prefinancing payments

The aim of the prefinancing is to provide the beneficiaries with a float

It remains the property of the granting authority until the final payment

For initial prefinancings (if any), the amount due, schedule and modalities are set out in the Data Sheet (see Point 4 2)

For **additional prefinancings** (if any), the amount due, schedule and modalities are also set out in the Data Sheet (see Point 4 2) However, if the statement on the use of the previous prefinancing payment shows that less than 70% was used, the amount set out in the Data Sheet will be reduced by the difference between the 70% threshold and the amount used

The contribution to the Mutual Insurance Mechanism will be retained from the prefinancing payments (at the rate and in accordance with the modalities set out in the Data Sheet, see Point 4 2) and transferred to the Mechanism

Prefinancing payments (or parts of them) may be offset (without the beneficiaries' consent) against amounts owed by a beneficiary to the granting authority — up to the amount due to that beneficiary

Payments will not be made if the payment deadline or payments are suspended (see Articles 29 and 30)

22.3.2 Amount due at beneficiary termination — Recovery

In case of beneficiary termination, the granting authority will determine the provisional amount due for the beneficiary concerned Payments (if any) will be made with the next interim or final payment

The **amount due** will be calculated in the following step

Step 1 — Calculation of the total accepted Metrology Partnership contribution

The granting authority will first calculate the 'accepted Metrology Partnership contribution' for the beneficiary for all reporting periods, by calculating the 'maximum Metrology Partnership contribution to costs' (applying the funding rate to the accepted costs of the beneficiary), taking into account requests for a lower contribution to costs and CFS threshold cappings (if any, see Article 24 5) and adding the contributions (accepted unit, flat-rate or lump sum contributions and financing not linked to costs, if any)

After that, the granting authority will take into account grant reductions (if any) The resulting amount is the 'total accepted Metrology Partnership contribution' for the beneficiary

The **balance** is then calculated by deducting the payments received (if any, see report on the distribution of payments in Article 32), from the total accepted Metrology Partnership contribution

{total accepted Metrology Partnership contribution for the beneficiary

minus

{prefinancing and interim payments received (if any)}}

If the balance is **positive**, the amount will be included in the next interim or final payment to the consortium

If the balance is **negative**, it will be **recovered** in accordance with the following procedure

The granting authority will send a **pre-information letter** to the beneficiary concerned

- formally notifying the intention to recover, the amount due, the amount to be recovered and the reasons why and
- requesting observations within 30 days of receiving notification

If no observations are submitted (or the granting authority decides to pursue recovery despite the observations it has received), it will confirm the amount to be recovered and ask this amount to be paid to the granting authority (**confirmation letter**)

If payment is not made to the granting authority by the date specified in the confirmation letter, the granting authority may call on the Mutual Insurance Mechanism to intervene, if continuation of the action is guaranteed and the conditions set out in the rules governing the Mechanism are met

In this case, it will send a **beneficiary recovery letter**, together with a **debit note** with the terms and date for payment

The debit note for the beneficiary will include the amount calculated for the affiliated entities which also had to end their participation (if any)

If payment is not made by the date specified in the debit note, the granting authority will **enforce recovery** in accordance with Article 22 4

The amounts will later on also be taken into account for the next interim or final payment

22.3.3 Interim payments

Interim payments reimburse the eligible costs and contributions claimed for the implementation of the action during the reporting periods (if any)

Interim payments (if any) will be made in accordance with the schedule and modalities set out the Data Sheet (see Point 4 2)

Payment is subject to the approval of the periodic report Its approval does not imply recognition of compliance, authenticity, completeness or correctness of its content

The **interim payment** will be calculated by the granting authority in the following steps

Step 1 — Calculation of the total accepted Metrology Partnership contribution

Step 2 — Limit to the interim payment ceiling

Step 1 — Calculation of the total accepted Metrology Partnership contribution

The granting authority will calculate the 'accepted Metrology Partnership contribution' for the action for the reporting period, by first calculating the 'maximum Metrology Partnership contribution to costs' (applying the funding rate to the accepted costs of each beneficiary), taking into account requests for a lower contribution to costs, and CFS threshold cappings (if any, see Article 24 5) and adding the contributions (accepted unit, flat-rate or lump sum contributions and financing not linked to costs, if any)

After that, the granting authority will take into account grant reductions from beneficiary termination (if any) The resulting amount is the 'total accepted Metrology Partnership contribution'

Step 2 — Limit to the interim payment ceiling

The resulting amount is then capped to ensure that the total amount of prefinancing and interim payments (if any) does not exceed the interim payment ceiling set out in the Data Sheet (see Point 4 2)

Interim payments (or parts of them) may be offset (without the beneficiaries' consent) against amounts owed by a beneficiary to the granting authority — up to the amount due to that beneficiary

Payments will not be made if the payment deadline or payments are suspended (see Articles 29 and 30)

22.3.4 Final payment — Final grant amount — Revenues and Profit — Recovery

The final payment (payment of the balance) reimburses the remaining part of the eligible costs and contributions claimed for the implementation of the action (if any)

The final payment will be made in accordance with the schedule and modalities set out in the Data Sheet (see Point 4 2)

Payment is subject to the approval of the final periodic report Its approval does not imply recognition of compliance, authenticity, completeness or correctness of its content

The **final grant amount for the action** will be calculated in the following steps

Step 1 — Calculation of the total accepted Metrology Partnership contribution

Step 2 — Limit to the maximum grant amount

Step 3 — Reduction due to the no-profit rule

Step 1 — Calculation of the total accepted Metrology Partnership contribution

The granting authority will first calculate the 'accepted Metrology Partnership contribution' for the action for all reporting periods, by calculating the 'maximum Metrology Partnership contribution to costs' (applying the funding rate to the total accepted costs of each beneficiary), taking into account requests for a lower contribution to costs, CFS threshold cappings (if any,

see Article 24 5) and adding the contributions (accepted unit, flat-rate or lump sum contributions and financing not linked to costs, if any)

After that, the granting authority will take into account grant reductions (if any) The resulting amount is the 'total accepted Metrology Partnership contribution'

Step 2 — Limit to the maximum grant amount

If the resulting amount is higher than the maximum grant amount set out in Article 5 2, it will be limited to the latter

Step 3 — Reduction due to the no-profit rule

If the no-profit rule is provided for in the Data Sheet (see Point 4 2), the grant must not produce a profit (i e surplus of the amount obtained following Step 2 plus the action's revenues, over the eligible costs and contributions approved by the granting authority)

'Revenue' is all income generated by the action, during its duration (see Article 4), for beneficiaries that are profit legal entities

If there is a profit, it will be deducted in proportion to the final rate of reimbursement of the eligible costs approved by the granting authority (as compared to the amount calculated following Steps 1 and 2 minus the contributions)

The **balance** (final payment) is then calculated by deducting the total amount of prefinancing and interim payments already made (if any), from the final grant amount

{final grant amount

minus

{prefinancing and interim payments made (if any)}}

If the balance is **positive**, it will be **paid** to the beneficiaries

The amount retained for the Mutual Insurance Mechanism (see above) will be released and **paid** to the beneficiaries (in accordance with the rules governing the Mechanism)

The final payment (or part of it) may be offset (without the beneficiaries' consent) against amounts owed by a beneficiary to the granting authority — up to the amount due to that beneficiary

Payments will not be made if the payment deadline or payments are suspended (see Articles 29 and 30)

If— despite the release of the Mutual Insurance Mechanism contribution — the balance is **negative**, it will be **recovered** in accordance with the following procedure

The granting authority will send a **pre-information letter** to the coordinator

- formally notifying the intention to recover, the final grant amount, the amount to be recovered and the reasons why
- invite the coordinator to submit observations on behalf of all beneficiaries within 30 days of receiving notification

If no observations are submitted (or the granting authority decides to pursue recovery despite the observations it has received) it will calculate the **share of the debt per beneficiary**, by

(a) identifying the beneficiaries for which the amount calculated as follows is negative

{{{total accepted Metrology Partnership contribution for the beneficiary

divided by

total accepted Metrology Partnership contribution for the action}

multiplied by

final grant amount for the action**}**,

minus

{prefinancing and interim payments received by the beneficiary (if any)}**}**

and

(b) dividing the debt

{{amount calculated according to point (a) for the beneficiary concerned

divided by

the sum of the amounts calculated according to point (a) for all the beneficiaries identified according to point (a)}

multiplied by

the amount to be recovered}

and confirm the amount to be recovered from each beneficiary concerned (**confirmation letter**), together with **debit notes** with the terms and date for payment

The debit notes for beneficiaries will include the amounts calculated for their affiliated entities (if any)

If payment is not made by the date specified in the debit note, the granting authority will **enforce recovery** in accordance with Article 22 4

22.3.5 Audit implementation after final payment — Revised final grant amount — Recovery

If — after the final payment (in particular, after checks, reviews, audits or investigations, see Article 25) — the granting authority rejects costs or contributions (see Article 27) or reduces the grant (see Article 28), it will calculate the **revised final grant amount** for the beneficiary concerned

The **beneficiary revised final grant amount** will be calculated in the following step

Step 1 — Calculation of the revised total accepted Metrology Partnership contribution

The granting authority will first calculate the 'revised accepted Metrology Partnership contribution' for the beneficiary, by calculating the 'revised accepted costs' and 'revised accepted contributions'

After that, it will take into account grant reductions (if any) The resulting 'revised total accepted Metrology Partnership contribution' is the beneficiary revised final grant amount

If the revised final grant amount is lower than the beneficiary's final grant amount (i e its share in the final grant amount for the action), it will be **recovered** in accordance with the following procedure

The **beneficiary final grant amount** (i e share in the final grant amount for the action) is calculated as follows

{{{total accepted Metrology Partnership contribution for the beneficiary

divided by

total accepted Metrology Partnership contribution for the action}

multiplied by

final grant amount for the action}

The granting authority will send a **pre-information letter** to the beneficiary concerned

- formally notifying the intention to recover, the amount to be recovered and the reasons why and
- requesting observations within 30 days of receiving notification

If no observations are submitted (or the granting authority decides to pursue recovery despite the observations it has received), it will confirm the amount to be recovered (**confirmation letter**), together with a **debit note** with the terms and the date for payment

Recoveries against affiliated entities (if any) will be handled through their beneficiaries

If payment is not made by the date specified in the debit note, the granting authority will **enforce recovery** in accordance with Article 22 4

22.4 Enforced recovery

If payment is not made by the date specified in the debit note, the amount due will be recovered

(a) by offsetting the amount — without the coordinator or beneficiary's consent — against any amounts owed to the coordinator or beneficiary by the granting authority

In exceptional circumstances, to safeguard the EU financial interests, the amount may be offset before the payment date specified in the debit note

(b) financial guarantee(s) Not applicable

(c) joint and several liability of beneficiaries Not applicable

(d) by holding affiliated entities jointly and severally liable (if any, see Data Sheet, Point 4 4) or

(e) by taking legal action (see Article 43)

If the Mutual Insurance Mechanism was called on by the granting authority to intervene, recovery will be continued in the name of the Mutual Insurance Mechanism If two debit notes were sent, the second one (in the name of the Mutual Insurance Mechanism) will be considered to replace the first one (in the name of the granting authority) Where the MIM intervened, offsetting, enforceable decisions or any other of the above-mentioned forms of enforced recovery may be used mutatis mutandis

The amount to be recovered will be increased by **late-payment interest** at the rate set out in Article 22 5, from the day following the payment date in the debit note, up to and including the date the full payment is received

Partial payments will be first credited against expenses, charges and late-payment interest and then against the principal

Bank charges incurred in the recovery process will be borne by the beneficiary, unless Directive 2015/2366[17] applies

22.5 Consequences of non-compliance

22.5.1 If the granting authority does not pay within the payment deadlines (see above), the beneficiaries are entitled to **late-payment interest** at the reference rate applied by the European Central Bank (ECB) for its main refinancing operations in euros, plus the percentage specified in the Data Sheet (Point 4 2) The ECB reference rate to be used is the rate in force on the first day of the month in which the payment deadline expires, as published in the C series of the *Official Journal of the European Union*

If the late-payment interest is lower than or equal to EUR 200, it will be paid to the beneficiaries only on request submitted within two months of receiving the late payment

If payments or the payment deadline are suspended (see Articles 29 and 30), payment will not be considered as late

Late-payment interest covers the period running from the day following the due date for payment (see above), up to and including the date of payment

Late-payment interest is not considered for the purposes of calculating the final grant amount

22.5.2 If a beneficiary breaches any of its obligations under this Article, the grant may be reduced (see Article 29) and the grant or the beneficiary may be terminated (see Article 32)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 23 — GUARANTEES

Not applicable

ARTICLE 24 — CERTIFICATES

24.1 Operational verification report (OVR)

Not applicable

24.2 Certificate on the financial statements (CFS)

If required by the granting authority (see Data Sheet, Point 4 3), the beneficiaries must provide certificates on their financial statements (CFS), in accordance with the schedule, threshold and conditions set out in the Data Sheet

The coordinator must submit them as part of the periodic report (see Article 21)

The certificates must be drawn up using the template published on the Portal, cover the costs declared on the basis of actual costs and costs according to usual cost accounting practices (if any), and fulfil the following conditions

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[17] Directive (EU) 2015/2366 of the European Parliament and of the Council of 25 November 2015 on payment services in the internal market, amending Directives 2002/65/EC, 2009/110/EC and 2013/36/EU and Regulation (EU) No 1093/2010, and repealing Directive 2007/64/EC (OJ L 337, 23 12 2015, p 35)

(a) be provided by a qualified approved external auditor which is independent and complies with Directive 2006/43/EC (or for public bodies by a competent independent public officer)

(b) the verification must be carried out according to the highest professional standards to ensure that the financial statements comply with the provisions under the Agreement and that the costs declared are eligible

The certificates will not affect the granting authority's right to carry out its own checks, reviews or audits, nor preclude the European Court of Auditors (ECA), the European Public Prosecutor's Office (EPPO) or the European Anti-Fraud Office (OLAF) from using their prerogatives for audits and investigations under the Agreement (see Article 25)

If the costs (or a part of them) were already audited by the granting authority, these costs do not need to be covered by the certificate and will not be counted for calculating the threshold (if any)

24.3 Certificate on the compliance of usual cost accounting practices (CoMUC)

Not applicable

24.4 Systems and process audit (SPA)

Beneficiaries which

- use unit, flat rate or lump sum costs or contributions according to documented (i e formally approved and in writing) usual costs accounting practices (if any) or
- have formalised documentation on the systems and processes for calculating their costs and contributions (i e formally approved and in writing), have participated in at least 150 actions under Horizon 2020 or the Euratom Research and Training Programme (2014-2018 or 2019-2020) and participate in at least 3 ongoing actions under Horizon Europe or the Euratom Research and Training Programme (2021-2025 or 2026-2027)

may apply to the granting authority for a systems and process audit (SPA)

This audit will be carried out as follows

Step 1 — Application by the beneficiary

Step 2 — If the application is accepted, the granting authority will carry out the systems and process audit, complemented by an audit of transactions (on a sample of the beneficiary's Horizon Europe or Euratom Research and Training Programme financial statements)

Step 3 — The audit result will take the form of a risk assessment classification for the beneficiary low, medium or high

Low-risk beneficiaries will benefit from less (or less in-depth) ex-post audits (see Article 25) and a higher threshold for submitting certificates on the financial statements (CFS, see Articles 21 and 24 2 and Data Sheet, Point 4 3)

24.5 Consequences of non-compliance

If a beneficiary does not submit a certificate on the financial statements (CFS) or the certificate is rejected, the accepted Metrology Partnership contribution to costs will be capped to reflect the CFS threshold

If a beneficiary breaches any of its other obligations under this Article, the granting authority may apply the measures described in Chapter 5

ARTICLE 25 — CHECKS, REVIEWS, AUDITS AND INVESTIGATIONS — EXTENSION OF FINDINGS

25.1 Granting authority checks, reviews and audits

25.1.1 Internal checks

The granting authority may — during the action or afterwards — check the proper implementation of the action and compliance with the obligations under the Agreement, including assessing costs and contributions, deliverables and reports

25.1.2 Project reviews

The granting authority may carry out reviews on the proper implementation of the action and compliance with the obligations under the Agreement (general project reviews or specific issues reviews)

Such project reviews may be started during the implementation of the action and until the time-limit set out in the Data Sheet (see Point 6) They will be formally notified to the coordinator or beneficiary concerned and will be considered to start on the date of the notification

If needed, the granting authority may be assisted by independent, outside experts If it uses outside experts, the coordinator or beneficiary concerned will be informed and have the right to object on grounds of commercial confidentiality or conflict of interest

The coordinator or beneficiary concerned must cooperate diligently and provide — within the deadline requested — any information and data in addition to deliverables and reports already submitted (including information on the use of resources) The granting authority may request beneficiaries to provide such information to it directly Sensitive information and documents will be treated in accordance with Article 13

The coordinator or beneficiary concerned may be requested to participate in meetings, including with the outside experts

For **on-the-spot** visits, the beneficiary concerned must allow access to sites and premises (including to the outside experts) and must ensure that information requested is readily available

Information provided must be accurate, precise and complete and in the format requested, including electronic format

On the basis of the review findings, a **project review report** will be drawn up

The granting authority will formally notify the project review report to the coordinator or beneficiary concerned, which has 30 days from receiving notification to make observations

Project reviews (including project review reports) will be in the language of the Agreement

25.1.3 Audits

The granting authority may carry out audits on the proper implementation of the action and compliance with the obligations under the Agreement

Such audits may be started during the implementation of the action and until the time-limit set out in the Data Sheet (see Point 6) They will be formally notified to the beneficiary concerned and will be considered to start on the date of the notification

The granting authority may use its own audit service, delegate audits to a centralised service or use external audit firms If it uses an external firm, the beneficiary concerned will be informed and have the right to object on grounds of commercial confidentiality or conflict of interest

The beneficiary concerned must cooperate diligently and provide — within the deadline requested — any information (including complete accounts, individual salary statements or other personal data) to verify compliance with the Agreement Sensitive information and documents will be treated in accordance with Article 13

For **on-the-spot** visits, the beneficiary concerned must allow access to sites and premises (including for the external audit firm) and must ensure that information requested is readily available

Information provided must be accurate, precise and complete and in the format requested, including electronic format

On the basis of the audit findings, a **draft audit report** will be drawn up

The auditors will formally notify the draft audit report to the beneficiary concerned, which has 30 days from receiving notification to make observations (contradictory audit procedure)

The **final audit report** will take into account observations by the beneficiary concerned and will be formally notified to them

Audits (including audit reports) will be in the language of the Agreement

25.2 European Commission checks, reviews and audits in grants of other granting authorities

The European Commission has the same rights of checks, reviews and audits as the granting authority

25.3 Access to records for assessing simplified forms of funding

The beneficiaries must give the European Commission access to their statutory records for the periodic assessment of simplified forms of funding which are used in EU programmes

25.4 OLAF, EPPO and ECA audits and investigations

The following bodies may also carry out checks, reviews, audits and investigations — during the action or afterwards

- the European Anti-Fraud Office (OLAF) under Regulations No 883/2013[18] and No 2185/96[19]
- the European Public Prosecutor's Office (EPPO) under Regulation 2017/1939
- the European Court of Auditors (ECA) under Article 287 of the Treaty on the Functioning of the EU (TFEU) and Article 257 of EU Financial Regulation 2018/1046

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[18] Regulation (EU, Euratom) No 883/2013 of the European Parliament and of the Council of 11 September 2013 concerning investigations conducted by the European Anti-Fraud Office (OLAF) and repealing Regulation (EC) No 1073/1999 of the European Parliament and of the Council and Council Regulation (Euratom) No 1074/1999 (OJ L 248, 18/09/2013, p 1)

[19] Council Regulation (Euratom, EC) No 2185/1996 of 11 November 1996 concerning on-the-spot checks and inspections carried out by the Commission in order to protect the European Communities' financial interests against fraud and other irregularities (OJ L 292, 15/11/1996, p 2)

If requested by these bodies, the beneficiary concerned must provide full, accurate and complete information in the format requested (including complete accounts, individual salary statements or other personal data, including in electronic format) and allow access to sites and premises for on-the-spot visits or inspections — as provided for under these Regulations

To this end, the beneficiary concerned must keep all relevant information relating to the action, at least until the time-limit set out in the Data Sheet (Point 6) and, in any case, until any ongoing checks, reviews, audits, investigations, litigation or other pursuits of claims have been concluded

25.5 Consequences of checks, reviews, audits and investigations — Extension of findings

25.5.1 Consequences of checks, reviews, audits and investigations in this grant

Findings in checks, reviews, audits or investigations carried out in the context of this grant may lead to rejections (see Article 27), grant reduction (see Article 28) or other measures described in Chapter 5

Rejections or grant reductions after the final payment will lead to a revised final grant amount (see Article 22)

Findings in checks, reviews, audits or investigations during the action implementation may lead to a request for amendment (see Article 39), to change the description of the action set out in Annex 1

Moreover, findings arising from an OLAF or EPPO investigation may lead to criminal prosecution under national law

25.5.2 Extension from other grants

Not applicable

25.6 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, costs or contributions insufficiently substantiated will be ineligible (see Article 6) and will be rejected (see Article 27), and the grant may be reduced (see Article 28)

Such breaches may also lead to other measures described in Chapter 5

ARTICLE 26 — IMPACT EVALUATIONS

26.1 Impact evaluation

The granting authority or the European Commission may carry out impact evaluations of the action, measured against the objectives and indicators of the Metrology Partnership

Such evaluations may be started during implementation of the action and until the time-limit set out in the Data Sheet (see Point 6) They will be formally notified to the coordinator or beneficiaries and will be considered to start on the date of the notification

If needed, the granting authority or the European Commission may be assisted by independent outside experts

The coordinator or beneficiaries must provide any information relevant to evaluate the impact of the action, including information in electronic format

26.2 Consequences of non-compliance

If a beneficiary breaches any of its obligations under this Article, the granting authority may apply the measures described in Chapter 5

CHAPTER 5 CONSEQUENCES OF NON-COMPLIANCE

SECTION 1 REJECTIONS AND GRANT REDUCTION

ARTICLE 27 — REJECTION OF COSTS AND CONTRIBUTIONS

27.1 Conditions

The granting authority will — at beneficiary termination interim payment, final payment or afterwards — reject any costs or contributions which are ineligible (see Article 6), in particular following checks, reviews, audits or investigations (see Article 25)

The rejection may also be based on the extension of findings from other grants to this grant (see Article 25)

Ineligible costs or contributions will be rejected

27.2 Procedure

If the rejection does not lead to a recovery, the granting authority will formally notify the coordinator or beneficiary concerned of the rejection, the amounts and the reasons why The coordinator or beneficiary concerned may — within 30 days of receiving notification — submit observations if it disagrees with the rejection (payment review procedure)

If the rejection leads to a recovery, the granting authority will follow the contradictory procedure with pre-information letter set out in Article 22

27.3 Effects

If the granting authority rejects costs or contributions, it will deduct them from the costs or contributions declared and then calculate the amount due (and, if needed, make a recovery, see Article 22)

ARTICLE 28 — GRANT REDUCTION

28.1 Conditions

The granting authority may — at beneficiary termination, final payment or afterwards — reduce the grant for a beneficiary, if

(a) the beneficiary (or a person having powers of representation, decision-making or control, or person essential for the award/implementation of the grant) has committed

(i) substantial errors, irregularities or fraud or

(ii) serious breach of obligations under this Agreement or during its award (including improper implementation of the action, non-compliance with the call conditions, submission of false information, failure to provide required information, breach of ethics or security rules (if applicable), etc), or

(b) extension of findings Not applicable

The amount of the reduction will be calculated for each beneficiary concerned and proportionate to the seriousness and the duration of the errors, irregularities or fraud or breach

of obligations, by applying an individual reduction rate to their accepted Metrology Partnership contribution

28.2 Procedure

If the grant reduction does not lead to a recovery, the granting authority will formally notify the coordinator or beneficiary concerned of the reduction, the amount to be reduced and the reasons why The coordinator or beneficiary concerned may — within 30 days of receiving notification — submit observations if it disagrees with the reduction (payment review procedure)

If the grant reduction leads to a recovery, the granting authority will follow the contradictory procedure with pre-information letter set out in Article 22

28.3 Effects

If the granting authority reduces the grant, it will deduct the reduction and then calculate the amount due (and, if needed, make a recovery, see Article 22)

SECTION 2 SUSPENSION AND TERMINATION

ARTICLE 29 — PAYMENT DEADLINE SUSPENSION

29.1 Conditions

The granting authority may — at any moment — suspend the payment deadline if a payment cannot be processed because

(a) the required report (see Article 21) has not been submitted or is not complete or additional information is needed

(b) there are doubts about the amount to be paid (e g queries about eligibility, need for a grant reduction, etc) and additional checks, reviews, audits or investigations are necessary, or

(c) there are other issues affecting the EU financial interests

29.2 Procedure

The granting authority will formally notify the coordinator of the suspension and the reasons why

The suspension will **take effect** the day the notification is sent

If the conditions for suspending the payment deadline are no longer met, the suspension will be **lifted** — and the remaining time to pay (see Data Sheet, Point 4 2) will resume

If the suspension exceeds two months, the coordinator may request the granting authority to confirm if the suspension will continue

If the payment deadline has been suspended due to the non-compliance of the report and the revised report is not submitted (or was submitted but is also rejected), the granting authority may also terminate the grant or the participation of the coordinator (see Article 32)

ARTICLE 30 — PAYMENT SUSPENSION

30.1 Conditions

The granting authority may — at any moment — suspend payments, in whole or in part for one or more beneficiaries, if

(a) a beneficiary (or a person having powers of representation, decision-making or control, or person essential for the award/implementation of the grant) has committed or is suspected of having committed

(i) substantial errors, irregularities or fraud or

(ii) serious breach of obligations under this Agreement or during its award (including improper implementation of the action, non-compliance with the call conditions, submission of false information, failure to provide required information, breach of ethics or security rules (if applicable), etc), or

(b) extension of findings Not applicable

If payments are suspended for one or more beneficiaries, the granting authority will make partial payment(s) for the part(s) not suspended If suspension concerns the final payment, the payment (or recovery) of the remaining amount after suspension is lifted will be considered to be the payment that closes the action

30.2 Procedure

Before suspending payments, the granting authority will send a **pre-information letter** to the beneficiary concerned

- formally notifying the intention to suspend payments and the reasons why and
- requesting observations within 30 days of receiving notification

If the granting authority does not receive observations or decides to pursue the procedure despite the observations it has received, it will confirm the suspension (**confirmation letter**) Otherwise, it will formally notify that the procedure is discontinued

At the end of the suspension procedure, the granting authority will also inform the coordinator

The suspension will **take effect** the day after the confirmation notification is sent

If the conditions for resuming payments are met, the suspension will be **lifted** The granting authority will formally notify the beneficiary concerned (and the coordinator) and set the suspension end date

During the suspension, no prefinancing will be paid to the beneficiaries concerned For interim payments, the periodic reports for all reporting periods except the last one (see Article 21) must not contain any financial statements from the beneficiary concerned (or its affiliated entities) The coordinator must include them in the next periodic report after the suspension is lifted or — if suspension is not lifted before the end of the action — in the last periodic report

ARTICLE 31 — GRANT AGREEMENT SUSPENSION

31.1 Beneficiaries-requested Grant Agreement suspension

31.1.1 Conditions and procedure

The beneficiaries may request the suspension of the grant or any part of it, if exceptional circumstances — in particular *force majeure* (see Article 35) — make implementation impossible or excessively difficult

The coordinator must submit a request for **amendment** (see Article 39), with

- the reasons why

- the date the suspension takes effect, this date may be before the date of the submission of the amendment request and

- the expected date of resumption

The suspension will **take effect** on the day specified in the amendment

Once circumstances allow for implementation to resume, the coordinator must immediately request another **amendment** of the Agreement to set the suspension end date, the resumption date (one day after suspension end date), extend the duration and make other changes necessary to adapt the action to the new situation (see Article 39) — unless the grant has been terminated (see Article 32) The suspension will be **lifted** with effect from the suspension end date set out in the amendment This date may be before the date of the submission of the amendment request

During the suspension, no prefinancing will be paid Costs incurred or contributions for activities implemented during grant suspension are not eligible (see Article 6 3)

31.2 Granting authority-initiated Grant Agreement suspension

31.2.1 Conditions

The granting authority may suspend the grant or any part of it, if

(a) a beneficiary (or a person having powers of representation, decision-making or control, or person essential for the award/implementation of the grant) has committed or is suspected of having committed

  (i) substantial errors, irregularities or fraud or

  (ii) serious breach of obligations under this Agreement or during its award (including improper implementation of the action, non-compliance with the call conditions, submission of false information, failure to provide required information, breach of ethics or security rules (if applicable), etc), or

(b) extension of findings Not applicable

(c) other

  (i) linked action issues Not applicable

  (ii) additional GA suspension grounds

    - the action has lost its scientific or technological relevance

    - for Horizon Europe Missions the action has lost its relevance as part of the Portfolio for which it has been initially selected

31.2.2 Procedure

Before suspending the grant, the granting authority will send a **pre-information letter** to the coordinator

- formally notifying the intention to suspend the grant and the reasons why and

- requesting observations within 30 days of receiving notification

If the granting authority does not receive observations or decides to pursue the procedure despite the observations it has received, it will confirm the suspension (**confirmation letter**) Otherwise, it will formally notify that the procedure is discontinued

The suspension will **take effect** the day after the confirmation notification is sent (or on a later date specified in the notification)

Once the conditions for resuming implementation of the action are met, the granting authority will formally notify the coordinator a **lifting of suspension letter**, in which it will set the suspension end date and invite the coordinator to request an amendment of the Agreement to set the resumption date (one day after suspension end date), extend the duration and make other changes necessary to adapt the action to the new situation (see Article 39) — unless the grant has been terminated (see Article 32) The suspension will be **lifted** with effect from the suspension end date set out in the lifting of suspension letter This date may be before the date on which the letter is sent

During the suspension, no prefinancing will be paid Costs incurred or contributions for activities implemented during suspension are not eligible (see Article 6 3)

The beneficiaries may not claim damages due to suspension by the granting authority (see Article 33)

Grant suspension does not affect the granting authority's right to terminate the grant or a beneficiary (see Article 32) or reduce the grant (see Article 28)

ARTICLE 32 — GRANT AGREEMENT OR BENEFICIARY TERMINATION

32.1 Beneficiary-requested Grant Agreement termination

32.1.1 Conditions and procedure

The beneficiaries may request the termination of the grant

The coordinator must submit a request for **amendment** (see Article 39), with

- the reasons why
- the date the consortium ends work on the action ('end of work date') and
- the date the termination takes effect ('termination date'), this date must be after the date of the submission of the amendment request

The termination will **take effect** on the termination date specified in the amendment

If no reasons are given or if the granting authority considers the reasons do not justify termination, it may consider the grant terminated improperly

32.1.2 Effects

The coordinator must — within 60 days from when termination takes effect — submit a **periodic report** (for the open reporting period until termination)

The granting authority will calculate the final grant amount and final payment on the basis of the report submitted and taking into account the costs incurred and contributions for activities implemented before the end of work date (see Article 22) Costs relating to contracts due for execution only after the end of work are not eligible

If the granting authority does not receive the report within the deadline, only costs and contributions which are included in an approved periodic report will be taken into account (no costs/contributions if no periodic report was ever approved)

Improper termination may lead to a grant reduction (see Article 28)

After termination, the beneficiaries' obligations (in particular Articles 13 (confidentiality and security), 16 (IPR), 17 (communication, dissemination and visibility), 21 (reporting), 25 (checks, reviews, audits and investigations), 26 (impact evaluation), 27 (rejections), 28 (grant reduction) and 42 (assignment of claims)) continue to apply

32.2 Beneficiary-requested beneficiary termination

32.2.1 Conditions and procedure

The coordinator may request the termination of the participation of one or more beneficiaries, on request of the beneficiary concerned or on behalf of the other beneficiaries

The coordinator must submit a request for **amendment** (see Article 39), with

- the reasons why
- the opinion of the beneficiary concerned (or proof that this opinion has been requested in writing)
- the date the beneficiary ends work on the action ('end of work date')
- the date the termination takes effect ('termination date'), this date must be after the date of the submission of the amendment request

If the termination concerns the coordinator and is done without its agreement, the amendment request must be submitted by another beneficiary (acting on behalf of the consortium)

The termination will **take effect** on the termination date specified in the amendment

If no information is given or if the granting authority considers that the reasons do not justify termination, it may consider the beneficiary to have been terminated improperly

32.2.2 Effects

The coordinator must — within 60 days from when termination takes effect — submit

(i) a **termination report** from the beneficiary concerned, for the open reporting period until termination, containing an overview of the progress of the work, the financial statement, the explanation on the use of resources, and, if applicable, the certificate on the financial statement (CFS, see Articles 21 and 24 2 and Data Sheet, Point 4 3)

(ii) a second **request for amendment** (see Article 39) with other amendments needed (e g reallocation of the tasks and the estimated budget of the terminated beneficiary, addition of a new beneficiary to replace the terminated beneficiary, change of coordinator, etc)

The granting authority will calculate the amount due to the beneficiary on the basis of the report submitted and taking into account the costs incurred and contributions for activities implemented before the end of work date (see Article 22) Costs relating to contracts due for execution only after the end of work are not eligible

The information in the termination report must also be included in the periodic report for the next reporting period (see Article 21)

If the granting authority does not receive the termination report within the deadline, only costs and contributions which are included in an approved periodic report will be taken into account (no costs/contributions if no periodic report was ever approved)

If the second request for amendment is accepted by the granting authority, the Agreement is **amended** to introduce the necessary changes (see Article 39)

If the second request for amendment is rejected by the granting authority (because it calls into question the decision awarding the grant or breaches the principle of equal treatment of applicants), the grant may be terminated (see Article 32)

Improper termination may lead to a reduction of the grant (see Article 31) or grant termination (see Article 32)

After termination, the concerned beneficiary's obligations (in particular Articles 13 (confidentiality and security), 16 (IPR), 17 (communication, dissemination and visibility), 21 (reporting), 25 (checks, reviews, audits and investigations), 26 (impact evaluation), 27 (rejections), 28 (grant reduction) and 42 (assignment of claims)) continue to apply

32.3 Granting authority-initiated Grant Agreement or beneficiary termination

32.3.1 Conditions

The granting authority may terminate the grant or the participation of one or more beneficiaries, if

(a) one or more beneficiaries do not accede to the Agreement (see Article 40)

(b) a change to the action or the legal, financial, technical, organisational or ownership situation of a beneficiary is likely to substantially affect the implementation of the action or calls into question the decision to award the grant (including changes linked to one of the exclusion grounds listed in the declaration of honour)

(c) following termination of one or more beneficiaries, the necessary changes to the Agreement (and their impact on the action) would call into question the decision awarding the grant or breach the principle of equal treatment of applicants

(d) implementation of the action has become impossible or the changes necessary for its continuation would call into question the decision awarding the grant or breach the principle of equal treatment of applicants

(e) a beneficiary (or person with unlimited liability for its debts) is subject to bankruptcy proceedings or similar (including insolvency, winding-up, administration by a liquidator or court, arrangement with creditors, suspension of business activities, etc)

(f) a beneficiary (or person with unlimited liability for its debts) is in breach of social security or tax obligations

(g) a beneficiary (or person having powers of representation, decision-making or control, or person essential for the award/implementation of the grant) has been found guilty of grave professional misconduct

(h) a beneficiary (or person having powers of representation, decision-making or control, or person essential for the award/implementation of the grant) has committed fraud, corruption, or is involved in a criminal organisation, money laundering, terrorism-related crimes (including terrorism financing), child labour or human trafficking

(i) a beneficiary (or person having powers of representation, decision-making or control, or person essential for the award/implementation of the grant) was created under a different jurisdiction with the intent to circumvent fiscal, social or other legal obligations in the country of origin (or created another entity with this purpose)

(j) a beneficiary (or person having powers of representation, decision-making or control, or person essential for the award/implementation of the grant) has committed

(i) substantial errors, irregularities or fraud or

(ii) serious breach of obligations under this Agreement or during its award (including improper implementation of the action, non-compliance with the call conditions, submission of false information, failure to provide required information, breach of ethics or security rules (if applicable), etc)

(k) extension of findings Not applicable

(l) despite a specific request by the granting authority, a beneficiary does not request an amendment to the Agreement to end the participation of one of its affiliated entities or associated partners that is in one of the situations under points (d), (f), (e), (g), (h), (i) or (j) and to reallocate its tasks, or

(m) other

(i) linked action issues Not applicable

(ii) additional GA termination grounds

- the action has lost its scientific or technological relevance
- for Horizon Europe Missions the action has lost its relevance as part of the Portfolio for which it has been initially selected

32.3.2 Procedure

Before terminating the grant or participation of one or more beneficiaries, the granting authority will send **a pre-information letter** to the coordinator or beneficiary concerned

- formally notifying the intention to terminate and the reasons why and
- requesting observations within 30 days of receiving notification

If the granting authority does not receive observations or decides to pursue the procedure despite the observations it has received, it will confirm the termination and the date it will take effect (**confirmation letter**) Otherwise, it will formally notify that the procedure is discontinued

For beneficiary terminations, the granting authority will — at the end of the procedure — also inform the coordinator

The termination will **take effect** the day after the confirmation notification is sent (or on a later date specified in the notification, 'termination date')

32.3.3 Effects

(a) for **Grant Agreement termination**

The coordinator must — within 60 days from when termination takes effect — submit a **periodic report** (for the last open reporting period until termination)

The granting authority will calculate the final grant amount and final payment on the basis of the report submitted and taking into account the costs incurred and contributions for activities implemented before termination takes effect (see Article 22) *Costs relating to contracts due for execution only after termination are not eligible*

If the grant is terminated for breach of the obligation to submit reports, the coordinator may not submit any report after termination

If the granting authority does not receive the report within the deadline, only costs and contributions which are included in an approved periodic report will be taken into account (no costs/contributions if no periodic report was ever approved)

Termination does not affect the granting authority's right to reduce the grant (see Article 28)

The beneficiaries may not claim damages due to termination by the granting authority (see Article 33)

After termination, the beneficiaries' obligations (in particular Articles 13 (confidentiality and security), 16 (IPR), 17 (communication, dissemination and visibility), 21 (reporting), 25 (checks, reviews, audits and investigations), 26 (impact evaluation), 27 (rejections), 28 (grant reduction) and 42 (assignment of claims)) continue to apply

(b) for **beneficiary termination**

The coordinator must — within 60 days from when termination takes effect — submit

(i) a **termination report** from the beneficiary concerned, for the open reporting period until termination, containing an overview of the progress of the work, the financial statement, the explanation on the use of resources, and, if applicable, the certificate on the financial statement (CFS, see Articles 21 and 24 2 and Data Sheet, Point 4 3)

(ii) a **request for amendment** (see Article 39) with any amendments needed (e g reallocation of the tasks and the estimated budget of the terminated beneficiary, addition of a new beneficiary to replace the terminated beneficiary, change of coordinator, etc)

The granting authority will calculate the amount due to the beneficiary on the basis of the report submitted and taking into account the costs incurred and contributions for activities implemented before termination takes effect (see Article 22) Costs relating to contracts due for execution only after termination are not eligible

The information in the termination report must also be included in the periodic report for the next reporting period (see Article 21)

If the granting authority does not receive the termination report within the deadline, only costs and contributions included in an approved periodic report will be taken into account (no costs/contributions if no periodic report was ever approved)

If the request for amendment is accepted by the granting authority, the Agreement is **amended** to introduce the necessary changes (see Article 39)

If the request for amendment is rejected by the granting authority (because it calls into question the decision awarding the grant or breaches the principle of equal treatment of applicants), the grant may be terminated (see Article 32)

After termination, the concerned beneficiary's obligations (in particular Articles 13 (confidentiality and security), 16 (IPR), 17 (communication, dissemination and visibility), 21 (reporting), 25 (checks, reviews, audits and investigations), 26 (impact evaluation), 27 (rejections), 28 (grant reduction) and 42 (assignment of claims)) continue to apply

SECTION 3 OTHER CONSEQUENCES: DAMAGES AND ADMINISTRATIVE SANCTIONS

ARTICLE 33 — DAMAGES

33.1 Liability of the granting authority

The granting authority cannot be held liable for any damage caused to the beneficiaries or to third parties as a consequence of the implementation of the Agreement, including for gross negligence

The granting authority cannot be held liable for any damage caused by any of the beneficiaries or other participants involved in the action, as a consequence of the implementation of the Agreement

33.2 Liability of the beneficiaries

The beneficiaries must compensate the granting authority for any damage it sustains as a result of the implementation of the action or because the action was not implemented in full compliance with the Agreement, provided that it was caused by gross negligence or wilful act

The liability does not extend to indirect or consequential losses or similar damage (such as loss of profit, loss of revenue or loss of contracts), provided such damage was not caused by wilful act or by a breach of confidentiality

ARTICLE 34 — ADMINISTRATIVE SANCTIONS AND OTHER MEASURES

Not applicable

SECTION 4 FORCE MAJEURE

ARTICLE 35 — FORCE MAJEURE

A party prevented by force majeure from fulfilling its obligations under the Agreement cannot be considered in breach of them

'Force majeure' means any situation or event that

- prevents either party from fulfilling their obligations under the Agreement,
- was unforeseeable, exceptional situation and beyond the parties' control,
- was not due to error or negligence on their part (or on the part of other participants involved in the action), and
- proves to be inevitable in spite of exercising all due diligence

Any situation constituting force majeure must be formally notified to the other party without delay, stating the nature, likely duration and foreseeable effects

The parties must immediately take all the necessary steps to limit any damage due to force majeure and do their best to resume implementation of the action as soon as possible

CHAPTER 6 FINAL PROVISIONS

ARTICLE 36 — COMMUNICATION BETWEEN THE PARTIES

36.1 Forms and means of communication

Communication under the Agreement (information, requests, submissions, 'formal notifications', etc.) must:

- be made in writing,
- clearly identify the Agreement (project number and acronym) and
- be using the forms and templates when provided.

Except for formal notifications, the parties should recourse to communications using electronic means.

Formal notifications must be made by registered post with proof of delivery ('formal notification on paper').

However, formal notifications may be sent electronically if the applicable national law in the Member State concerned allows it, notably with proof of delivery.

36.2 Date of communication

Communications are considered to have been made when they are sent by the sending party (i.e. on the date and time they are sent).

Formal notifications on paper sent by registered post with proof of delivery are considered to have been made on either:

- the delivery date registered by the postal service or
- the deadline for collection at the post office.

36.3 Addresses for communication

Formal notifications on paper addressed **to the granting authority** must be sent to the following address:

EURAMET European Partnership on Metrology - Management Support Unit (MSU)
Hampton Road, Teddington
Middlesex, TW11 0LW
United Kingdom

Email: part.msu@euramet.org

Formal notifications on paper addressed **to the beneficiaries** must be sent to their legal address.

ARTICLE 37 — INTERPRETATION OF THE AGREEMENT

The provisions in the Data Sheet take precedence over the rest of the Terms and Conditions of the Agreement.

Annex 5 takes precedence over the Terms and Conditions; the Terms and Conditions take precedence over the Annexes other than Annex 5.

Annex 2 takes precedence over Annex 1.

ARTICLE 38 — CALCULATION OF PERIODS AND DEADLINES

In accordance with Regulation No 1182/71[20], periods expressed in days, months or years are calculated from the moment the triggering event occurs

The day during which that event occurs is not considered as falling within the period

'Days' means calendar days, not working days

ARTICLE 39 — AMENDMENTS

39.1 Conditions

The Agreement may be amended, unless the amendment entails changes to the Agreement which would call into question the decision awarding the grant or breach the principle of equal treatment of applicants

Amendments may be requested by any of the parties

39.2 Procedure

The party requesting an amendment must submit a request for amendment (see Article 36)

The coordinator submits and receives requests for amendment on behalf of the beneficiaries (see Annex 3) If a change of coordinator is requested without its agreement, the submission must be done by another beneficiary (acting on behalf of the other beneficiaries)

The request for amendment must include

- the reasons why
- the appropriate supporting documents and
- for a change of coordinator without its agreement the opinion of the coordinator (or proof that this opinion has been requested in writing)

The granting authority may request additional information

If the party receiving the request agrees, it must sign the amendment within 45 days of receiving notification (or any additional information the granting authority has requested) If it does not agree, it must formally notify its disagreement within the same deadline The deadline may be extended, if necessary for the assessment of the request If no notification is received within the deadline, the request is considered to have been rejected

An amendment **enters into force** on the day of the signature of the receiving party

An amendment **takes effect** on the date of entry into force or other date specified in the amendment

ARTICLE 40 — ACCESSION AND ADDITION OF NEW BENEFICIARIES

40.1 Accession of the beneficiaries mentioned in the Preamble

The beneficiaries which are not coordinator must accede to the grant by signing the accession form (see Annex 3), within 30 days after the entry into force of the Agreement (see Article 44)

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[20] Regulation (EEC, Euratom) No 1182/71 of the Council of 3 June 1971 determining the rules applicable to periods, dates and time-limits (OJ L 124, 8/6/1971, p 1)

They will assume the rights and obligations under the Agreement with effect from the date of its entry into force (see Article 44)

If a beneficiary does not accede to the grant within the above deadline, the coordinator must — within 30 days — request an amendment (see Article 39) to terminate the beneficiary and make any changes necessary to ensure proper implementation of the action This does not affect the granting authority's right to terminate the grant (see Article 32)

40.2 Addition of new beneficiaries

In justified cases, the beneficiaries may request the addition of a new beneficiary

For this purpose, the coordinator must submit a request for amendment in accordance with Article 39 It must include an accession form (see Annex 3) signed by the new beneficiary

New beneficiaries will assume the rights and obligations under the Agreement with effect from the date of their accession specified in the accession form (see Annex 3)

Additions are also possible in mono-beneficiary grants

ARTICLE 41 — TRANSFER OF THE AGREEMENT

In justified cases, the beneficiary of a mono-beneficiary grant may request the transfer of the grant to a new beneficiary, provided that this would not call into question the decision awarding the grant or breach the principle of equal treatment of applicants

The beneficiary must submit a request for **amendment** (see Article 39), with

- the reasons why
- the accession form (see Annex 3) signed by the new beneficiary and
- additional supporting documents (if required by the granting authority)

The new beneficiary will assume the rights and obligations under the Agreement with effect from the date of accession specified in the accession form (see Annex 3)

ARTICLE 42 — ASSIGNMENTS OF CLAIMS FOR PAYMENT AGAINST THE GRANTING AUTHORITY

The beneficiaries may not assign any of their claims for payment against the granting authority to any third party, except if expressly approved in writing by the granting authority on the basis of a reasoned, written request by the coordinator (on behalf of the beneficiary concerned)

If the granting authority has not accepted the assignment or if the terms of it are not observed, the assignment will have no effect on it

In no circumstances will an assignment release the beneficiaries from their obligations towards the granting authority

ARTICLE 43 — APPLICABLE LAW AND SETTLEMENT OF DISPUTES

43.1 Applicable law

The Agreement is governed by the applicable EU law, supplemented if necessary by the national law of the Member State of the granting authority

Special rules may apply for beneficiaries which are international organisations or the Joint Research Centre (JRC) (if any, see Data Sheet, Point 5)

43.2 Dispute settlement

If a dispute concerns the interpretation, application or validity of the Agreement, the parties must bring action before the competent court of the Member State of the granting authority

For beneficiaries with arbitration as special dispute settlement forum (if any, see Data Sheet, Point 5), the dispute will — in the absence of an amicable settlement — be settled in accordance with the Rules for Arbitration published on the Funding and Tenders Portal

ARTICLE 44 — ENTRY INTO FORCE

The Agreement will enter into force on the day of signature by the granting authority or the coordinator, depending on which is later

SIGNATURES:

For the **coordinator**

Name of authorised representative

Function of authorised representative

Signature of authorised representative

Date

For the **granting authority**

Maguelonne Chambon
Name of authorised representative

Partnership Chair
Function of authorised representative

Signature of authorised representative

Date

Done in English

Annex I – JRP protocol

Version Date: 21 May 2024

23IND11 ThermoSI

Thermometry with embedded SI traceability for industrial applications

Start date. 01 September 2024

Duration. 36 months

Coordinator
Henrik Kjeldsen
DTI

Glossary

AI	Artificial Intelligence
AMS	Aerospace Material Specification
ASCII	American Standard Code for Information Interchange
arXiv	Open-access repository of electronic preprints and postprints
ASME	American Society of Mechanical Engineers
BIPM	International Bureau of Weights and Measures
BS	British Standard
CC 0	Creative Commons copyright waiver to enable free distribution in the public domain without restriction
CC BY	As per CC 0, but with a requirement to give attribution to the creator
CCT	Consultative Committee for Thermometry
CIPM	International Committee for Weights and Measures
CMC	Calibration and Measurement Capability
CMINT	CMI Johnson noise thermometer
CSV	Comma Separated Variables
DART	Dual-mode auto-calibrating resistance thermometer (the PTB Johnson noise thermometer)
DCE	Dissemination, communication and exploitation (plan)
DI	Designated Institute
DMP	Data Management Plan
DOI	Digital Object Identifier
EC	European Commission
EMAF	Emissivity Measurement in Air Facility (PTB)
EMC	Electromagnetic Compatibility
EMN	European Measurement Network
EMPIR	European Metrology Programme for Innovation and Research
EMRP	European Metrology Research Programme
EN	European Norm (i e European Standard)
engrXiv	Open-access preprint repository for engineering
EPM	European Partnership on Metrology
EU	European Union
FAIR	Findability, accessibility, interoperability, and reusability
FEM	Finite Element Modelling
FET	Field Effect Transistor
FOV	Field of View
FTIR	Fourier Transform Infrared
GUM	Guide to the Expression of Uncertainty in Measurement
IEC	International Electrotechnical Commission
IJNT	Industrial Johnson noise thermometer (the Metrosol Johnson noise thermometer)
InstMC	Institute of Measurement and Control
IoP	Institute of Physics
IoT	Internet of Things
IP	Intellectual Property
IPR	Intellectual Property Rights
IR	Infrared
ISAT	Instrument Science and Technology Committee (a committee of the Institute of Physics)
ISO	International Organisation for Standardization
ITS-90	International Temperature Scale of 1990
JAWS	Josephson arbitrary waveform synthesiser
JNT	Johnson noise thermometer
JPEG	Joint Photographic Experts Group, a compressed digital image file format
JRP	Joint Research Proposal
MeP-K	*Mise en pratique* for the definition of the kelvin in the SI
Nadcap	National Aerospace and Defense Contractors Accreditation Program
NMI	National Metrology Institute
NO_x	Nitrogen oxides, a group of gases mainly formed during the combustion of fossil fuels
ORE	Open Research Europe
PC	Personal computer
PRN	Pseudo-random noise
SAE	SAE International, a global professional association and engineering standards organisation
SI	International System of Units

SME	Small and medium-sized enterprises
SNCR	Selective non-catalytic reduction
STD	Portable standard flame
TC-T	Technical committee for thermometry
TDLAS	Tunable diode laser absorption spectroscopy
TG	Task Group
UKAS	United Kingdom Accreditation Service
UkrNDNC	Ukrainian Research and Training Center for Standardization, Certification and Quality Problems
ULNT	University of Ljubljana Johnson noise thermometer
WG	Working Group
WtE	Waste-to-Energy

Contents

Section A: Key data

A1 Project data summary

Coordinator contact details:

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Address.	DTI, Kongsvang Allé 29, DK-8000 Aarhus C , Denmark
Phone	+45 7220 2909
Email·	hkje@teknologisk dk

Participant details:

no.	Participant Type	Short Name	Organisation legal full name	Country
1	Internal Beneficiary	DTI	Teknologisk Institut	Denmark
2	Internal Beneficiary	CMI	Cesky Metrologicky Institut	Czechia
3	Internal Beneficiary	PTB	Physikalisch-Technische Bundesanstalt	Germany
4	Internal Beneficiary	SMU	Slovensky Metrologický Ústav	Slovakia
5	Internal Beneficiary	UL	Univerza v Ljubljani	Slovenia
6	Internal Beneficiary	VTT	Teknologian tutkimuskeskus VTT Oy	Finland
7	External Beneficiary	DTU	Danmarks Tekniske Universitet	Denmark
8	External Beneficiary	NSC-IM	National Scientific Centre Institute of Metrology	Ukraine
9	External Beneficiary	OVGU	Otto-von-Guericke-Universitaet Magdeburg	Germany
10	Unfunded Beneficiary	B&W Volund	Babcock & Wilcox Vølund A/S	Denmark
11	Unfunded Beneficiary	Beamex	Beamex Oy Ab	Finland
12	Associated Partner - linked to all beneficiaries	BAE	BAE Systems Marine Ltd	United Kingdom
13	Associated Partner - linked to all beneficiaries	CCPI	CCPI Europe Ltd	United Kingdom
14	Associated Partner - linked to all beneficiaries	Metrosol	Metrosol Limited	United Kingdom
15	Associated Partner - linked to all beneficiaries	NPL	NPL Management Limited	United Kingdom
16	Associated Partner - linked to all beneficiaries	STRATH	University of Strathclyde	United Kingdom
17	Associated Partner - linked to all beneficiaries	UoM	The University of Manchester	United Kingdom

A2 Financial summary

	Internal Beneficiaries	External Beneficiaries	Unfunded Beneficiaries	Associated Partners	Total	Total Eligible
Labour (€)	798 283 00	176 757 00	35 000 00	566 295 00	1 576 335 00	1 010 040 00
Subcontracts (€)						
T&S (€)	68 600 00	19 203 00	12 000 00	55 320 00	155 123 00	99 803 00
Equipment (€)			30 060 00		30 060 00	30 060 00
Other Goods, Works, and Services (€)	78 495 00	24 040 00	5 000 00	76 591 00	184 126 00	107 535 00
Internally Invoiced Goods and Services (€)	20 777 00			39 000 00	59 777 00	20 777 00
Financial support to 3rd parties (N/A) (€)						
Indirect (€)	236 344 50	55 000 00	20 515 00	174 551 50	486 411 00	311 859 50
Total costs (€)	1 202 499 50	275 000 00	102 575 00	911 757 50	2 491 832 00	1 580 074 50
Costs as % of Total costs	76 %	17 %	6 %	58 %		
Total Eligible Costs (€)	1 202 499 50	275 000 00	102 575 00		1 580 074 50	1 580 074 50
EU contribution (€)	**1 202 499 50**	**275 000.00**			**1 580 074.50**	**1 477 499 50**
EU contribution as % of total EU contribution	81 %	19 %	0 %	0 %		
Months	107 1	25 2	3 9	77 1	213 3	213 3

A3 Work packages summary

WP No	Work Package Title	Active Participants (WP leader in bold)	Months
WP1	Traceable, quantitative thermal imaging from -100 °C to 500 °C	**PTB**, DTI, CMI, SMU, VTT, Beamex, NPL, STRATH	28 8
WP2	Improving the technology readiness of practical Johnson noise thermometry	**PTB**, CMI, UL, Metrosol, NPL, STRATH, UoM	70 0
WP3	Thermographic phosphor thermometry up to 1250 °C	**NPL**, DTI, PTB, VTT, DTU, OVGU, Beamex, BAE, STRATH	32 9
WP4	Artificial Intelligence to facilitate improved thermometry	**DTU**, PTB, VTT, UL, NPL, NSC-IM, B&W Volund, Beamex, CCPI, STRATH, DTI	45 3
WP5	Creating impact	**STRATH**, all participants	17 0
WP6	Management and coordination	**DTI**, all participants	19 3
		Total months	**213.3**

The information in tables A2 and A3 reflect the estimates of resources as of the start of project in September 2024 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

Most industrial processes rely on temperature measurement, which directly influences product quality, energy efficiency, and emissions All conventional temperature sensors exhibit calibration drift leading to inefficiencies Poor surface thermometry causes process control problems in advanced manufacturing Poor gas thermometry causes sub-optimal noxious emissions and reduced efficiency This project will overcome specific process control challenges by implementing embedded traceable thermometry *in-situ* through driftless practical primary thermometry and self-validation, gas/combustion thermometry, and new traceable surface temperature measurement methods Traceability will be either directly to the redefined SI kelvin, or indirectly via the International Temperature Scale of 1990 (ITS-90)

Need

Advanced manufacturing is considered by the EU to be at the heart of its industrial strategy (E Westkamper Towards the Re-Industrialization of Europe - A Concept for Manufacturing for 2030, Springer-Verlag 2014) and new techniques are important for European growth and sustainability (EC COM(2017) 479) Adoption of advanced manufacturing technologies (EC COM(2014) 14), as well as improved energy efficiency (the price differential between Europe and other regions is increasing) and measurement traceability, is key to achieving that Maintaining leadership in energy efficiency is crucial in a time of growing competition for resources

The need for improved in-process temperature measurement is demonstrated by a) industries, being Funded or Unfunded Beneficiaries or Associated Partners, identifying their key issues, and b) the requirement to address temperature sensor calibration drift and surface temperature measurement, which were identified as key needs for Advanced Manufacturing in the Draft Strategic Research Agenda published by the European Metrology Network (EMN) for Advanced Manufacturing

Reliable, traceable surface temperature measurement with thermal imaging is notoriously difficult It requires knowledge of the surface emissivity and any reflected thermal radiation, including knowledge of the geometry of the scene Contact probes are even worse There is a need for a completely new approach which can provide a reliable, non-perturbative measurement of the surface temperature in the field of view

Long-term reliable temperature measurement and control is required to make autonomous production/Industry 4 0 a reality However, in the harsh measurement environments encountered in industry (e g high temperature), sensor materials degrade, and they drift out of calibration There is a need for practical primary thermometers that measure thermodynamic temperature irrespective of any damage to the sensor

Traditional techniques for surface temperature measurement such as thermal imaging are seriously compromised due to the unknown emissivity of the surface and reflected and background thermal radiation For welding, forming, forging and additive manufacturing, surface temperature measurement is not sufficiently accurate Phosphor thermometry offers a solution but robust coatings, new phosphor formulations and higher temperature operation (up to 1250 °C) are needed

Self-validating thermometers which make use of an *in-situ* reference temperature are of growing interest for autonomous in-process recalibration but require manual intervention, automation requires recognition of characteristic features in temperature-time data which is beyond conventional software techniques, and artificial intelligence (AI) solutions are needed Spectroscopic infrared gas thermometry for industrial hot gas (e g combustion) processes also relies on AI to retrieve the temperature but this needs improving to reduce the temperature measurement uncertainty to ± 2 %

These all reflect the need to introduce traceability to the SI in process

Objectives

The overall aim of the project is to enhance advanced manufacturing processes by improving temperature measurement and control capability The specific objectives of the project are

1 To develop techniques for truly traceable, quantitative thermal imaging, by using at least 4 key engineering materials and selected thermographic phosphors with known temperature in the field of view of the thermal imager in the range of -100 °C to 500 °C with an uncertainty of less than 5 °C This will include characterisation (e g , spectral, angular, and hemispherical emissivity) of the surface or of the phosphor itself and in-situ correction for camera non-uniformity

2 To improve practical Johnson noise thermometry with a technology readiness level (TRL) of 6, and an uncertainty of less than 3 °C, and to provide truly driftless thermometry for harsh environments

(e g , nuclear power generation and decommissioning) In particular, to develop a robust probe assembly for measuring Johnson noise and demonstrate its performance in harsh environments (e g , high temperatures up to 1200 °C, ionising radiation (gamma rays and neutrons), electromagnetic fields)

3 To develop robust thermographic phosphor techniques for surface temperature measurement with an uncertainty of less than 3 °C and up to temperatures of 1250 °C in collaboration with metals processing organisations and end-users (e g , marine manufacturing), to progress towards the goal of zero carbon production in e g , steel processing, and more generally improved energy efficiency of heavy industry

4 To develop artificial intelligence (e g , machine learning) approaches to enable traceable *in-situ* temperature measurement for industrial applications with an uncertainty less than 2 % up to 1500 °C, demonstrated through at least three case studies (e g , i) machine learning for autonomous operation of self-validating thermometers, ii) spectroscopic infrared thermometry for in-situ gas temperature and gas temperature profile measurements and iii) reference surface temperature calibration insert)

5 To facilitate the take-up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e g , sensor manufacturers), standards developing organisations (e g , IEC) and e end users (metals processing organisations, nuclear power industry, space industry, etc) and via the EMN for Advanced Manufacturing

Progress beyond the state of the art and results

Significant progress in this collaborative research was made in the two EMPIR projects 14IND04 EMPRESS and 17IND04 EMPRESS 2, particularly in developing working prototypes of several novel thermometers including the phosphor thermometer, self-validating thermocouples, a portable standard flame, and combustion temperature diagnostic techniques

Thermal imaging (objective 1)

Reliable, traceable surface temperature measurement is notoriously difficult Currently industry uses contact surface probes which are prone to very large uncertainties (difficult to mitigate or quantify), or thermal imaging which requires knowledge of the surface emissivity and any reflected thermal radiation, including knowledge of the geometry of the scene, to give meaningful temperature measurements This objective focuses on enabling quantitative thermal imaging via deployment of known temperature artefacts based on thermographic phosphors in the field of view

Johnson noise thermometry (objective 2)

A practical primary thermometer measures a property (e g , speed of sound in a gas, or Johnson noise voltage) which can be related to the sensor temperature without the need for calibration, and in some cases e g , Johnson noise thermometry, all the sensor properties that change in harsh environments can be measured, ensuring the temperature is always determined absolutely Practical Johnson noise thermometer prototypes work in benign environments but need developing for harsh environments, here the aim is to make robust practical primary thermometers, using graphene and other constructions, within the time frame of the project and this represents a disruptive development in industrial thermometry

Phosphor thermometry to 1250 °C (objective 3)

Phosphor thermometry can be used for monitoring the surface temperature of parts undergoing forming, forging, welding or heat treatment but it is only reliable to 750 °C with intermittent use to 1000 °C The consortium participants, bringing complementary expertise, will go beyond the state of the art by enabling development and validation of phosphor thermometry techniques and instruments up to 1250 °C This will be through development of robust coating methods and phosphor formulations that exhibit sufficient fluorescence at elevated temperatures, and through in-process implementation in a range of manufacturing field trials The techniques developed will also be applied to practical devices for calibrating end-user thermometers

Artificial intelligence (objective 4)

Locating any instance of the melting plateau of self-validating thermocouples and performing the corresponding *in-situ* recalibration is currently a manual operation which limits uptake New machine learning (ML) techniques will be used to automate this, enabling truly driftless thermometry *In-situ* measurements of gas temperature at Selective Non-Catalytic Reduction (SNCR) locations at power plants or waste incinerators are essential for efficient NO_x removal from the flue gas (so-called NO_x reduction) and efficient reagent (ammonia, urea) consumption but are too slow and not suitable for real-time process control Gas temperature profile retrievals with the use of new AI tools will enable real-time temperature measurements, process optimisation and pollutant emission control For surface thermometry neural net-based dry-block calibrator inserts to provide a practical reference surface temperature will be developed, the AI approach will enable

reliable determination of the true reference surface temperature by 3D interpolation of a small network of thermometers

Outcomes and impact

The project is industry-focused with the outputs being trialled in-process during the project's lifetime Knowledge transfer will be maximised through holding industry focused workshops, a project newsletter sent to the project's Stakeholder Community, reporting the project's aims, objectives and outcomes in relevant trade journals and at scientific conferences

Outcomes for industrial and other user communities

The project will establish new resources for enabling traceable, quantitative thermal imaging and phosphor thermometry, practical Johnson noise thermometers which do not suffer from calibration drift, and machine learning techniques for a number of commonly used thermometry scenarios The direct impact on the industrial project participants is very significant The introduction of *in situ* traceability to the SI is embedded in all tasks of the project A stakeholder community will be established, and a workshop will be held in the second half of the project to disseminate outputs, as well as attendance at conferences and publication in scientific and trade journals More widely, improved temperature measurement will result in tighter process control which in turn enhances competitiveness Examples of wider uses include the petrochemical industry, nuclear power industry (especially decommissioning which currently requires widespread process improvements, and small modular reactors), shipbuilding, aerospace and space, iron and steel manufacture, oil and gas, automotive industry, consumer electronics industry, metals industries, refractory insulation manufacture, solar heat capture and heat storage, and district heating/cooling networks

Outcomes for the metrology and scientific communities

The development of practical Johnson noise thermometer (JNT) is directly aligned with the *mise en pratique* for the redefined kelvin (*MeP*-K) which details how to attain temperature traceability by means of primary thermometry without recourse to any defined scale, and supports the long-term aim of the BIPM Consultative Committee for Thermometry (CCT) (as expressed in the CCT strategy 2021-2030+) to shift emphasis from secondary thermometry (i e thermometers that need calibration) to primary thermometry (direct temperature measurement) The route to market for JNTs is built into the project

The consortium is involved in coordinating the Guides on Thermometry, and several Task and Working Groups, of the BIPM Consultative Committee for Thermometry (CCT) These are responsible for promoting good thermometry practice and traceability to the SI The consortium also has representation on the EURAMET Technical Committee on Thermometry (TC-T) and will ensure that project outputs are widely disseminated via the EURAMET TC-T activities In addition, a member of the consortium (NPL) is the past president of the UK Institute of Measurement and Control (InstMC) and will use the InstMC network to disseminate project outputs to a highly relevant user community

Outcomes for relevant standards

This project will have a significant impact by enabling industries to ensure a greater level of compliance with relevant standards This will be achieved through influencing committees including IEC TC 65/SC 65B/WG5 (thermocouple standards e g , IEC 60584), CCT (wide ranging relevant areas of interest), EURAMET TC-T (wide ranging relevant areas of interest), InstMC – Standards Policy Panel (promotion of excellence in instrumentation and control), IoP ISAT committee (promotion of new developments in sensing)

Better surface thermometry will enhance participants' ability to meet the requirements of standards associated with pre- and post-welding heat treatment temperature, namely BS EN 13445, ASME VIII, PD 5500, and compliance with the umbrella standard ISO 15614-1 Surface coating of marine and aerospace structures is subject to comparable thermometry challenges, here the ability to meeting BS EN ISO 8502-4 2000 will be enhanced Compliance with the aerospace heat treatment standard AMS2750F will be facilitated by improved low drift temperature sensors such as JNT and self-validating thermometers and the associated SAE committee will be kept informed of the project progress

As JNT becomes more widespread, industry will look to the European metrology community for guidance on the associated calibration and traceability framework, and standardisation will come to the fore This project will provide the underpinning work for this This framework may look significantly different from one designed for conventional thermometers (i e , the ITS-90) The work will feed into ongoing discussions within the CCT

Longer-term economic, social and environmental impacts

This project will coordinate expertise distributed across a number of NMIs and enterprises to solve specific measurement challenges Europe has a very strong high value / advanced manufacturing base when seen in a global context Its aerospace and space industry supply chains extend throughout Europe and are largely knowledge-based Enhancement of efficiency in processes will breed innovation and technological solutions,

with a resulting improvement in the competitiveness of industry across the EU This in turn boosts economic output and growth and both retain and create high quality jobs in several sectors

Industry accounts for almost a quarter of energy consumed within the EU, with power generation, manufacturing and industrial processing accounting for two thirds of greenhouse gas emissions Improving the reliability of thermometry, which is the basis of much process control in industry, is a key enabler to improving energy efficiency Expertise in energy efficient processes is identified by the EC as being very likely to be a growth area in the near future and will give a competitive edge to European industries

In nuclear decommissioning, the requirement for traceable low uncertainty thermometry of nuclear waste storage containers over the timescale of tens to hundreds of years or more is required until waste is secured in planned underground storage repositories The measurement of temperature is a key assurance monitoring parameter for such containers, so a process-ready JNT and quantitative thermal imaging and phosphor thermometry are key enablers

The EU also has a vibrant sensor manufacturing base, the global market for temperature sensing alone is estimated to be worth €4 5 billion and sensors for monitoring process variables account for the majority of this EU sensor manufacturers can take advantage of the project developments through licensing and selling innovative and improved sensors in the global market Most of these manufacturers are small- to medium-sized enterprises AI/ML and hardware developments are expected to lead to post-project spin-off activities e g , industrial commercial instrument development

B2 Excellence

B2.a Overview of the objectives

The overall aim of the project is to enhance advanced manufacturing processes by improving temperature measurement and control capability The specific objectives of the project are

1 To develop techniques for truly traceable, quantitative thermal imaging, by using at least 4 key engineering materials and selected thermographic phosphors with known temperature in the field of view of the thermal imager in the range of -100 °C to 500 °C with an uncertainty of less than 5 °C This will include characterisation (e g , spectral, angular, and hemispherical emissivity) of the surface or of the phosphor itself and in-situ correction for camera non-uniformity (WP1)

2 To improve practical Johnson noise thermometry with a technology readiness level (TRL) of 6, and an uncertainty of less than 3 °C, and to provide truly driftless thermometry for harsh environments (e g , nuclear power generation and decommissioning) In particular, to develop a robust probe assembly for measuring Johnson noise and demonstrate its performance in harsh environments (e g , high temperatures up to 1200 °C, ionising radiation (gamma rays and neutrons), electromagnetic fields) (WP2)

3 To develop robust thermographic phosphor techniques for surface temperature measurement with an uncertainty of less than 3 °C and up to temperatures of 1250 °C in collaboration with metals processing organisations and end-users (e g , marine manufacturing), to progress towards the goal of zero carbon production in e g , steel processing, and more generally improved energy efficiency of heavy industry (WP3)

4 To develop artificial intelligence (e g , machine learning) approaches to enable traceable *in-situ* temperature measurement for industrial applications with an uncertainty less than 2 % up to 1500 °C, demonstrated through at least three case studies (e g , i) machine learning for autonomous operation of self-validating thermometers, ii) spectroscopic infrared thermometry for in-situ gas temperature and gas temperature profile measurements and iii) reference surface temperature calibration insert) (WP4)

5 To facilitate the take-up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e g , sensor manufacturers), standards developing organisations (e g , IEC) and e end users (metals processing organisations, nuclear power industry, space industry, etc) and via the EMN for Advanced Manufacturing (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 2 9)	D1	Emissivity dataset for at least 4 key engineering materials and selected phosphors, including spectral, angular, and hemispherical emissivity	Dataset	**PTB**, SMU, NPL	Jun 2027 (M34)
1 (A1 4 4)	D2	Paper on the techniques developed for truly traceable, quantitative thermal imaging, by using at least 4 key engineering materials and selected phosphors with known temperature in the field of view of the thermal imager in the range of -100 °C to 500 °C with an uncertainty of less than 5 °C submitted to a peer-reviewed journal	Paper	**NPL**, CMI, PTB, SMU, VTT, Beamex	Aug 2027 (M36)
2 (A2 1 6)	D3	Paper summarising Johnson noise thermometry electronics with a technology readiness level of 6 and an uncertainty less than 3 °C for practical use in harsh industrial environments at temperatures up to 1200 °C submitted to a peer-reviewed journal	Paper	**PTB**, CMI, UL Metrosol, NPL	Nov 2026 (M27)
2 (A2 2 5)	D4	Report on a robust probe assembly for measuring Johnson noise in harsh environments (e g , high temperatures up to 1200 °C, ionising radiation (gamma rays and neutrons), electromagnetic fields)	Report	**NPL**, CMI, PTB, UL, Metrosol, STRATH, UoM	Jun 2027 (M34)
3 (A3 1 7)	D5	Paper on robust thermographic phosphor techniques for surface temperature measurement with an uncertainty of less than 3 °C and up to temperatures of 1250 °C submitted to a peer-reviewed journal	Paper	**NPL**, DTI, OVGU, STRATH	Feb 2027 (M30)
3 (A3 3 4)	D6	Article on the practical application of phosphor thermometry submitted to a trade journal	Article	**NPL**, DTI, STRATH, BAE	Jun 2027 (M34)
4 (A4 3 7)	D7	Article on the application of AI approaches to enable traceable in-situ temperature measurement in industrial applications with an uncertainty less than 2 % up to 1500 °C (e g , i) machine learning for autonomous operation of self-validating thermometers, ii) spectroscopic infrared thermometry for *in-situ* gas temperature and gas temperature profile measurements and iii) reference surface temperature calibration insert) submitted to a trade journal	Article	**DTU**, PTB, UL, VTT, NPL, NSC-IM, STRATH, B&W Volund, Beamex, CCPI	May 2027 (M33)

4 (A4 3 8)	D8	Paper on the application of AI to enable in-situ traceable thermometry in industrial applications (e g , i) machine learning for autonomous operation of self-validating thermometers, ii) spectroscopic infrared thermometry for *in-situ* gas temperature and gas temperature profile measurements and iii) reference surface temperature calibration insert) submitted to a peer-reviewed journal	Paper	**DTU**, PTB, UL, VTT, NPL, NSC-IM, STRATH, B&W Volund, Beamex, CCPI	Aug 2027 (M36)
n/a	D9	Evidence of contributions to or influence on new or improved international guides, recommendations and standards with a specific focus on CCT, IEC TC 65/SC 65B/WG5, Nadcap/SAE AMS2750 Examples of early uptake of project outputs by end-users Updated dissemination, communication and exploitation plan	Reporting documents	**STRATH**, all participants	Aug 2027 (M36)
n/a	D10	Delivery of all technical and financial reporting documents as required by EURAMET	Reporting documents	**DTI**, all participants	Aug 2027 (M36) + 60 days

B2.c Need for the project

Advanced manufacturing is considered by the EU to be at the heart of its industrial strategy [18] and new techniques are important for European growth and sustainability [19] Adoption of advanced manufacturing technologies [20], as well as improved energy efficiency [21] and measurement traceability is key to achieving that Maintaining leadership in energy efficiency is crucial in a time of growing competition for resources

The focus of this project will be to address a selected set of specific, documented process control challenges by demonstrating improved in-process temperature measurement traceable to the International Temperature Scale of ITS-90 (ITS-90) [3] or directly to the SI kelvin [1] during the life of the project The need is demonstrated by a) industries, being Funded or Unfunded Beneficiaries or Associated Partners, identifying their key issues, and b) the requirement to address temperature sensor calibration drift and surface temperature measurement, which were identified as key needs for Advanced Manufacturing in the Draft Strategic Research Agenda published by the European Metrology Network (EMN) for Advanced Manufacturing (in Cross Cutting Topics Johnson noise thermometry on page 4, *in-situ* validation on page 31, and Key Industry Sector Topics surface temperature on page 7) [22] For the specific objectives in this project

1 Thermal imaging is used to monitor surface temperature in a wide range of applications, including forming and forging, welding, annealing, spacecraft thermal vacuum testing, nuclear waste monitoring, gas turbine manufacturing and operation The difficulty of characterising the surface emissivity when performing quantitative thermal imaging results in measurement uncertainties which are often so large that the process quality/efficiency is significantly adversely affected There is a need for a completely new approach which can provide a reliable measurement of the local surface temperature without perturbing it Thermographic phosphor spots can be adhered directly to the surface being measured and in the thermal imager field of view, allowing the surface emissivity to be determined and hence the true surface temperature to be determined, but this approach requires a) knowledge of the emissivity of the phosphor itself and b) knowledge of the inherent camera non-uniformity Existing phosphor thermometry techniques are well established from ambient temperatures up to 750 °C, with prototype instruments able to approach 1000 °C However, there is a growing need to measure below 0 °C, e g for the space sector, where traditional thermal imaging is particularly challenging due to the low signal levels and relatively high background thermal radiation, and above 1000 °C for manufacturing processes e g high reliability steel structures

2 Conventional thermometers are all prone to calibration drift which results in progressive loss of information about the process temperature and necessitates regular thermometer recalibration or replacement Recent work by participants Metrosol (an SME) and NPL [23], PTB [24], UL and CMI together with routes to market will, for the first time, result in the world's first practical Johnson noise thermometers (JNTs) for industry with varying degrees of performance (and hence cost) All the JNTs

exist as prototypes but the formidable technical challenges around electronics and probes fit for industry, as well as the unexplored traceability mechanisms, are common to all types of JNT This is of great importance for applications where long-term monitoring and control is needed, examples include ionising radiation environments including nuclear waste storage and aerospace heat treatment JNT is also needed for calibration laboratories [25] JNT is very difficult because a) the noise voltage is minuscule [26] and needs to be extracted from other, much larger electrical noise and b) the requirements for sensing elements and probes are more demanding than for conventional thermometers The route for traceability of the Johnson noise voltage measurement and resistance measurement to electrical standards, and a robust sensing element and probe assembly useable to 1200 °C, need to be developed Graphene is a promising candidate for the sensing element [27] but destructively oxidises at modest temperatures so the development and characterisation of a practical ceramic-encapsulated graphene sensing element is needed JNT is one of the practical primary thermometry types recommended for further development by the BIPM Consultative Committee on Thermometry (CCT) [2] It is in the CCT strategy (2021-2030+) as it implements the redefined kelvin by offering the possibility of thermometry free from calibration and drift Joint development of the distinct JNT approaches is needed to provide a) diversity of design, metrological performance and cost, which translates into more options for customers, b) downward price pressure, and c) increased propagation to end users

3 Accurate and traceable non-contact temperature measurement of surfaces is challenging but it is often the only option during high temperature dynamic processes Traditional non-contact techniques such as thermal imaging are seriously compromised due to the unknown emissivity of the surface being measured, background thermal radiation, and often rapidly changing temperatures In industry such as marine, aerospace and space manufacturing, surface temperature measurement is not sufficiently accurate, and imaging capability is needed to obtain instantaneous temperature gradients Phosphor thermometry offers a solution to these challenges and has been progressed substantially in EMPIR projects 14IND04 EMPRESS [5] and 17IND04 EMPRESS 2 [6] However, although it can work at temperatures approaching 1000 °C, for consistent use it is currently limited to 750 °C for both single spot measurements and imaging Robust coatings, new phosphor formulations and higher temperature operation for both imaging and single spot technologies are needed to extend the upper temperature to 1250 °C bringing many relevant applications in its purview e g steel processing and marine manufacturing

4 New AI techniques are needed to address specific thermometry challenges

- Starting with EMRP project ENG08 MetroFission and further developed by EMPIR project 14IND04 EMPRESS, self-validating thermometers which make use of an *in-situ* invariant temperature reference to overcome calibration drift have been developed to the point where they are viable in industrial applications, and recent industry trials in aerospace heat treatment have proven their robustness and operational effectiveness However, the feature which enables *in-situ* re-calibration, i e the 'change point', currently can only be identified manually by a human operator Self-validating techniques based on change point detection (of *in-situ* phase change materials) need to be automated before they can enter widespread use Attempts to develop conventional algorithms for automating this process have failed AI methods such as machine learning are needed to determine the change point and its uncertainty Such automation is identified as a priority in the European Metrology Network (EMN) for Mathematics and Statistics (MATHMET) Strategic Research Agenda [28]
- The efficiency and effectiveness of noxious emission reduction of combustion processes e g , waste incineration for heat and electricity production are strongly dependent on temperature Gas temperature retrievals are mostly limited to atmosphere and planetary research and applications In industrial applications local and effective gas temperature measurements are frequently made with use of a) thermocouples (suction pyrometers) and b) hand-held IR pyrometers, respectively The former is time consuming and prone to possible sensor contamination and blocking, while the latter can only give an overall picture of maximum gas and effective particle temperatures in distributed industrial systems such as boilers (power plants and waste incinerators) and large-scale high-temperature (glass, steel, gas-reforming) production Non-uniform temperature profiles can reduce NO_x removal process efficiency (so-called SNCR or SCR processes) and lead to increased reagent (ammonia, urea) consumption and unnecessarily high NO_x/NH_3 emissions Infrared spectroscopic techniques are promising but the iterative algorithms needed to extract the temperature are far too slow to be used in real time New machine learning approaches are needed to speed them up

- Reference surfaces for calibration of thermal imagers and phosphors are extremely difficult to implement in practice due to heat flow effects which make it difficult to determine the areal surface temperature distribution, and the effect of placing items in physical contact with them

B2.d Progress beyond the state of the art

EMRP projects IND01 HiTeMS [29] and ENG08 MetroFission [30], and EMPIR projects 14IND04 EMPRESS and 17IND04 EMPRESS 2 [4-6] brought together European activity in practical industrial thermometry to overcome a suite of specific, documented process control challenges Some of those developments have reached maturity, but for others, including surface temperature measurement, much remains to be done to enable companies to achieve efficiency and accuracy goals set both internally and externally by e g EU regulations Some, such as self-validating thermocouples and infrared spectroscopic gas thermometry, are approaching maturity and commercialisation but are being held back by software considerations and emerging AI techniques are needed to overcome these limitations This will be done by substantially extending the state of the art in traceable surface temperature, by introducing a completely new practical primary thermometer based on the measurement of Johnson noise, and by implementing applications of artificial intelligence to enable automation of new *in-situ* traceable thermometry

WP1: Thermal imaging: Due to the uncertain (often unknown) emissivity and reflected background thermal radiation, thermography can suffer from uncertainties in excess of 100 °C even at relatively modest surface temperatures This project will overcome these difficulties by employing thermographic phosphors in the form of a coated area in the field of view of the thermal imager By using the phosphor (which is immune to the above confounding influences) to measure the surface temperature, the temperature indicated by the thermal imager can be calibrated by adjusting the emissivity setting, thus determining both the true surface temperature and emissivity simultaneously, dramatically reducing the measurement uncertainty to a target of around 5 K To facilitate this, capabilities for measuring the emissivity of both the surface under investigation and the emissivity of the phosphor itself – which are both needed for the thermal imager correction – need to be established, as well as the effect of perturbing environmental influences such as surrounding gas and humidity, these factors can limit the achievable uncertainty in the temperature measurement

- NPL will develop ITS-90 traceable calibration targets [31] Emissivity measurements of the phosphors at PTB will enable a thermal model of the calibration targets to be developed, facilitating the connection between contact and non-contact thermometry
- The emissivity of commonly industrially used materials under controlled environmental conditions such as pressure, relative humidity, and temperature will be measured by PTB The reference emissivity data set will be made available on the Zenodo repository This information will help industry to reduce the uncertainties and to extend the scope of application of non-contact thermometry
- The virtual source method developed by SMU [32] provides an independent traceability path for emissivity measurements, albeit with larger uncertainties than the established emissivity measurement methods It is based on Kirchhoff's law and incorporates a comparatively low-cost approach for industrial applications This method will be validated with uncertainty of the order of 0 5 %
- Large-area flat-plate reference blackbodies will be developed by VTT and Beamex In conjunction with a digital twin of these devices, the temperature and heat flux distribution on the surface can be calculated The blackbody sources will provide a compensated, high-resolution surface with a known, traceable thermal radiation temperature This will be validated by comparison measurements by NPL and PTB The last key comparison of radiation thermometry was EUROMET T-S1 almost 20 years ago [33] In this project, PTB, NPL and CMI will aim to establish, for the first time, prototype Calibration and Measurement Capabilities (CMCs) for thermal imager calibrations by performing a pilot study comparison

WP2: Practical primary thermometry: The redefinition of the kelvin in 2019 in terms of the Boltzmann constant opened the way for practical benefits through stimulating the development of practical primary thermometers which measure temperature directly independent of any temperature scale Primary thermometry therefore offers the possibility of a method that is free from calibration and is free from calibration *drift* in harsh environments The type closest to commercialisation is the Johnson noise thermometer (JNT) The temperature-dependent voltage arising from thermal motion of electrons can be measured, and thermodynamic temperature determined from first principles Because all parameters associated with the thermometer which are degraded by harsh environments can be measured, a drift-free thermometer with continuous reference to the SI units based on fundamental constants can be implemented Several JNTs exist in NMI laboratories, but they are essentially large physics experiments and are far from practical for industry Four practical JNTs are currently actively being developed (by members of this consortium Metrosol and NPL, PTB, UL and CMI) which are portable and practical to operate [23] This project provides an opportunity for

Europe to take a global lead in implementing practical primary thermometry in industry by developing practical systems for harsh environments

- The basic principle of the PTB dual-mode auto-calibrating resistance thermometer (DART), a joint JNT and resistance thermometer, and its electrical calibration have already been discussed in several publications [24] However, the experiments presented were carried out with simplified prototypes which did not have the complete functionality of a practical noise thermometer In this project a complete noise thermometer with traceable operations of the final instrument will be demonstrated
- The JNT being developed by Metrosol and NPL (IJNT) is aimed at practical industrial use [34,35] Currently it is a pure JNT, not dual mode This thermometer has already had some testing at EMC facilities Several factors limiting accuracy, calibration of the electronics, and improved stability for this thermometer need to be developed Use in harsh environments such as high temperature, nuclear and challenging EMC environments (for example an induction furnace) needs to be demonstrated
- The JNT being developed at UL (ULNT) is also aimed at practical industrial use, using low-cost components such as a PC sound card It operates over the temperature range from -196 °C to 300 °C The uncertainty is approximately 0 5 °C The device uses a relatively small 46 kHz bandwidth, a key aim is to integrate this low-cost device with a practical probe suitable for industrial use and validate it
- The JNT at CMI (CMINT) uses a 130 kHz bandwidth and consists of two identical amplifiers It has been tested over the temperature range from -196 °C to 200 °C and a key aim is to integrate the electronics with a practical probe suitable for industrial use and validate it

This project will build on the existing JNTs by extending their temperature range (which is currently 0 °C to about 150 °C) up to 1200 °C, greatly increasing the range of applications in which they can be applied A common theme for all four JNTs is the development of robust sensor element and probe assembly Conventional wire-wound resistive sensors and a completely novel sensor using graphene [36] will be developed Boron nitride encapsulated graphene devices are robust against oxidation and can sustain high lattice temperatures up to about 1300 °C without degradation [37] and their resistance can be tuned to match the requirements of the measurement setup This will be incorporated in practical, robust probe assembly and tested in harsh environments

Equally importantly, traceability of the Johnson noise voltage measurement and resistance measurement to electrical standards will be developed jointly by the project participants to ensure the accuracy and traceability of the JNT measurements As the small signal in JNTs can easily be distorted by electromagnetic interference, testing in very high power electrical and induction furnaces will allow for unprecedented realistic testing of the suitability of the practical JNT in a very harsh environment The participants will also assess the effect of high temperatures and ionising radiation environments These three types of tests reflect the most likely stakeholder interest

WP3: Phosphor thermometry to 1250 °C: Thermographic phosphor thermometry will be developed for operation at higher temperatures than previously attempted to validate surface temperature spot measurements and 2D mapping, and to provide an in-situ reference temperature 'spots' to facilitate qualitative thermal imaging The maximum continuous temperature is currently 750 °C with intermittent use to 1000 °C, this project will elevate the maximum continuous temperature to a target of 1250 °C This will be through development of enhanced instrumentation, robust coating formulations and application methods, and phosphor formulations that exhibit sufficient fluorescence at elevated temperatures These will be demonstrated through in-process implementation in a range of manufacturing field trials The techniques developed will be applied to practical devices for calibrating end-user thermometers, including contact surface temperature probes, ultimately for implementation as ISO 17025 [38] compliant services

WP4: Artificial intelligence: AI is increasingly being used throughout society, and techniques are now available that can be adapted to solve some specific thermometry challenges in this project

- Self-validating thermocouples are now mature To enable their automation, an algorithm was recently developed, using training data from aerospace heat treatment trials [39], which uses machine learning to locate a single instance of a melting plateau and automate the corresponding *in-situ* recalibration This algorithm showed promising results upon data drawn from a single industrial furnace environment However, the algorithm needs to locate multiple melting plateaus and perform well across a range of industrial scenarios This will be achieved by enhancing the algorithm to make it robust to a wide range of industrial furnace environments
- EMPIR project 17IND04 EMPRESS 2 pioneered the traceable measurement of temperature profiles along a path in combustion environments with a proof-of-concept demonstration in waste incineration Improved AI techniques to retrieve the temperature profile from the spectroscopic infrared measurements in these highly dynamic environments will be developed, to enable development of

simplified equipment and compact, low-cost instrumentation The temperature of the boiler/combustor walls is also needed in temperature profile retrievals, and the phosphor thermometry and emissivity measurements in WP3 will be employed These measurements cannot currently be performed in real-time, machine learning will enable faster processing to enable real-time thermometry

- Reference surfaces which can be inserted in conventional dry-block calibrators will be developed which makes use of AI (a neural network) to interpolate between the temperatures indicated by a network of embedded sensors in order to establish the areal temperature distribution at the surface This will complement the thermal imaging and phosphor thermometry developments to enable manufacture of a practical, low-cost calibration device

B2.e Gender dimension

The research and innovation made in this project is not based on gender dimension data or activities and will not produce statistics, tables etc focusing on gender differences Practical thermometry approaches for the determination of temperature in industrial settings are gender neutral

Whilst the actual research itself in this project does not have a gender dimension, the impact of this project could have some implications on gender dimensions as several key applications are related to increasing efficiency of high energy industrial processes, and hence the goals of the European Green Deal

Currently, the reduced availability of fossil fuels (e g Russian natural gas) has resulted in a surge in electricity prices This has had unfortunate consequences for people with low incomes The number of people in Europe who were unable to keep their homes adequately warm increased to 9 3 % in 2022 [40] Energy poverty makes the gender gap bigger and more serious worldwide, 1 3 billion people in developing countries live in poverty Around 70 % of these are women According to the latest research, women are more likely to fall into energy poverty as they are the main users and producers of household energy In Europe single mothers and older women are particularly affected The risk of energy poverty is higher in single-parent families (80 % of them are made up of women) and for older women due to a higher life expectancy and lower pensions than men [41] Thus, as industry accounts for almost a quarter of energy consumed within the EU, with energy industries, manufacturing, and industrial processing accounting for two thirds of greenhouse gas emissions [16] the potential gain from improved energy efficiency is significant and will mean reduced energy consumption and lower electricity prices which again reduces the gender gap in energy poverty

Project results will be valuable and relevant for all in industry and in temperature metrology, regardless of their gender Regarding the implementation and dissemination of the results, the project will target its dissemination and impact activities equally to all genders

B2.f Open science

During the lifetime of this project, open science practices will be implemented as integral parts of the methodology As stipulated in the Partnership Grant Agreement (Annex 5) and planned in the data management plan (DMP), the data and other research outputs generated in the project will be managed responsibly, in line with the FAIR principles Open access will also be provided to scientific publications under the conditions set in the Grant Agreement (Annex 5)

In addition to the mandatory open science practices, the project will implement the following practices

Early and open sharing of research

Pre-prints of the project manuscript(s) will be submitted to a suitable open access platform, in order to accelerate the dissemination of results, ahead of publishing Preprints will be submitted by the project to widely used and accessible repositories, e g arXiv and engrXiv, which are most relevant to the stakeholders communities

Measures to ensure reproducibility of research outputs

The project will provide information about the research outputs/tools/instruments needed to validate the conclusions of scientific publications or to validate/re-use research data

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

The project will ask its Stakeholder Community to provide input and feedback on the project's work plan to support the robustness and reproducibility of its methods and research outputs

All participants are either accredited to, or work in compliance with, ISO/IEC 17025 'Testing and calibration laboratories' This enables the participants to demonstrate that they operate competently and generate valid results, thereby promoting confidence in their work

Reliability and reusability of the project's results and methods will be demonstrated not only by the peer-review process but also by verification of the project's outcomes through standardisation committees that the project disseminates to

Providing open access to research outputs

In addition to providing open access to scientific publications under the conditions in the Grant Agreement, where appropriate, the project will provide open access to its research outputs via the Horizon Results Platform and/or the EOSC Portal, an EC initiative aimed at promoting open science practices

Furthermore, the project will provide free links to the project's reports on the project website and project participants' websites to promote their availability to stakeholders

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 participants It is a no-fee, open access, peer-reviewed publishing venue for EU-funded research, where reviewers' comments and recommendations and authors' feedback are open for others to view

Involving all relevant knowledge actors in the co-creation of R&I agendas and contents

Project workshops involving key stakeholders and end users will be held to gain input and feedback on the project's work plan, results and impact activities

The project's Stakeholder Community will provide input and feedback to the project in order to support its work plan, results and impact activities This will be effected through direct communication with the consortium, either via the project website where comments can be made or direct to the coordinator

Further to this, the project will use social media and knowledge sharing channels (e g ResearchGate, LinkedIn) to involve stakeholders and gain their feedback on and input to the project

Research mobility between the participants from NMIs/DIs will be used to support the transfer of knowledge between these communities

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

Types of data/research outputs

Data/research outputs generated in this project will be from measurements, calibrations and comparisons, and processed and computed data The project will collect the following types of data images in JPEG format, numerical data in ASCII formats and other proprietary formats e g COMSOL Research outputs will include new software, new calibration methods and protocols The estimated overall size is expected to be in the range 2 GB – 20 GB Existing data sources include participant's pre-existing data, scientific literature, real-world data Data generated in this project will not be combined with existing data

Findability of data/research outputs

The data/research outputs (protocols, reports, software, training material) will be findable as each will be identifiable with a DOI, Commit/tag, Handle, 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 The data will be identifiable and locatable by means a DOI link available through the Zenodo platform Where possible, keywords associated with the paper linked to the data will be included All the datasets will provide version numbers and the version history Where applicable, the metadata will include persistent identifiers for related publications and research outputs

Accessibility of data/research outputs

All of the data needed to validate the results presented in scientific publications/research outputs will be made openly available by default unless there is a specific reason not to publish them Other data/research outputs will be made available on a case-by-case basis if relevant for third parties The coordinator and relevant participant(s) will be responsible for IPR / access considerations Open access will be decided on a case-by-case basis and agreed with the data owners (for cases where confidentiality is required for proprietary information) Open access will be granted as soon as is reasonably possible If necessary, open access will not be provided to some of the data/research outputs due to IPR considerations (e g whilst a patent application is pending) The data/research outputs will remain accessible for the lifetime of the repository

There are no restrictions on the use of the published data/research outputs for verification purposes, but users will be required to acknowledge the project and the funding source in any resulting publications, according to the Creative Commons Attribution International Public License (CC BY) 4 0

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 During the project, unique metadata vocabularies, standards and methodologies will be followed, e g the International Vocabulary of Metrology (VIM) document Other methodologies such as GUM and ISO 9001 will be used to allow interdisciplinary interoperability The project's datasets will not include any references to other datasets

Reusability of data/research outputs

Creative Commons Attribution 4 0 international license will be used as the basis for licensing the data and permitting the widest re-use possible The data will be re-usable as soon as it is published in the repositories Any data published in open-access journals and made available to third parties will be re-usable If an embargo is required to allow time to publish or seek patents, the consortium will try to facilitate the requirements in the shortest possible time

Users will be required to acknowledge the consortium and the source of the data in any resulting publications Availability of tools, software and models for data generation and validation, interpretation, and re-use Templates will be documented with embedded instructions rather than with separate README files to maintain reusability by minimising the number of files required The data will be in a common format and can be read using widely available software (open source or commercial) 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 curation and storage costs for making the data and research outputs Findable, Accessible, Interoperable and Reusable (FAIR) will be minimised by using Zenodo (https //zenodo org/), and by making only relevant data and outputs FAIR Privacy of data subjects will be secured by following the General Data Protection Regulation (Regulation (EU) 2016/679 of the European Parliament and of the Council) The consortium members have measures in place to ensure data protection

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

This consortium will not establish a Data Access Committee The coordinator 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 will be a direct impact on the practice of industrial thermometry for improved process control

- Improved surface temperature measurement capability through using phosphor thermometry in the field of view of thermal imagers in conjunction with substantially improved characterisation of emissivity of both the surfaces and the phosphors in the image will facilitate traceable quantitative thermography Publication of spectral, angular and hemispherical emissivity for key engineering materials will give an immediate step-change improvement in quantitative thermography This will enable improved thermometry for a wide range of processes including, but not limited to, heat treatment, nuclear waste monitoring, electrical infrastructure condition monitoring, and healthcare The chief benefits of such improved remote thermometry include better product consistency and better efficiency
- Practical JNT offers the potential for drift-free measurement At least two exploitation routes exist thanks to the commercial relationship between Metrosol and collaborators e g , Isothermal Technology Ltd, and PTB and collaborators e g , Magnicon GmbH, the two collaborators manufacture temperature metrology equipment and sell to a global market JNT will be an important tool for process control for applications where replacement of sensors is difficult and hazardous (or simply very expensive) e g , nuclear power generation and nuclear waste In the longer term it will enable equipment manufacturers to integrate into their equipment a practical primary reference thermometer The project

will demonstrate the utility of encapsulated graphene as a stable sensing element for other types of probes (not just JNT)

- In addition to facilitating traceable quantitative thermography, improved surface temperature measurement capability based on phosphor thermometry will enable reliable surface temperature measurement in-process up to 1250 °C through e g , consultancy and measurement services The visualisation of temperature distribution through coating a surface with thermographic phosphor will enable improved heat treatment processes, the improved traceability will improve product consistency
- Currently the inability to automate self-validating thermocouples is hindering full commercial exploitation The deployment of AI for feature recognition will enable full automation and accelerate commercialisation It will also provide reliable uncertainty statements which conform to the principles of the GUM [42] These aspects will provide the groundwork needed to enable accreditation within the regulatory frameworks (e g , AMS2750F [13]) with which end users must comply Using self-calibration will reduce the need for expensive recalibration and replacement of thermocouples in high value manufacturing [14], advanced manufacturing [15], and other process control applications Impact will be through licensing to thermocouple manufacturers
- Temperature profile retrievals from a single line-of-sight gas/combustion process measurement is a time-consuming process The use of AI tools will significantly speed up the process by enabling the retrieved data to be obtained in just few seconds or less due to in-advance retrieval method training This will open-up many possibilities for integration of the developed AI-based approach into on-line process monitoring and control on industrial units The latter will allow an efficient gaseous emission control and reagent consumption optimisation The developed hardware and AI software can potentially lead to new spin-off (commercial) instrument developments

The project outputs will contribute to reduced energy use, enhanced quality and yield, reduced waste, and lower CO_2 emissions These benefits will be demonstrated in a range of industrial process settings Marine construction (BAE), aerospace forming, forging and heat treatment, induction heating, and steel re-heat processes prior to strip rolling (STRATH), high value heat treatment (CCPI via their customers), electricity and heat generation through waste incineration (B&W Volund), nuclear power plant operation (NSC-IM), nuclear decommissioning and waste storage (NPL with the support of collaborators e g , NDA and Sellafield) Developments including improved detector non-uniformity corrections (PTB, CMI via manufacturers) will be implemented in the products via manufacturers of thermal imager instrumentation who intend to be collaborators

The direct impact on project participants is very significant The introduction of *in-situ* traceability is embedded in all tasks of the project The longer-term impact on industry could be very significant with these new approaches displacing current methods of industrial thermometry Improved temperature measurement will result in tighter process control leading to better, more consistent products which in turn enhances competitiveness Examples of wider uses include the petrochemical industry, nuclear power industry (especially decommissioning which currently requires widespread process improvements, and small modular reactors), shipbuilding, aerospace and space, iron and steel manufacture, oil and gas, automotive industry, consumer electronics industry, metals industries, refractory insulation manufacture, solar heat capture and heat storage, and district heating/cooling networks

The consortium will liaise closely with EURAMET TC-T and the European Metrology Networks (EMNs) for Advanced Manufacturing, Climate and Ocean Observation, and Mathematics and Statistics to maximise outreach

B3.b Projected outcomes for the metrological and scientific communities

The consortium has representation on the CCT Task Group on Guides on Thermometry which is responsible for promoting good thermometry practice and traceability to the SI by preparing and publishing guides on thermometry, with an emphasis on secondary thermometry, i e the subject of this project The consortium will ensure that CCT members are kept informed of the project outputs The consortium also has representation on the EURAMET TC-T and will ensure that project outputs are widely disseminated via the EURAMET TC-T activities A member of the consortium is also represented on the Institute of Physics Instrumentation Science and Technology (ISAT) committee, whose remit is to organise meetings in the physics community and other dissemination activities In addition, a consortium member (NPL) is the past president of the Institute of Measurement and Control (InstMC) [7] and will use that position to promote the project and its outputs to members

The project will foster further significant collaborations with the scientific community, particularly between NMIs/DIs and universities specialising in fundamental phosphor thermometry Research outputs will be disseminated via trade journals, peer-reviewed papers, and international conferences including TEMPMEKO

2025 (to include a focused ThermoSI session on industrial thermometry), Congrès International de Métrologie 2025/2027 and the IMEKO World Congress 2026

Practical primary JNT will be an important tool for industrial process control but will also have benefits for NMIs and other calibration laboratories as it will eliminate the need for periodic recalibration of reference thermometers and could, in the long term, eliminate the need for expensive, complicated and time-consuming international comparisons of ITS-90 fixed points The route to commercialisation is already well established by some of the project participants Uptake of practical primary JNT by end users will require a metrological framework to establish measurement traceability Such frameworks are in early discussions, e g , within the CCT This project will pioneer such frameworks and expedite their development within the relevant metrology and standard committees, which will enable NMIs and other organisations to fulfil quality requirements, such as accreditation to ISO 17025

At the start of the EMPIR projects 14IND04 EMPRESS and 17IND04 EMPRESS 2 no NMI had considered phosphor thermometry to be a viable practical technique and now there are at least two NMIs/DIs (NPL and DTI) and two universities (OVGU and STRATH) actively involved in the area The area is growing rapidly as interest from industry accelerates, with attendance at the annual International Conference on Phosphor Thermometry growing steadily from 2018 to 2023 Importantly, the improvements in traceable surface thermometry will feed directly into improved calibrations at NMIs and further afield Extending the temperature range to 1250 °C will increase the number of applications e g , validation of thermal imaging over a wider temperature range

Traceable quantitative thermal imaging will be facilitated by improved access to reference artefacts based on phosphor, or a flat-plate blackbody with known temperature, which can be placed in the field of view to provide a reference temperature, enabling a calibration which directly pertains to the surface being measured Published, validated spectrally and angularly resolved emissivity data for key engineering materials will further improve the accuracy of thermal imagers

One of the direct benefits for NMIs is that this project enables direct engagement with stakeholder needs, enabling the NMIs to shape their work so that it is better aligned with user requirements *In-situ* traceability allows all the capability developed at the NMI to be taken advantage of by users There are a number of smaller NMIs in the consortium and their participation will contribute substantially to capacity building

B3.c Projected outcomes for relevant standards

The availability of more accurate, traceable surface thermometry via phosphor thermometers in WP4, in their various forms, will greatly enhance the ability of participants to meet the requirements of standards associated with pre- and post-welding heat treatment temperature, namely BS EN 13445 [8], ASME VIII [9], PD 5500 [10], and provide confidence to end users and their customers of compliance with the umbrella standard ISO 15614-1 [11] Surface coating of marine and aerospace structures is subject to comparable thermometry challenges, here the ability to meet the requirements of BS EN ISO 8502-4 2000 [12] will be enhanced

The IEC committee IEC TC 65/SC 65B/WG5 (responsible for IEC 60584 on thermocouples [43], IEC/TS 62492 on thermal imagers [44,45] and other temperature sensor standards), of which NPL and PTB have membership status, will be provided with updates on the development of automation of self-validating thermocouples

This project will have a significant impact by enabling industries to demonstrate compliance to the AMS2750 [13] processes (governing aerospace heat treatment) and CQI-9 Heat Treatment System Assessment [46] (governing automotive heat treatment), thanks to greater confidence in the stability of control thermocouples used for heat treatment of high value components The relevant Nadcap [47] standards committee will be kept up to date with project developments relating to self-calibration thermocouples

More broadly, the participants who are members of technical committees (see table below) will inform them about the results of this project and will endeavour to ensure they are incorporated in any updates to the standards or guidelines, for example by asking the chairperson to include a point in the agenda to briefly present the outputs of the project related to the working group activities and to ask for comments from the other committee members

Standards Committee / Technical Committee / Working Group	**Participants involved**	**Likely area of impact / activities undertaken by participants related to standard / committee**
IEC TC 65 Industrial-process measurement, control and automation SC 65B Measurement and control devices WG5 Temperature sensors and instruments	**NPL**, PTB	IEC TC 65/SC 65B/WG5 meets annually The underlying work necessary to begin development of a new IEC standard(s) governing self-validating thermocouples and JNT, for which there are no existing frameworks, will be undertaken NPL and PTB contribute to this committee Thermal imaging developments will ultimately feed into IEC/TS 62492-2 2013 which is due an update, IEC/TS 62492-1 2008, and indirectly IEC 62828-3 2018 [48]
Consultative Committee for Thermometry (CCT)	**NPL**, PTB, VTT, CMI, SMU, NSC-IM	CCT meets biennially The committee establishes the framework for improved temperature measurement and improved traceability to the International System of Units (SI) Several of the NMI participants in this project are delegates to the world's leading committee for temperature measurement, the Consultative Committee of Thermometry (CCT) The work of the CCT is very important for setting the framework for improved temperature measurement and is very supportive of all efforts to achieve and improve traceability to the International System of Units (SI) The outcomes of this project will be presented to the CCT mainly through its Working Groups and Task Groups which many of the NMI participants sit on and in one case chairs (NPL chairs WG5 on non-contact thermometry) Two briefing reports will be submitted to the CCT on the state of the art of • Practical Johnson noise thermometry (A2 3 4), which is of special interest to the international metrology community • Practical phosphor thermometry (A3 2 5), which is currently under-represented in CCT discussions and documentation
EURAMET Technical Committee for Interdisciplinary Metrology (TC-IM) Metrology for Digital Transformation (WG M4D)	**NPL**, PTB, VTT, CMI, SMU, DTI	This technical committee and the working group meet twice-yearly and often more frequently in the interim They will be kept up to date by NPL, PTB, VTT, CMI, SMU and DTI with the machine learning and sensor network metrology developments to inform wider discussion and consultation over applications of these to metrology in general
EURAMET Technical Committee on Thermometry (TC-T)	**NPL**, PTB, DTI, CMI, SMU, UL, VTT, NSC-IM	All the NMI participants in this project are members of the EURAMET TC Thermometry (TC-T) EURAMET TC-T will be used as a mechanism for dissemination of the outcomes of this project to the broader NMI temperature measurement community All of the EURAMET TC-T community will be kept informed about the progress of this project through regular reporting to the TC-T at the annual meeting Annual oral reports of the project progress will be presented to the committee and the participants will be asked for feedback on the work and results presented Peer-reviewed papers will also provide a reference for the committee The EURAMET TC-T is the natural place to identify possible secondees/trainees from other NMIs who wish to develop like capability or who may wish to participate in the research underway in this project

IEC/TC 65 UkrNDNC TK 65	**NSC-IM**	The Ukrainian Research and Training Center for Standardization, Certification and Quality Problems (UkrNDNC) committee on Industrial process measurement, control and automation meets biennially and often more frequently in the interim They establish the framework for improved temperature measurement and improved traceability to the International System of Units (SI) and promote excellence in instrumentation and control NSC-IM will disseminate project outputs to physicists, engineers and scientists involved in high value manufacturing and will ask for feedback on the work and results presented
IEC/TC 65 Ukrainian National Mirror Committee TK 85	**NSC-IM**	The UkrNDNC committee on Measuring Equipment for electrical and electromagnetic quantities meets biennially and often more frequently in the interim They establish the framework for improved temperature measurement and improved traceability to the International System of Units (SI) and promote excellence in instrumentation and control NSC-IM will disseminate project outputs to physicists, engineers and scientists involved in high value manufacturing and will ask for feedback on the work and results presented
VDI – The Association of German Engineers	**PTB**	This association meets four times per year PTB is a member of the technical committee "FA 8 14 Radiation thermometry and thermography" PTB will disseminate projects outputs to the association and will ask for feedback on the work and results presented
IMEKO TC12 Temperature and Thermal Measurements	**DTI**	The committee meets irregularly and will physically meet in 2025 It provides a forum for the organisation of international scientific events in temperature and thermal measurements TC12 organises a main symposium (TEMPMEKO) every three years and other specialist scientific events (workshops, seminars) DTI will promote the project and its work to this forum
Nadcap/SAE	**CCPI**, NPL	Nadcap/SAE meets annually CCPI and NPL will endeavour to raise awareness of relevant developments and testing of self-validating thermocouples within the Nadcap community, with the ultimate goal of feeding developments into future updates of the AMS2750 standard CCPI is a member of the committee responsible for AMS2750

B3.d Projected wider impact of the project

The impact of this project would be significant for the industrial and commercial participants but would also have significant spinout to industry and to the manufacturing ecosystem more generally It should lead to improvements by facilitating more precise and efficient manufacture and process control and lower energy use, specifically by allowing tighter process control yielding better, more consistent quality products, reduced waste, improved safety margins and lower greenhouse gas and pollutant emissions More efficient processes directly cause a reduction in greenhouse gas emissions

The introduction of *in-situ* traceability to ITS-90 or directly to the kelvin is a fundamental part of all tasks of this project, which will ensure better consistency across the range of processes impacted Examples of wider uses include the petrochemical industry, nuclear power industry (especially decommissioning which is currently the subject of widespread process improvements, and small modular reactors), shipbuilding, aerospace and space, cement manufacture, iron and steel manufacture, oil and gas, automotive industry, consumer electronics industry, metals industries, solar heat capture and heat storage, solar photovoltaic panel manufacturing, and heating networks to name but a few

Society as a whole – and industry in particular – is increasingly reliant on sensors for a very wide range of monitoring and control applications This leads to a requirement for mechanisms to ensure these sensors are 'right' Practical, driftless temperature sensors with embedded SI traceability address this need where temperature measurements are critical and constitute a key component of the Internet of Things (IoT), providing measurement assurance at the point of delivery

Economic

Europe has a very strong high value/advanced manufacturing base when seen in a global context Industry provides 36 million direct jobs [49], and 80 % of private R&D investment comes from manufacturing [50] Its aerospace and space industry supply chains extend throughout Europe and are largely knowledge-based Industry's interactions with the rest of the economy are far-reaching, spanning upstream to raw materials and energy, and downstream to services EU companies cannot compete on low price and low-quality products, they rely on innovation, productivity, resource efficiency and high value added [51] to compete in global markets Enhancement of efficiency in processes will breed innovation and technological solutions, with a

resulting improvement in the competitiveness of industry across the EU This in turn boosts economic output and growth and creates high quality jobs in several sectors

The EU has a vibrant sensor manufacturing base, the global market for temperature sensing alone is estimated to be worth €4 5 billion, sensors for monitoring process variables account for the majority of this EU sensor manufacturers can take advantage of the innovations in this project through licensing and selling novel and improved sensors in the global market

Europe is currently at the forefront of development of practical primary thermometry and this project represents a unique opportunity to consolidate that position, bringing together the key elements of innovative companies with global commercial distribution networks, innovative NMIs with electrical and thermometry know-how, and universities with a novel probe technology to facilitate access to hitherto unreachable temperatures

Environmental and social

Cheap energy has been integral to the success of the EU, but energy production has downsides as well as benefits, chiefly air pollution which causes premature death [52], accidents (along the supply chain) and greenhouse gas emissions [53] This potentially leads to long-term health, social, and economic effects arising from climate change [54]

Industry accounts for almost a quarter of energy consumed within the EU, with energy industries, manufacturing and industrial processing accounting for two thirds of greenhouse gas emissions As a result, any improvement in thermometry, which is the key process control parameter for many of these industries, will have a direct positive impact on greenhouse gas emissions

Thermometry is also critical for safe, efficient operation and decommissioning in the nuclear power sector Nuclear power remains an important part of the energy mix in a number of European countries, and thermometry of nuclear waste storage containers is currently attracting a large amount of interest, demonstrating a need for robust and low uncertainty implementation of traceable and stable thermometry techniques This is required for tens, possibly even hundreds of years or more, until planned underground storage repositories are built and commissioned The measurement of temperature is a key assurance monitoring parameter for such storage containers, so alternative methods such as JNT, quantitative thermal imaging and phosphor thermometry will enable thermometry in this harsh environment without the problems associated with conventional thermometry

Energy efficiency is directly linked to reduced carbon emissions [55], meeting the EU's goals for reduction by e g the Integrated Pollution Prevention and Control (IPPC) Directive 2008/1/EC [56], recast as 2010/75/EU in 2010 [57], requires a minimum efficiency level in energy use and emissions The European Directive 2012/27/EU [58], whose 2018 amendment came into force in December 2018 with even more ambitious targets for energy efficiency, and which was required to be transposed into national law by Member States by the 25th of June 2020, imposes very ambitious targets for energy efficiency across a wide range of applications Expertise in energy efficient processes is very likely to be a growth area in the near future [17], and therefore the advanced measurement technology to be developed in this project will give a competitive edge to European industries

The driftless thermometry objectives (development of practical Johnson noise thermometers and developed of autonomous AI-driven self-validating thermocouples) are also applicable to needs identified for *in-situ* calibration and measurement in the European Metrology Network (EMN) for Climate and Ocean Observation (page 20) [59]

Going forward, global factors such as climate change, growing populations and pandemics will increase the vulnerability of global supply chains European consumers will call for products that meet higher environmental standards across the entire product life cycle [60], and environmental regulations will become ever stricter Manufacturers will therefore need to strive for greater efficiency in their use of materials and energy, and tighter process control, both of which require improved thermometry

B3.e Summary of the project's impact pathway

SPECIFIC NEEDS	EXPECTED RESULTS	DCE MEASURES
What are the specific needs that triggered this project? The European Directive 2012/27/EU imposes very ambitious targets for energy efficiency across a wide range of applications The integrated Pollution Prevention and Control (IPPC) Directive 2008/1/EC, recast as 2010/75/EU in 2010 , requires a minimum efficiency level in energy use and emissions Furthermore, the EU's aim of making the 2020s Europe's 'digital decade', and its associated aims and directives, are key drivers for digital and AI developments Accurate, traceable surface temperature measurement with quantitative thermal imaging from -100 °C to 500 °C Practical industrial thermometry that is inherently free of calibration drift Accurate, traceable emissivity-free thermometry for surface temperature measurement up to 1250 °C A suite of artificial intelligence methods to enable automation of • self-validating thermometry using phase-change cells • gas temperature retrievals with infrared spectroscopic techniques • reference surface for practical calibration of thermal imagers, phosphor thermometers and contact probes	*What results do you expect to generate by the end of the project?* Practical quantitative thermal imaging using in-situ references, including spectral, angular and hemispherical emissivity datasets for several key engineering materials and selected phosphors For the first time, prototype Calibration and Measurement Capabilities (CMCs) for thermal imager calibrations by performing a pilot study comparison Elevated operational readiness of practical JNT for use in industrial environments at temperatures up to 1200 °C Phosphor thermometry up to 1250 °C The use of machine learning for automation of self-validating thermometers, including case studies in industrial heat treatment plants AI-driven reference surface for calibrating thermal imagers and phosphors Applications of AI tools for expedited retrievals of gas temperature from line-of-sight measurements	*What dissemination, communication and exploitation measures will you apply to the results?* **Dissemination towards the scientific community and industry** At least 9 scientific papers written and published in peer-reviewed journals and trade journals Datasets published At least 20 presentations of project results and findings at national and international conferences Two Stakeholder Community workshops held during the project Training activities in view of capacity building organised, including staff exchanges amongst participant institutes Trials in industry are integral to the project Case studies on the use of AI for traceable process control thermometry will form an important part of the dissemination activities **Dissemination towards standardisation bodies** Participation as expert members in the activities of the technical committees and working groups Reporting of project results at TC and WG meetings, in particular the CCT and IEC TC/65/SC 65B/WG5 **Communications** Project website created Newsletters produced promoting the value of the results and outputs These will be published on the project website and distributed to stakeholders Achieved progress regularly communicated by means of the project webpage, newsletter and a LinkedIn group **Exploitation** Products and services prototypes ready for the commercialisation process • Improved thermal imager capability from -100 °C to 500 °C • Johnson noise thermometers to 1200 °C • Phosphors to 1250 °C Publicly available spectrally and angularly resolved emissivities for key engineering materials Extended measurement capabilities and services across a European network of 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? • International and European technical committees in thermometry CIPM Consultative Committee for Thermometry (CCT), EURAMET and other RMO TC-Ts • Standardisation committee within IEC TC/65/SC 65B/WG5 • Metrology NMIs/DIs without primary thermometry capabilities Stakeholders who manufacture temperature metrology equipment e g Isothermal Technology More widely, the measurement supply chain (accredited laboratories, instrument manufacturers) • Industry Manufacturers and distributors of temperature sensors e g beneficiaries Metrosol, CCPI, Beamex and via collaborators e g Isothermal Technology, Kambic and Workswell • Industry Owners of processes involving harsh environments e g beneficiaries BAE, B&W Volund • Industrial communities contemplating the development of fully autonomous production streams, smart monitoring solutions for power plants, nuclear waste repositories, etc Broader society through the stimulation of technological innovation for the European manufacturing and supply chain (e g smart sensor networks within the systems of systems approach)	*What change do you expect to see after successful dissemination and exploitation of project results to the target group(s)?* • The project outputs will support many EU directives related to e g Industry 4 0/5 0, Energy efficiency and CO_2 emissions • Over time, practical primary thermometry progressive adoption by other users, thus reducing the reliance on traceability to defined temperature scales • Reduction and even elimination of dependency on the old "carriers of the scale" sensors • Reduction in uncertainty of surface temperature measurement and corresponding improvement in process assurance / reliability • Improved measurement capabilities of participants, and NMIs in general, for o Surface temperature measurement (thermal imaging, phosphor thermometry) o Process temperature in harsh environments (high temperature, ionising radiation, electromagnetic fields) o Gas and combustion temperature measurement	*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?* • High level measurement capability within the EURAMET region broadened to wider range of NMIs with differing capacities • **Scientific** Improved efficiency (in terms of energy and in terms of product yield and quality) Improved safety • **Economic** Supporting Europe's vibrant sensor market, reducing cost of processes through reduced energy use, reduced process down time, improved ability to meet greenhouse gas emissions limits • **Environmental and societal** Reduced energy use, reduced emissions and pollution, improved health • In the long term, development of more reliable temperature measurement techniques to improve efficiency and safety in processes

B4 The quality and efficiency of the implementation

B4.a Overview of the consortium

This project brings together eight of the leading national metrology institutes (NMIs) and designated institutes (DIs) working in this field and having broad experience and expertise in physical and chemical metrology (CMI, DTI, NPL, NSC-IM, PTB, SMU, UL and VTT) Four renowned universities (DTU, OVGU, STRATH and UoM) participate and five industrial participants (Metrosol, B&W Volund, BAE, Beamex and CCPI) each are specialists in their field and representing instrument manufacturers and end-users to facilitate uptake and demonstration of the project's developments

- **DTI** participated in EMPIR projects 14IND04 EMPRESS and 17IND04 EMPRESS 2 where they developed a measurement system for phosphor thermometry for laboratory and on-site use Furthermore, test facilities for surface temperature measurements using e g phosphor thermometry were established All these facilities will be exploited (WP1, WP3) and further developed (WP3) in the project DTI will also support the work in WP4 DTI has a large number of industrial partners and is abundantly end-user and impact oriented, which will assist the uptake of the technologies developed in the project (WP5) DTI coordinates the project (WP6)
- **CMI** provides services in all basic fields of metrology, including fundamental metrology, development of national standards, research and development in metrology, transfer of units, calibration of standards and measuring instruments CMI will contribute to WP1 in close collaboration of local Czech manufacturers of thermal imagers for implementation of upgraded non-uniformity correction In WP2 CMI will develop high temperature JNT
- **PTB** has broad experience in non-contact thermometry and emissivity measurements and will apply this in WP1 and WP3 respectively PTB's expertise in the development of practical metrological electronic designs, resulting in establishing a JNT for metrological applications, will support the

planned activities in WP2 In WP4, PTB will apply its 20+ years of experience in optical spectroscopy to focus on H_2O measurements for spectroscopic gas temperature measurements

- **SMU** has experience in multiple EMRP and EMPIR projects in the field of non-contact thermometry with specific focus on the determination of emissivity of materials Furthermore, SMU has an active role in the EURAMET working group on thermophysical quantities where it focuses on the emissivity of solid materials SMU will be involved in WP1 where it will focus on the determination of emissivity of phosphor materials
- **UL** has leading facilities for the realisation of the ITS-90 from the triple point of Ar to the freezing point of Cu comparable to the best laboratories in the world In this project, UL's main contribution will be to WP2, by developing a high temperature JNT and to WP4, using Al for *in-situ* fixed point cells
- **VTT** MIKES division is distinguished for its expertise in SI unit realisations, high-accuracy measurements, measurement innovations, digital transformation, and calibration technologies In WP4, VTT will concentrate on the conceptualisation and development of an AI-assisted low-cost insert for dry-block calibrators This instrument aims to act as a comparator, linking phosphor thermometry with thermal imaging techniques VTT will also support work in WP1 and WP3
- **DTU** has participated in EMPIR projects 14IND04 EMPRESS and 17IND04 EMPRESS 2 with a particular focus on developing of infrared and ultraviolet spectroscopy techniques for the measurements of the gas temperature and radiative properties of hot gases in the laboratory and industrial environments DTU will contribute to the WP3 and WP4 with focus on surface temperature and emissivity measurements and use of AI tools for temperature profiles retrievals in industrial environments DTU will work closely with B&W Volund
- **NSC-IM** provides Ukrainian industry with the necessary accuracy and reliability of thermometric measurements NSC-IM will contribute to WP4 on implementing self-validating thermocouples, with particular application to temperature measurement in restricted access environments in nuclear power plants at collaborators' sites
- **OVGU**'s technical thermodynamics team is a world leading research group in fluid phase thermometry using thermographic phosphors including fundamental technique development, and application in engineering with over a decade of experience OVGU will work on WP3 to identify and test suitable phosphor materials, and to identify and test the most suitable measurement method Additionally, OVGU will cooperate closely with NPL and DTI in the thermometer development and application
- **B&W Volund** uses the newest waste-to-energy (WtE) and CO_2-neutral advancements to produce energy more efficiently and sustainably B&W Volund will support the consortium by providing access to WtE incinerator plants in Denmark and Sweden where there are established access ports for measurements B&W Volund will work closely with DTU in WP4, providing assistance with the on-site measurements and insight into process aspects of instrument implementation
- **Beamex** specialises in advanced calibration equipment and software used in on-site calibrations and calibration management in a wide range of industries In close collaboration with VTT, Beamex will work on the development of the AI-assisted inserts for enabling calibration of thermal imagers with dry-block calibrators and associated AI modelling in WP4 Beamex will also support work in WP1 and WP3
- **BAE** specialises in heavy industrial manufacturing for marine applications Large scale induction annealing and welding facilities are available to the consortium for trials of phosphor thermometers developed in WP3 BAE will work closely with NPL BAE is associated to all beneficiaries
- **CCPI** specialises in thermocouple manufacturing and supplies to a wide range of customers in high value manufacturing sectors Their facility has state of the art manufacturing equipment and clean room environments, as well as a calibration laboratory operating up to 1600 °C, including the latest high temperature fixed points CCPI will work closely with NPL, NSC-IM and UL on the self-validating thermocouples in WP4 CCPI is associated to all beneficiaries
- **Metrosol** specialises in the development of temperature measurement instrumentation It will develop the Johnson noise thermometer electronics and associated probe methodology in WP2 with the aim of extending the temperature range to 1200 °C and establishing traceability of the electrical noise measurements to electrical standards It will work closely with NPL, PTB, CMI, UL, UoM and STRATH Metrosol is associated to all beneficiaries
- **NPL** has expertise in its key activities supporting the development of practical Johnson noise thermometry and probes (WP2), development of new thermal imaging techniques (WP1),

self-validating thermocouple manufacture and calibration, and machine learning approaches to their automation (WP4), phosphor thermometry including calibration of the phosphor itself (WP1 and WP3) NPL will provide an ionising (gamma and neutron) radiation facility in WP2 for assessing the immunity of instrumentation developed in the project NPL will work closely with PTB, BAE, CCPI, Metrosol, STRATH, OVGU and UoM NPL is associated to all beneficiaries

- **STRATH** in this instance comprises of the Advanced Forming Research Centre (AFRC) which is an R&D incubation facility with full production scale manufacturing equipment e g aerospace heat treatment furnaces and forming rigs, which will be made available to participants across all four WPs for trialling project outputs STRATH will also lead WP5 on impact STRATH is associated to all beneficiaries
- **UoM** will work closely with NPL and Metrosol in WP2 on the development and testing/characterisation of encapsulated graphene sensing elements and probe assembly for the JNT using their unique graphene fabrication and encapsulation facilities, including the National Graphene Institute UoM is associated to all beneficiaries

Section C: Detailed project plans by work package

C1 WP1: Traceable, quantitative thermal imaging from -100 °C to 500 °C

Thermal imaging is widespread, but it is extremely difficult to do quantitatively due to poor knowledge of the target surface emissivity, reflections and thermal imager non-uniformity The aim of this work package is to develop techniques for traceable quantitative thermal imaging, for the low-to-medium temperature range of 100 °C to 500 °C with uncertainty less than 5 °C, by using objects with known temperature (e g phosphors) in the field of view of the thermal imager, including the emissivity characterisation (e g of the surface or of the phosphor itself) and *in-situ* correction for imager non-uniformity

Task 1 1 identifies suitable phosphors and methodologies for using them in the field of view of thermal imagers Task 1 2 is concerned with measuring the emissivity of the target surface and of the phosphor itself using the various methodologies developed Task 1 3 develops methods for thermal imager non-uniformity and thermal imager calibration in conjunction with WP4 Task 1 4 brings these methods together for direct comparison and validation

C1.a Task 1.1: Using phosphors in the field of view of the thermal imagers

Thermographic phosphors offer a solution to the problem of unknown emissivity in thermal imaging The aim of this task is to define the requirements for the thermographic phosphors and identify the phosphors holding these properties Based on the identified phosphors, calibration methods for these will be developed by defining and quantifying the key uncertainties such as the heat flow in the thermographic phosphor and the underlying substrate These findings will be compared with measurements of thermographic phosphors in cavities where the heat flow uncertainties are negligible To simplify the optical measurements of the phosphors, a large-area flat-plate blackbody source that comes with a digital twin will be used

Activity number	Activity description	Participants (Lead in bold)
A1 1 1 M3	NPL, with support from DTI and PTB, will define the necessary properties (e g , wavelength dependent luminescence, fluorescence lifetime, minimum thickness of the coating, sensitivity) of thermographic phosphors for their use in quantitative thermal imaging, and will select the phosphor(s) most suitable for A1 1 2	**NPL**, DTI, PTB
A1 1 2 M12	Based on the defined properties and selected phosphor(s) in A1 1 1, NPL and DTI will develop ITS-90 traceable calibration targets for the following temperature ranges a) -100 °C to 20 °C (NPL) b) -50 °C to 20 °C (DTI) c) 20 °C to 500 °C (NPL, DTI) The methods used will include the surface temperature extrapolation method using embedded traceable thermocouples and/or phosphor coating embedded in a uniform temperature cavity	**NPL**, DTI
A1 1 3 M8	NPL, with the support of DTI, will optimise the binder/phosphor selection recipe for the phosphor(s) selected in A1 1 1 and will evaluate aspects such as adhesion, calibration cycle stability, durability and temperature sensitivity NPL, with the support of DTI, will define the key uncertainties such as repeatability, sensitivity and heat flow/temperature gradients in the thermographic phosphor and the underlying substrate	**NPL**, DTI
A1 1 4 M6	NPL, DTI and PTB will develop a thermal model to assess the relationship between phosphor temperature and the embedded traceable thermocouples, to quantify key uncertainties such as repeatability, sensitivity and heat flow/temperature gradients in the thermographic phosphor and the underlying substrate	**NPL**, DTI, PTB
A1 1 5 M14	STRATH and PTB will investigate the properties of a cavity with phosphor and a cavity without phosphor, for use in furnaces at STRATH, and will simulate the effective emissivity of the furnaces	**STRATH**, PTB
A1 1 6 M20	Using input from A1 1 1 – A1 1 5, NPL, PTB, CMI, DTI, SMU, VTT, STRATH and Beamex will develop methodologies (e g where to put the phosphors in the field of view of the thermal imager, how to combine the uncertainties of the phosphor thermometry and thermal imager) to employ phosphors for traceable, quantitative thermal imaging by placing them in the thermal imager field of view and assess the uncertainties	**NPL**, PTB, CMI, DTI, SMU, VTT, STRATH, Beamex

A1 1 7 M24	In order to assess how the AI technique functions with thermal imaging, VTT and Beamex will use one of the large-area flat-plate reference phosphor blackbodies developed and connected to a dry-block calibrator in A4 3 2 in conjunction with a digital twin developed in A4 3 3 to compensate for deviations in the reference temperature (to assess thermal contact resistance, i e thermal perturbations due to contact/phosphor spot) The AI technique will act as another reference service The output will be a compensated, high-resolution surface with a known, traceable temperature VTT and Beamex will assess the uncertainties	**VTT**, Beamex

C1.b Task 1.2: Emissivity characterisation of a) the surface and b) the phosphor itself

Quantitative thermal imaging cannot be performed without knowing the emissivity of the surface (and any phosphors in the field of view), which is often difficult to determine accurately enough The aim of the task is to measure the emissivity of the phosphors and common engineering materials with 3 different methods (PTB's Emissivity Measurement in Air Facility apparatus, SMU's virtual source method, and the method of adjusting the thermal imager's emissivity setting while viewing an object of known temperature) Due to the extreme difficulty of measuring emissivity, it is necessary to assess the agreement between the different techniques This task combines the three techniques, and then demonstrates how these can be applied to an actual in-field-of-view reference artefact with known emissivity

Activity number	Activity description	Participants (Lead in bold)
A1 2 1 M3	NPL will prepare from scratch three different metal surfaces (bare metal, binder only, and phosphor coated) for assessment of their emissivity in A1 2 3 and A1 2 5	**NPL**
A1 2 2 M9	PTB, with support from NPL, will select at least 4 samples representative of commonly used materials in industry (e g , titanium, steel, aluminium) PTB, with support from NPL, will measure spectral, angular and hemispherical emissivity in air (20 °C to 500 °C), and in vacuum (-40 °C to ambient) of these at least 4 samples, using PTB's Emissivity Measurement in Air Facility (EMAF) At least 3 samples will be measured in air and at least 1 will be measured in vacuum PTB will then assess the effect of vacuum, humidity and gas on the emissivity measurement and calibration of the phosphor coating (from A1 1 1) The reference emissivity dataset for key engineering materials will be made available in Zenodo repository	**PTB**, NPL
A1 2 3 M16	SMU, with support from PTB and NPL, will develop a virtual source method to determine the emissivity of the phosphor(s) selected in A1 1 1 and prepared in A1 2 1 (in air only) at elevated temperatures above 250 °C The virtual source method will be based on the equivalency of emissivity and reflectance according to Kirchhoff's law Furthermore, it provides an independent traceability chain for emissivity measurements SMU will apply the method to measure the emissivity of the representative samples used in A1 2 2 in air only at temperatures above 250 °C	**SMU**, PTB, NPL
A1 2 4 M18	SMU will analyse the data obtained from A1 2 3 and determine the uncertainty budget of the developed emissivity virtual source measurement method from A1 2 3 when applied to phosphors	**SMU**
A1 2 5 M28	NPL and PTB will measure the emissivity of the surfaces from A1 2 1 This will include using methods of a) emissivity deduced from the thermal image (i e , adjusting the thermal imager's emissivity setting while viewing an object of known temperature) and b) measuring emissivity with PTB's EMAF equipment The two methods will be compared by NPL and PTB	**NPL**, PTB
A1 2 6 M33	NPL, PTB and SMU will compare the different emissivity determination methods from A1 2 2, A1 2 3 and A1 2 5, and will draft a paper on the results and submit it to a peer-reviewed journal	**NPL**, PTB, SMU
A1 2 7 M36	NPL and DTI will modify an existing phosphor thermometer (fibre coupled or camera based) to operate below 0 °C and will demonstrate the successful operation over the full temperature range (NPL -100 °C to 500 °C, DTI -50 °C to 500 °C) This will feed into A1 2 8	**NPL**, DTI

A1 2 8 M36	Using input from A1 2 7 and the different emissivity determination methods from A1 2 2, A1 2 3 and A1 2 5, NPL and PTB will conduct cross-comparison thermal imager measurements of a 'reference' scene (i e , end result) or in-field-of-view reference materials at their respective laboratories in order to establish that the newly developed techniques work as intended	**NPL**, PTB
A1 2 9 M34	PTB with support from NPL and SMU will collate the emissivity dataset for key engineering materials (A1 2 2) and the emissivity dataset for selected phosphor coatings (A3 1 5) into one dataset Once agreed by the consortium, the coordinator on behalf of PTB, NPL and SMU will submit the collated dataset to EURAMET as **D1** *'Emissivity dataset for at least 4 key engineering materials and selected phosphors, including spectral, angular and hemispherical emissivity'*	**PTB**, NPL, SMU

C1.c Task 1.3: Scene-based corrections and traceable calibration for quantitative thermal imaging

The aim of this task is to establish methods to correct for the non-uniform response of thermal imaging systems using AI, increase the range of traceable calibration of thermal imagers, and calibrate the selected phosphors from -100 °C to 500 °C

Activity number	Activity description	Participants (Lead in bold)
A1 3 1 M18	PTB will employ a scene-based correction method for non-uniformity even when there is a non-uniform scene and identify the limits when there are e g , sharp edge temperature changes that cause artefacts The results will be compared with an *ex-situ* (i e using a reference scene without sharp temperature gradients in the lab) non-uniformity correction	**PTB**
A1 3 2 M30	PTB and CMI will implement scene-based non-uniformity correction factors obtained in A1 3 1 into thermal imagers PTB and CMI will contact a collaborator (e g , Workswell, AMETEK-LAND) and request their advice/support and the provision of the thermal imagers	**PTB**, CMI
A1 3 3 M18	NPL will extend its range of ITS-90 traceable calibrations, i e update its ITS-90 calibration facility, for infrared thermal imaging to incorporate a minimum target temperature of -100 °C	**NPL**
A1 3 4 M24	Using input from A1 3 3, NPL will select a phosphor coating and a thermometer best suited for given temperature range and calibrate it from -100 °C to 500 °C This will include reproducibility with thermal cycling and development of a calibration uncertainty budget, with a target uncertainty of 1 °C	**NPL**
A1 3 5 M36	In order to assess how the AI technique can correct the produced artefacts, NPL and PTB will measure the temperature distribution of one of the VTT / Beamex flat-plate blackbodies developed in A4 3 2 using phosphor thermometry and thermal imaging respectively and will compare their measurements with the predictions of the AI algorithm (digital twin) dedicated to the flat-plate in A4 3 3 This will establish new methods to correct for the non-uniform response of thermal imaging systems using AI	**NPL**, PTB, VTT, Beamex

C1.d Task 1.4: Validated quantitative thermal imaging

The aim of this task is to perform a comparison of surface temperature measurements using the improved phosphors, embedded thermocouples and improved thermal imager This will be used to perform a pilot study to develop readiness for a future CCT key comparison of thermal imagers These activities represent validation of traceable, quantitative thermal imaging, and draw together the emissivity determinations, phosphor thermometry, thermal imaging, and reference flat-plate

Activity number	Activity description	Participants (Lead in bold)
A1 4 1 M24	NPL with input from PTB, will perform a comparison of surface temperature measurements with phosphor thermometry embedded thermocouples and the calibrated thermal imager developed in A1 3 4 on the samples tested in A1 2 2, thereby validating the new techniques	**NPL**, PTB

A1 4 2 M30	Using input from A1 3 2 and A1 3 3, PTB, NPL and CMI will perform a pilot study to facilitate readiness for a future CCT key comparison on the calibration of thermal imagers The pilot study will, on a smaller scale, assess the feasibility of a future key comparison and will include a development of a draft protocol for it This will enable PTB, NPL and CMI to validate the thermal imager measurements A thermal imager calibrated in A1 3 4 and a common 'standard' surface will be used in the study, candidates will include one of the VTT / Beamex large-area blackbodies developed in A4 3 2	**PTB**, CMI, VTT, NPL, Beamex
A1 4 3 M36	PTB, with input from NPL and CMI, will draft a paper on the results of the pre-key comparison of surface thermometry performed in A1 4 2 and submit it to a peer-reviewed journal	**PTB**, CMI, NPL
A1 4 4 M36	Using input from A1 1 1-A1 1 7, A1 2 1 -A1 2 9, A1 3 1-A1 3 5 and A1 4 1-A1 4 3, NPL, with support from CMI, PTB, SMU, VTT and Beamex, will draft a paper on the techniques developed for traceable quantitative thermal imaging, by using at least 4 key engineering materials and selected phosphors with known temperature in the field of view of the thermal imager in the range of -100 °C to 500 °C with an uncertainty of less than 5 °C Once agreed by the consortium, the coordinator on behalf of NPL, CMI, PTB, SMU, VTT and Beamex will submit the paper to EURAMET as **D2** *'Paper on the techniques developed for truly traceable, quantitative thermal imaging, by using at least 4 key engineering materials and selected phosphors with known temperature in the field of view of the thermal imager in the range of -100 °C to 500 °C with an uncertainty of less than 5 °C submitted to a peer-reviewed journal'*	**NPL**, CMI, PTB, SMU, VTT, Beamex

C2 WP2: Improving the technology readiness of practical Johnson noise thermometry

JNT is, in principle, immune to calibration drift due to sensor degradation in harsh environments Recently, new JNT concepts have been introduced and are currently being finalised

The Metrosol IJNT is designed for temperature sensors in the kΩ range and has a wide measurement bandwidth to allow short measurement times It performs simultaneous calculation of the sensor resistance and system frequency response as well as the Johnson noise power The ULNT is based on the Metrosol approach but involves a commercial sound card for data acquisition and a wideband transformer for injecting the reference signal The CMINT is based on two channel noise measurement, using low noise discrete FET transistors with high input impedance, connected in parallel In contrast to the other JNTs, the DART involves only a single highly stable and linear signal channel that is calibrated with a Josephson arbitrary waveform synthesiser (JAWS) The spectral density of the thermal noise in the sensing resistor is determined directly in a sequential measurement procedure without the need for correlation techniques Since the DART simultaneously measures the resistance and the noise of the temperature sensor, it combines noise and resistance thermometry

The aim of this work package is to establish the operational readiness of the new JNT concepts outlined above for industrial applications (e g nuclear decommissioning and waste storage, high value heat treatment) This includes concepts for and demonstrations of calibration, traceability, and temperature measurements at fixed points as well as at industry-relevant temperatures In Task 2 1 metrological characterisation of the JNTs will be performed and the achievable measurement uncertainty with the calibrated instruments will be demonstrated Due to the small amplitude of the thermal noise, external electromagnetic interference is a severe problem in JNT so the electrical shielding will be improved to achieve a target uncertainty of less than 3 °C at 1200 °C Task 2 2 addresses the development and testing of robust sensor elements which are usable for temperature measurements up to about 1200 °C This includes measurements in harsh environments (high temperature, electromagnetic fields) and susceptibility of the sensor to ionisation radiation Finally in Task 2 3, a comparison of the JNT systems will be carried out and uncertainty budgets developed

C2.a <u>Task 2.1: Establishing the operational readiness of practical JNTs</u>

The aim of this task is the metrological characterisation of a complete JNT including its traceability, to lay the metrological framework needed for operation in harsh industrial environments The calibration of the DART will be performed entirely electrically with an uncertainty of about 10 parts per million (ppm) by using a JAWS The other JNTs will be calibrated against electrical standards and checked against temperature standards Here, the target uncertainty of 3 °C for measurements (this is independent of calibration uncertainty) results

from Rice's equation [61] for short time periods First measurements with the calibrated instruments will be performed at the melting point of gallium (29 7646 °C)

Activity number	Activity description	Participants (Lead in bold)
A2 1 1 M6	PTB will implement an electrical calibration setup for their DART including a JAWS used for generating the calibration signals Metrosol, NPL, UL and CMI will explore the ability of their JNT systems to retain calibration (to electrical standards, as per their respective existing calibration schemes) over extended periods of time	**PTB**, CMI, UL, Metrosol, NPL
A2 1 2 M9	Using input from A2 1 1, Metrosol and NPL will determine the optimal calibration approach to their joint IJNT to permit traceability, and then develop a way of calibrating the IJNT, either from an electrical point of view or, if necessary, from a temperature point of view (e g , calibrate at one temperature to realise quasi-primary thermometry)	**Metrosol**, NPL
A2 1 3 M18	PTB will use the setup implemented in A2 1 1 to demonstrate an electrical calibration of the DART with a target uncertainty of about 10 parts per million The Metrosol/NPL IJNT will be calibrated by Metrosol and NPL with the method from A2 1 2 with a target uncertainty of 0 1 °C at room temperature The ULNT and the CMINT will be calibrated by CMI and UL, using the same method with a target uncertainty of 0 5 °C up to 300 °C and tenths of °C, respectively	**PTB**, CMI, NPL, UL, Metrosol
A2 1 4 M24	Using input from A2 1 2, Metrosol and NPL will complete the design of the measurement procedure and will check the robustness of the IJNT to electromagnetic interference characteristic of use in harsh industrial environments, and intercompare with the PTB DART system to share best practice PTB will implement measurement procedures and setups of the DART for highly accurate temperature measurements This includes the development of suitable shielding against electromagnetic interference to achieve a target uncertainty of less than 3 °C at 1200 °C UL and CMI will assess the performance of their systems in different AC/DC magnetic fields Procedures developed within this activity will serve as an input to A2 1 5 and A2 2 2 and interdependently, the feedback from A2 1 5 and A2 2 2 will serve as an input to this activity to refine the procedures if required	**Metrosol**, CMI, PTB, UL, NPL
A2 1 5 M24	NPL, Metrosol, PTB and UL will evaluate the accuracy of temperature measurements at the melting point of gallium, with a well-known temperature of 29 7646 °C (302 9146 K) defined in the ITS-90 Also, the ability of the thermometer to retain its accuracy over time with the upgraded calibration scheme will be explored and compared with the findings of A2 1 1 Since the DART uses a calibrated platinum resistance thermometer, its dual-mode feature allows a direct comparison to the ITS-90 CMI will focus on the evaluation of their JNT at fixed points from the triple point of mercury (-38 8433 °C) to the freezing point of zinc (419 527 °C) This activity will use input and provide feedback to A2 1 4	**NPL**, CMI, PTB, UL, Metrosol
A2 1 6 M27	Using input from A2 1 1-A2 1 5, PTB, NPL, Metrosol, UL and CMI will draft a paper summarising Johnson noise thermometry electronics with a technology readiness level of 6 and an uncertainty less than 3 °C for practical use in harsh industrial environments at temperatures up to 1200 °C and submit it to a peer-reviewed journal Once agreed by the consortium, the coordinator on behalf of PTB, NPL, Metrosol, UL and CMI will submit the paper to EURAMET as **D3** *'Paper summarising Johnson noise thermometry electronics with a technology readiness level of 6 and an uncertainty less than 3 °C for practical use in harsh industrial environments at temperatures up to 1200 °C submitted to a peer-reviewed journal'*	**PTB**, CMI, NPL, UL, Metrosol

C2.b Task 2.2: Developing and testing of robust probe assembly up to 1200 °C

The aim of the task is to develop and to test a robust noise temperature probe assembly (e g , leading wires, insulators, sensing elements) which is usable for temperature measurements up to about 1200 °C with a measurement uncertainty of less than 3 °C In addition, measurements in harsh environments (high temperature i e , industrial and induction furnaces) and the sensor's susceptibility to electromagnetic interference and ionising radiation will be investigated For the DART, low-ohmic sensors that are adaptable to high-temperature operation will be used In contrast, for the other JNT systems (IJNT, ULNT and CMINT), sensor elements with a relatively high resistance (a few kΩ) are preferable

Activity number	Activity description	Participants (Lead in bold)
A2 2 1 M18	Metrosol will increase the temperature range of their sensor based on thin wire from 1000 °C to 1200 °C In addition, Metrosol, NPL and UoM will investigate suitable micro-fabricated devices such as graphene encapsulated in protective ceramics which can achieve the desired electrical characteristics, e g , resistance, up to 1200 °C, while protecting the sensor element from contamination and oxidation PTB will investigate suitable materials and assembly techniques for sensors, lead-in wires, insulators and probes up to 1200 °C High-temperature resistant materials will be used to design the noise resistor and will be used for the signal transmission lines, which are electrically insulated from each other in a suitable manner UL will develop a sensor for temperatures up to 1200 °C with a resistance of about 1 kΩ CMI will extend the temperature range of their sensor to 1000 °C with usage of new materials and components suitable for this temperature range	**Metrosol**, CMI, PTB, UL, NPL, UoM
A2 2 2 M18	PTB will optimise the shielding techniques developed by M12 in A2 1 4 and minimise the electromagnetic interference for high-temperature operation A suitable metal tube for the sensor, efficient shielding for the cabling of the DART electronics, and suitable connection techniques will be developed Interdependently, feedback will be provided back to A2 1 4 Metrosol and NPL will share their prior knowledge of EMC immunity of the IJNT and check their results at high temperature The problem of electrical insulators starting to conduct at high temperature will be examined Metrosol, NPL and UoM will further develop a suitable robust probe to house the sensor elements developed in A2 2 1, and will provide a prototype probe assembly to UL to examine its utility with the ULNT UL will assess the effect of different magnetic fields on their sensors	**PTB**, UL, Metrosol, NPL, UoM
A2 2 3 M30	Using input from A2 2 1, NPL, Metrosol and UoM will demonstrate the IJNT using different sensors and probes at temperatures up to 1200 °C in an industrial furnace at STRATH, who will provide and operate the real-world manufacturing facilities The demonstration will include testing in an induction furnace which will be a challenging EMC environment for JNT systems PTB, UL and CMI will demonstrate a measurement under laboratory conditions at high temperatures up to 1200 °C with a target uncertainty of less than 3 °C This trial to assess the self-validation machine learning algorithm(s) also includes the self-validating thermocouple which will be done in A4 1 7	**NPL**, CMI, PTB, UL, Metrosol, STRATH, UoM
A2 2 4 M30	NPL will provide gamma and neutron radiation facilities representative of nuclear waste storage to investigate the influence of ionising radiation on sensors PTB will investigate the influence of ionising radiation on DART and their other sensors at NPL or at PTB For this purpose, a measurement will be made at a fixed point before and after the exposure of the sensor NPL, Metrosol and UoM will further test the IJNT and probe assembly under ionising radiation (neutron and gamma) with dose rates applicable to nuclear waste storage and monitoring The aim will be to look at short-term effects during irradiation (e g , difference between beam on and beam off), and long-term effects (significant changes in the indicated temperature)	**NPL**, PTB, Metrosol, UoM
A2 2 5 M34	Using input from A2 2 1-A2 2 4, NPL, Metrosol, PTB, UoM, UL, CMI and STRATH will draft a report on the development of a robust probe assembly for JNT and tests in harsh environments up to 1200 °C Once agreed by the consortium, the coordinator on behalf of NPL, PTB, Metrosol, UL, UoM, STRATH and CMI will submit the report to EURAMET as **D4** *'Report on a robust probe assembly for measuring Johnson noise in harsh environments (e g , high temperatures up to 1200 °C, ionising radiation (gamma rays and neutrons), electromagnetic fields)'*	**NPL**, CMI, PTB, UL, Metrosol, STRATH, UoM

C2.c Task 2.3: Intercomparison of JNT systems

The aim of this task is to assess the consistency of noise temperature measurements performed by different JNT approaches The JNT systems (DART, IJNT, ULNT and CMINT), are compared with each other at different fixed points as well as against calibrated standard thermocouples and an uncertainty budget developed

Activity number	Activity description	Participants (Lead in bold)
A2 3 1 M33	Using input from A2 1 5, PTB, with support from NPL, Metrosol, UL, and CMI, will perform intercomparison measurements between DART, IJNT, ULNT and CMINT systems at well-known temperatures in a largely interference-free environment (shielded cabin) at the melting point of gallium (29 7646 °C) and under laboratory conditions at one or two fixed points of the ITS-90, e g , Zn (419 527 °C), Al (660 323 °C), Ag (961 78 °C), or Cu (1084 62 °C) The development of an uncertainty budget will be included	**PTB**, CMI, UL, NPL, Metrosol
A2 3 2 M33	Using input from A2 1 5, PTB, with support from NPL and Metrosol, will perform intercomparison measurements of the DART and IJNT against calibrated standard thermocouples under largely interference-free conditions (shielded cabin) in a furnace with extra measures for interference suppression and under laboratory conditions by using a furnace routinely used for thermocouple calibrations The measurements will be carried out at at least two temperatures between 600 °C and 1200 °C The development of an uncertainty budget will be included	**PTB**, NPL, Metrosol
A2 3 3 M34	NPL, PTB, Metrosol, UL, UoM and CMI will analyse the measurement results from A2 3 1 and A2 3 2 and will draft a briefing report on the state of the art of practical JNT and submit it to CCT	**NPL**, CMI, PTB, UL, Metrosol, UoM

C3 WP3: Thermographic phosphor thermometry up to 1250 °C

Phosphor thermometry can overcome challenges experienced by thermal imaging, but so far has a limited temperature range, and lacks widely accepted, validated calibration methods The aim of this work package is to develop thermographic phosphor thermometry with a target uncertainty of less than 3 °C up to a temperature of 1250 °C, to provide low uncertainty traceable surface temperature measurement It encompasses tasks aimed at advancing high-temperature phosphor thermometry in a robust metrological way

In Task 3 1 thermographic phosphor coatings capable of operating at temperatures up to 1250 °C will be developed In Task 3 2 phosphor thermometry instrumentation capable of interrogating the newly developed high-temperature phosphor coating will be constructed, calibrated, and tested Task 3 3 will involve practical demonstration of the newly developed phosphor thermometry capability (robust high-temperature coating and instrumentation) in targeted high-value manufacturing sectors, i e , marine steel processing and induction heating of engineering alloys

C3.a Task 3.1: Developing thermographic phosphor coatings to 1250 °C

The aim of this task is to develop a thermographic phosphor coating capability suitable for measurements up to a target temperature of 1250 °C Currently, phosphors are limited to 750 °C for continuous use, with intermittent use to 1000 °C A comprehensive survey of high temperature phosphors up to 1250 °C, exploring temperature range, operational methods, and measurement/excitation wavelengths, will be undertaken Concurrently, an investigation of suitable high temperature binders will be carried out This will inform the procurement and/or synthesis of at least two target phosphors, and the development of a coating recipe that will be tested in terms of stability with thermal cycling, and luminescence The emissivity of selected coatings at temperatures up to 500 °C, and at wavelengths from 1 4 µm to 20 µm, will also be assessed, as will the impact of the coatings on surface temperature using numerical simulations

Activity number	Activity description	Participants (Lead in bold)
A3 1 1 M12	NPL, DTI and OVGU will jointly perform a survey on high temperature phosphors to 1250 °C, including temperature range, thermometry method (decay time, frequency shift, and intensity ratio), measurement wavelengths and excitation wavelengths NPL, DTI and OVGU will contact a collaborator from high-temperature phosphor specialists (e g ONERA) and request their support NPL, DTI and OVGU will select at least 2 novel high-temperature phosphors for use in A3 1 3 and A3 1 4	**NPL**, DTI, OVGU

A3 1 2 M12	NPL, DTI, OVGU and STRATH will perform a survey on high temperature binders to 1250 °C, including glass lubricant/coating NPL, DTI, OVGU and STRATH will contact a collaborator from a high-temperature phosphor specialist (e g ONERA) and request their support NPL, DTI, OVGU and STRATH will select at least 2 binders for use in A3 1 4	**NPL**, DTI, OVGU, STRATH
A3 1 3 M18	NPL with support from OVGU will synthesise at least 2 novel high-temperature phosphors selected in A3 1 1 (i e , manufacture a powder to develop the phosphor coatings) suitable for use to 1250 °C NPL will contact a collaborator from a high-temperature phosphor specialist (e g ONERA) and request their support	**NPL**, OVGU
A3 1 4 M24	Using input from A3 1 1, NPL, DTI and OVGU will develop and test at least 2 phosphor/binder recipes and then select the most promising one suitable for use to 1250 °C for producing the sample coatings This will include performing an assessment of at least two high temperature phosphors synthesised in A3 1 3 and at least 2 binders selected in A3 1 2, in terms of a) coating stability with thermal cycling, b) characterisation of the luminescence of phosphor/coating (spectral and temporal domain) and analysing measurement strategies (decay time, frequency shift and spectral intensity ratio) suitable for the high temperature conditions	**NPL**, DTI, OVGU
A3 1 5 M24	Using experience gained from A1 2 2, A1 2 3 and A3 1 4, PTB, with support from NPL, will select at least 4 coatings from A1 2 2 and A3 1 4 (e g Dy YAG phosphor and "HPC" binder from ZYP coatings) and determine their emissivity in line with criteria identified in A1 1 1 and survey in A3 1 1, at temperatures up to 500 °C, over the wavelength range 1 4 µm to 20 µm for input to A1 2 9 The reference emissivity dataset for selected thermographic phosphors will be made available on the Zenodo repository	**PTB**, NPL
A3 1 6 M24	Using input from A3 1 5, NPL will perform an assessment of the effect of the coatings from A3 1 5 on the temperature of the surface by developing a 1D analytical and 2D finite element thermal model of the coating/substrate/external environment NPL will apply a phosphor coating from A3 1 5 to one of the VTT / Beamex flat-plate blackbodies developed in A4 3 2 This will allow for the comparison of the phosphor thermometry indication (from applying the coating) with the temperature distribution determined with AI (included in the blackbody)	**NPL**, VTT, Beamex
A3 1 7 M30	Using input from A3 1 1-A3 1 6, NPL, DTI, OVGU and STRATH will draft a paper on the robustness of phosphor thermometry up to 1250 °C and submit it to a peer-reviewed journal Once agreed by the consortium, the coordinator on behalf of NPL, DTI, OVGU and STRATH will submit the paper to EURAMET as **D5** *'Paper on robust thermographic phosphor techniques for surface temperature measurement with an uncertainty of less than 3 °C and up to temperatures of 1250 °C submitted to a peer-reviewed journal'*	**NPL**, DTI, OVGU, STRATH

C3.b Task 3.2: Developing phosphor thermometry instrumentation capable of measuring phosphors up to 1250 °C

The aim of this task is to develop phosphor thermometry instrumentation or extend existing instruments to operate up to a target temperature of 1250 °C, to measure on the most promising phosphor/binder recipe developed in A3 1 4 This will include thermometer calibration, the effect of thermal cycling on the calibration with a target uncertainty of 3 °C at 1250 °C and determining the uncertainty for the extended range phosphor thermometer Additionally, a sensitivity analysis of the high temperature phosphor thermometer will be performed, exploring dependencies on excitation strength and stand-off distance

Activity number	Activity description	Participants (Lead in bold)
A3 2 1 M24	NPL and OVGU will develop a high temperature fibre-coupled phosphor thermometer (10 cm max stand-off) with a maximum target temperature of 1250 °C for the high temperature phosphor/binder recipe selected in A3 1 4 DTI will extend the maximum temperature from 500 °C for their current high temperature phosphor thermometer to 1200 °C	**NPL**, DTI, OVGU

A3 2 2 M24	NPL and OVGU will perform calibration and thermal cycling tests of the high temperature phosphor thermometer developed in A3 2 1, including uncertainty budgets, with target uncertainty of 3 °C at 1250 °C, using high temperature furnaces at NPL DTI, using their furnace, will perform calibration and thermal cycling tests of their high temperature phosphor thermometer from A3 2 1 with target uncertainty of 3 °C at 1200 °C	**NPL**, DTI, OVGU
A3 2 3 M24	NPL, DTI and OVGU will perform a sensitivity analysis of the high temperature phosphor thermometers calibrated in A3 2 2, including excitation strength and stand-off distance dependencies	**NPL**, DTI, OVGU
A3 2 4 M30	NPL, DTI and OVGU will draft a paper on metrological evaluation of novel high temperature phosphor thermometry and submit it to a peer-reviewed journal	**NPL**, DTI, OVGU
A3 2 5 M30	Using input from A3 1 4-A3 1 7 and A3 2 1-A3 2 4, NPL, with support from DTI, will prepare a briefing report on traceable phosphor thermometry, outlining best practice in the preparation, application, and temperature measurement of phosphor coatings and submit it to the CCT	**NPL**, DTI
A3 2 6 M30	Using input from A3 2 2, NPL and DTU will perform spectral surface emissivity measurements of the high temperature phosphors in mid-infrared and near-infrared spectral ranges using phosphor thermometer (NPL) and FTIR spectrometers (DTU) The results of the activity will be used in A3 3 3 and A4 2 6	**NPL**, DTU

C3.c Task 3.3: Demonstration of high-temperature phosphor thermometry in high-value manufacturing sector

The aim of this task is to trial the high-temperature phosphor thermometry capability developed in Task 3 1 and Task 3 2 in industrially relevant high-value manufacturing environments Field trials will be performed in two manufacturing environments, namely marine steel processing above 800 °C (BAE) and induction annealing of engineering alloys at temperatures of up to 1250 °C (STRATH) Additionally, the phosphor thermometer will be calibrated on boiler isolation materials (Inconel or refractory bricks) up to a maximum temperature of 1100 °C for utilisation in Task 4 2 (A4 2 6 and A4 2 7), focusing on surface temperature and spectral surface emissivity determinations

Activity number	Activity description	Participants (Lead in bold)
A3 3 1 M30	Using the phosphor thermometer from A3 2 1, NPL will perform a demonstration of high temperature phosphor thermometer measurements at temperatures above 800 °C on a BAE marine steel pipe annealing application, including laboratory calibration before and after trials to assess calibration drift	**NPL**, BAE
A3 3 2 M32	Using input from A3 3 1, NPL will perform trials of the high temperature phosphor thermometer on the STRATH induction heating system at temperatures up to 1250 °C on a number of engineering alloys, and will compare this new phosphor thermometry technique with the existing extrapolation method that uses embedded thermocouples DTI and DTU, with the support of NPL, will compare measurements of the inner surface temperature performed on reformer tubes from 700 °C to the 1050 °C using infrared spectrometry, miniature thermocouples and phosphor thermometry in DTU's emissivity facility Laser heating will be used to reduce temperature gradients in the sample NPL will contact a collaborator (e g , Topsoe A/S) for the provision of samples from new and used reformer tubes, some of which are already available for test at DTU	**NPL**, DTI, DTU, STRATH
A3 3 3 M34	Using input from A3 3 2 and A3 2 6, NPL, with support from DTU, will calibrate the high temperature phosphor thermometer on used and new boiler insulation materials such, e g , Inconel or refractory bricks at temperatures between 800 °C and 1100 °C for use in surface temperature and spectral surface emissivity determinations in A4 2 6 Preliminary results will be made available in M25 Surface temperature measurements will be compared by NPL and DTU in their laboratories (as opposed to industrial sites) where a high temperature phosphor thermometer, a FTIR spectrometer and an IR camera will be used	**NPL**, DTU
A3 3 4 M34	NPL, DTI, STRATH and BAE will draft an article describing practical high-temperature phosphor thermometry in high-value manufacturing and submit it to a trade journal Once the agreed by the consortium, the coordinator on behalf of NPL, STRATH, DTI and BAE will submit the article to EURAMET as **D6** *'Article on the practical application of phosphor thermometry submitted to a trade journal'*	**NPL**, DTI, BAE, STRATH

C4 WP4: Artificial Intelligence to facilitate improved thermometry

Many thermometry methods are sub-optimal due to the limited analysis techniques used The aim of this work package is to develop artificial intelligence (AI) approaches to enable *in-situ* temperature traceability, exemplified by case studies including practical demonstrations, including a) the application of AI to self-validating thermometers to enable autonomous, continuously traceable operation, b) spectroscopic infrared thermometry for *in-situ* gas temperature profile measurements in hot environments using new generation of infrared detectors, and c) surface temperature calibration flat-plate blackbody insert for dry-block calibrators for calibration of thermal imagers and phosphors

Self-validating thermocouples are now mature but are held back by the inability of conventional software to identify the characteristic phase-change cell melting plateau in the temperature-time data New techniques using the state-of-the-art in machine learning will be developed to locate any instance of the melting plateau and automate the corresponding *in-situ* recalibration, enabling truly driftless thermometry The target uncertainty for the *in-situ* calibration is 1 °C

In *in-situ* gas and combustion temperature measurements, because process conditions vary continuously, it is necessarily to develop robust measurement techniques that can provide a user with a real-time data flow This is only possible with the use of AI approaches in a complex real-time data analysis The target uncertainty for in-process gas temperature retrievals is 2 % which is aligned with the requirements for e g selective non-catalytic reduction (SNCR) process control (e g power plants and waste incineration)

Calibration surfaces generally have a large uncertainty in the areal temperature distribution due to the complicated heat exchange at the surface Inserts for dry-block calibrators will be developed with thermometers distributed throughout the volume, to be operated in conjunction with a neural network and digital twin which uses the data from the sensor network to determine the temperature distribution on the surface plate The target uncertainty on the plate temperature is 1 °C

Task 4 1 will investigate the use of machine learning for automation of self-validating thermometers In Task 4 2 AI approaches to enable retrieval of gas temperatures using spectroscopic techniques will be developed In Task 4 3 neural network approaches to thermometer networks used to retrieve the temperature distribution across low-cost dry-block calibrator inserts for calibration of thermal imagers and phosphors will be developed

C4.a Task 4.1: Machine learning for autonomous operation of self-validating thermometers

Self-validating thermometers which make use of a miniature phase-change cell are now reliable and have been demonstrated in high value manufacturing processes However, the detection and characterisation of the melting curve (plateau in temperature-time data) which enables re-calibration *in situ* remains a manual process and attempts to automate it have been resistant to conventional algorithms Machine learning represents a well-known approach to recognition of characteristic features in data The aim of this task is to investigate the use of a machine learning approach, based on a supervised Bayesian optimised learning procedure [39], for automation of self-validating thermometers Data will be procured from selected high value heat treatment processes in industry for training and testing the machine learning algorithm The robustness of the algorithm will then be tested under a range of different industrial furnace environments The target uncertainty in the *in-situ* calibration is 1 °C

Activity number	Activity description	Participants (Lead in bold)
A4 1 1 M12	DTU, PTB, VTT, UL, NPL, NSC-IM, STRATH, B&W Volund, Beamex and CCPI will perform a survey (questionnaire) of key existing AI methods, sensors/instruments, including their hardware & software implementations and platforms, and challenges for industrial use These will be divided into key sections relevant to end-user measurement techniques in industrial applications e g change point detection, instrument/sensor position, signal validation, diagnosis and correlation A questionnaire will be distributed by DTU to the Stakeholder Community to assist with this activity The targeted stakeholders will come from high volume manufacturing, nuclear decommissioning, waste storage, fundamental and sensor work metrology, utilities, environmental monitoring, smart buildings, etc The target number of stakeholders participating in the questionnaire will be 30	**DTU**, PTB, VTT, UL, NPL, NSC-IM, STRATH, B&W Volund, Beamex, CCPI

	DTU, PTB, VTT, UL, NPL, NSC-IM, STRATH, B&W Volund, Beamex and CCPI will draft a short report on key existing AI applications in industry based on the outcomes of the survey, The report will be made publicly available on the project website	
A4 1 2 M12	Based on results of the survey from A4 1 1, and on existing approach based on a supervised Bayesian optimised learning procedure (see [39] for details), NPL, CCPI and UL will share their experiences, and NPL and UL will then both develop dedicated machine learning algorithms suitable for a) locating multiple melting plateaus in any given temperature-time data set for self-validating thermocouples, b) characterising the part of the melting curve that corresponds to the calibration point, c) quantifying the uncertainty on the self-calibration	**NPL**, UL, CCPI
A4 1 3 M14	NSC-IM, with support from NPL, will adapt their existing self-validating thermocouples to enable their use in typical industrial applications and will develop an algorithm to automate their use NSC-IM will supply temperature-time data to NPL for further broadening the applicability of the NPL's machine learning algorithm of A4 1 2 UL will implement a self-validating thermocouple in a high temperature furnace up to 1200 °C and will assess the suitability of their algorithm developed in A4 1 2 for self-calibration	**NSC-IM**, UL, NPL
A4 1 4 M18	CCPI, NSC-IM and NPL will obtain training data for the NPL's machine learning algorithm developed in A4 1 2 (temperature as a function of time) from historic and currently running industrial trials in at least 3 high value manufacturing heat treatment facilities (under CCPI)	**CCPI**, NPL, NSC-IM
A4 1 5 M24	NPL will divide the data obtained in A4 1 4 into 2 sets a training set and a validation set NPL will use one set of the data (training set) to train the algorithm developed in A4 1 2 and the other set (validation set) to test/demonstrate the algorithm's general applicability to temperature-time data	**NPL**
A4 1 6 M30	Based upon the findings of A4 1 5, NPL, with support from CCPI, will enhance the algorithm developed in A4 1 2 to improve its robustness across the full range of data obtained in A4 1 4	**NPL**, CCPI
A4 1 7 M32	NPL, STRATH and CCPI will test the NPL's algorithm developed in A4 1 2 by placing a self-validating thermocouple in a heat treatment process environment at STRATH together with the JNTs in A2 2 3 and assessing the robustness of AI for self-validating *thermocouples under a range of this and other, different, industrial furnace* environments (i e , under a range of heat treatments in one environment, such as forging furnace, annealing furnace etc) NSC-IM will test their algorithm developed in A4 1 3 to assess the utility of AI for self-validating thermocouples in measuring channels with limited access (specifically in nuclear power plants)	**NPL**, CCPI, NSC-IM, STRATH
A4 1 8 M34	Using input from A4 1 1-A4 1 7, NPL, UL, CCPI, NSC-IM and STRATH will draft a paper on the use of machine learning for automation of self-validating thermometers, including case studies (A4 1 3, A4 1 4, A4 1 5) in industrial heat treatment plants and submit it to a peer-reviewed journal	**NPL**, UL, NSC-IM, STRATH, CCPI

C4.b Task 4.2: AI for traceable spectroscopic infrared thermometry to enable *in-situ* gas temperature and gas temperature profile measurements

Spectroscopic gas thermometry relies on an iterative approach to retrieving the temperature which can be very inefficient or even intractable The aim of this task is to develop AI approaches using computational narrow-band laser absorption (TDLAS) and broad band IR emission spectroscopy tools for retrieval of gas temperature measurements in high-temperature environments, enabling uncertainty of 2 % up to 1500 °C, and to demonstrate its applicability in selective non-catalytic reduction processes (SNCR) in e g waste incineration The time resolution of the TDLAS thermometry will be optimised to measure the dynamic temperature in fast industrial processes, e g thermal energy conversion The target time resolution will be 1 ms

Activity number	Activity description	Participants (Lead in bold)
A4 2 1 M18	Using the results of the survey from A4 1 1, DTU and PTB will jointly select a suitable AI method (machine learning to optimise the iterative reconciliation between calculated gas temperature/composition and the raw measurements e g random forest or stochastic particle swarm optimisation) and perform system hardware and software developments for use with new IR detectors and TDLAS lasers The new IR-based emission system will be developed by DTU to perform simultaneous IR H_2O/CO_2 emission measurements in A4 2 7 over a broad spectral range, while the	**DTU**, PTB

	developed TDLAS system by PTB will utilise the advantage of laser absorption spectroscopy for selected rotational H_2O lines The IR system will be based on a combination of a compact grating spectrometer and a new generation IR 1D array DTU will adapt the selected AI method to gas temperature profile retrievals from a single line-of-sight IR emission measurement	
A4 2 2 M12	NPL will re-commission, calibrate and assess the stability of the NPL standard (STD) flame facility The flame will be traceable to the ITS-90 for propane/air combustion for equivalence ratios from 0 8 to 1 4, giving maximum temperatures in the range from 2000 °C to 2250 °C	**NPL**
A4 2 3 M28	NPL will provide the NPL STD flame facility from A4 2 2 for validation of the optical systems of DTU and PTB This will include pre-calibration of the flame prior to shipping, shipping and installation at DTU and PTB, and post-calibration of the flame and assessment of any drift	**NPL**, DTU, PTB
A4 2 4 M24	Based on input from A4 2 1, PTB will use their own high-temperature gas cell for validation of the temperature calculations obtained from H_2O rotational lines (TDLAS system) PTB will employ the TDLAS system and newly developed AI methods for gas temperature measurements from A4 2 1 with the selected rotational H_2O lines PTB will validate the TDLAS system on the NPL STD flame facility from A4 2 2 The target time resolution will be 1 ms	**PTB**
A4 2 5 M24	DTU will use its own high-temperature flow gas cell for validation of gas temperature/gas temperature profiles retrievals (i e line-of-sight) from H_2O/CO_2 broad-band IR emission measurements DTU will also validate the IR-based emission system against the FTIR spectrometer on the NPL STD flame facility from A4 2 2	**DTU**, NPL
A4 2 6 M28	Using samples and preliminary results from A3 3 3 and A3 2 6, DTU, NPL and DTI will cooperatively adapt the high-temperature phosphor-based thermometry (from A3 2 2), improved thermal imaging techniques (using preliminary results from A1 2 8) and FTIR-based spectrometry for thermal imaging to perform surface temperature and surface emissivity measurements on used and new boiler wall samples such as Inconel and refractory bricks in the temperature range from 800 °C to 1100 °C	**DTU**, DTI, NPL
A4 2 7 M33	DTU, with support from B&W Volund, will perform a practical demonstration of the IR-based H_2O/CO_2 emission measurement system developed in A4 2 1 to measure gas temperature and gas temperature profiles in a combustion environment such as waste incinerator(s) at SNCR (NO_x removal) locations DTU, with support from B&W Volund, will contact project stakeholders (e g , AffaldPlus in Denmark, Filborna in Sweden) and request their support and provision of their facilities The target uncertainty is 2 % up to 1500 °C A thermal imager (e g DIAS Infrared) will be used for wall temperature measurements in the industrial environments to support line-of-sight AI based retrievals	**DTU**, B&W Volund
A4 2 8 M36	Using input from A4 1 1 and A4 2 1-A4 2 7, PTB, DTU, NPL and B&W Volund will draft an article describing applications of AI tools for retrievals of gas temperature from line-of-sight measurements and submit it to a trade journal	**PTB**, DTU, NPL, B&W Volund

C4.c Task 4.3: Reference surface temperature calibration inserts

Calibration surfaces generally have a large uncertainty in the areal temperature distribution The aim of this task is to develop neural network approaches to thermometer networks used to retrieve the temperature distribution throughout two low-cost plate inserts (large-area blackbodies) for calibration of thermal imagers and phosphors This will be done by distributing thermometers (temperature sensors embedded into the insert) throughout the volume and by operating in conjunction with a neural network and digital twin which uses the data from the sensor network to determine the temperature distribution over the plate surface The target uncertainty on the plate temperature is 1 °C

Activity number	Activity description	Participants (Lead in bold)
A4 3 1 M3	Beamex, with support from VTT, will identify 2 most appropriate dry-block calibrators from their commercially available products and will provide the geometry, material and control parameters to VTT as input for the numerical simulations VTT will perform finite element modelling (FEM) simulations for a large number of input combinations and will populate a dataset to be used in A4 3 3	**Beamex**, VTT

A4 3 2 M6	Based on results of the survey from A4 1 1, VTT and Beamex will design and develop 2 plate inserts (large-area blackbodies) with a sensor network and data aggregation hardware integrated with the Beamex calibrators identified in A4 3 1 One will be circulated in A4 3 5 for use in A1 3 5, A1 4 2 and A3 1 6, the other will stay for use at VTT/Beamex This will account for thermometer types, installation, response, stability etc	**VTT**, Beamex
A4 3 3 M9	VTT will develop a neural network (AI/deep learning) using one of the plate inserts from A4 3 2 VTT, with support from Beamex, will employ the dataset from A4 3 1 to train the neural network to solve the inverse heat transfer problem and to extract the temperature and heat flux distribution at the boundary based on the data automatically implied/collected from the sensor network of A4 3 2 This mathematical model is effectively a mechanism for interpolating between, and extrapolating from, the temperature measurements at individual points, to yield the temperature at any given point throughout the entire volume of the flat plate insert, it will serve as a digital twin for the sensor network	**VTT**, Beamex
A4 3 4 M12	VTT, with support from Beamex and NPL, will exploit an adaptive Monte Carlo algorithm to propagate the uncertainty from individual sensors of the blackbody developed in A4 3 2 to find out the uncertainty of the temperature distribution at the reference surface The target uncertainty on the plate temperature is 1 °C VTT will also examine tools for the detection of malfunctioning sensors, and sensor fusion techniques, at the network level	**VTT**, Beamex, NPL
A4 3 5 M16	Beamex and VTT will validate the 2 calibrators identified in A4 3 1 and the 2 inserts (large-area blackbodies) developed in A4 3 2, by performing comparisons with the existing surface temperature probes and will distribute one of the inserts for use in A1 3 5, A1 4 2 and A3 1 6	**Beamex**, VTT
A4 3 6 M36	Using input from A4 1 1 and A4 3 1-A4 3 5, VTT, with support from Beamex, NPL and PTB, will draft a paper describing the AI-driven reference surface and submit it to a peer-reviewed journal	**VTT**, PTB, NPL, Beamex
A4 3 7 M33	Using input from A4 1 1- A4 1 8, A4 2 1-A4 2 8 and A4 3 1-A4 3 6, DTU, PTB, UL, VTT, NPL, NSC-IM, STRATH, B&W Volund, Beamex and CCPI will draft an article describing possibilities for AI use in industrial temperature measurements with a target uncertainty of better than ± 2 % The article will summarise key practical developments (i e , the 3 case studies i) Machine learning for autonomous operation of self-validating thermometers, ii) spectroscopic infrared thermometry for *in-situ* gas temperature and gas temperature profile measurements and iii) reference surface temperature calibration insert) and will be submitted to a trade journal Once agreed by the consortium, the coordinator on behalf of DTU, PTB, UL, VTT, NPL, NSC-IM, STRATH, B&W Volund, Beamex and CCPI will submit the article to EURAMET as **D7** *'Article on the application of AI approaches to enable traceable in-situ temperature measurement in industrial applications with an uncertainty less than 2 % up to 1500 °C (e g , i) machine learning for autonomous operation of self-validating thermometers, ii) spectroscopic infrared thermometry for in-situ gas temperature and gas temperature profile measurements and iii) reference surface temperature calibration insert) submitted to a trade journal'*	**DTU**, PTB, VTT, NSC-IM, UL, NPL, STRATH, B&W Volund, Beamex, CCPI
A4 3 8 M36	DTU, PTB, UL, VTT, NPL, NSC-IM, STRATH, B&W Volund, Beamex and CCPI will draft a paper on the application of AI to enable *in-situ* traceable thermometry in industrial applications The article will summarise the key technical developments from A4 1 7, A4 2 7 and A4 3 5, namely i) Machine learning for autonomous operation of self-validating thermometers, ii) spectroscopic infrared thermometry for *in-situ* gas temperature and gas temperature profile measurements, and iii) reference surface temperature calibration insert, and will be submitted by DTU to a peer-reviewed journal Once agreed by the consortium, the coordinator on behalf of DTU, PTB, UL, VTT, NPL, NSC-IM, STRATH, B&W Volund, Beamex and CCPI will submit the paper to EURAMET as **D8** *'Paper on the application of AI to enable in-situ traceable thermometry in industrial applications (e g , i) machine learning for autonomous operation of self-validating thermometers, ii) spectroscopic infrared thermometry for in-situ gas temperature and gas temperature profile measurements and iii) reference surface temperature calibration insert) submitted to a peer-reviewed journal'*	**DTU**, PTB, VTT, NSC-IM, UL, NPL, STRATH, B&W Volund, Beamex, CCPI

C5 WP5: Creating impact

The overall aim of this work package is to ensure that efficient knowledge transfer is affected through tailored dissemination efforts to the appropriate stakeholders (such as industry, CCT and the RMOs) The wider scientific community will be engaged through refereed papers and conference presentations Training will take place at the broadest level from Stakeholder Community workshops, to customised articles and talks for trade bodies and associations

C5.a Task 5.1: Dissemination and communication

Activity number	Activity description	Participants (Lead in bold)
A5 1 1 M36	At the beginning of this project the consortium will start the formation of an industrial advanced manufacturing Stakeholder Community, with supporters and collaborators as its members, building on the Stakeholder Community, numbering 140, that was built up during the EMPIR projects 14IND04 EMPRESS and 17IND04 EMPRESS 2 The Stakeholder Community will be open to any organisation that has an interest in improving temperature measurements for advanced manufacturing, and it is expected that its size will grow during the project The aim of setting up such a Stakeholder Community is to ensure that all stakeholders are engaged with the project from the beginning and can advise on industrial temperature measurement, both problems and best practice This will ensure that the practical requirements for the developed sensors are well understood by the consortium members The consortium will liaise with the coordinator of 22DIT02 FunSNM (VTT, who is also a participant in this project) to maximise the commonality of the Stakeholder Communities which will be relevant to both projects The target number of members of the Stakeholder Community will be 50 The community will be kept informed by regular project updates and invitations to at least two workshops where feedback on end-user requirements will be sought	**STRATH**, all participants
A5 1 2 M36	A project webpage will be created on STRATH's website with public access in M6 The webpage will be regularly updated with information such as project reports, papers published by the participants, and project meetings In addition there will be a special section dedicated to "News on the project" where information about workshops, public reports, presentations, etc will be available to the public The project webpage 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	**STRATH**, all participants
A5 1 3 M36	The participants will submit at least 9 papers to peer-reviewed journals during the course of the project Target journals include • Open Research Europe • Metrology (MDPI) • Thermo (MDPI) • Acta IMEKO • Johnson Matthey Technology Review The expectation is that all of the 9 publications will be the result of a collaborative effort from participants from different countries The authors of the 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 (23IND11 ThermoSI) 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 • Funder name European Partnership on Metrology • Funder ID 10 13039/100019599 • Grant number 23IND11 ThermoSI	**STRATH**, all participants

<table>
<tr><td></td><td>The participants will comply with open access requirements detailed in the Grant Agreement Section 17 by also depositing each paper in a suitable open access trusted repository</td><td></td></tr>
<tr><td>A5 1 4
M36</td><td>The participants plan to present at least 20 papers to international conferences such as
• TEMPMEKO (France, 2025) – to include focused ThermoSI session on industrial thermometry
• Congres International de Métrologie (France, 2025 and 2027)
• 5th International Conference on Phosphor Thermometry (ICPT2026) (TBC, July 2026
• 15th European Conference on Industrial Furnaces and Boilers (INFUB) (location and date TBC)
• IMEKO World Congress 2026 (location TBC)
Further relevant conferences will be identified during the project
The participants also plan to present results at national conferences to ensure a broad dissemination
• Metrologidagen (“Metrology Day”, annual conference for Danish Industrial Stakeholders, calibration laboratories and metrology institutes, Copenhagen or Aarhus, Denmark)
• NPL thermocouple users conference (approximately 18-monthly conference for UK and European stakeholders involved with thermocouple measurements but also more broadly industrial thermometry)
• Regular nuclear decommissioning and waste storage events in the UK run by, and for, national stakeholders</td><td>STRATH, all participants</td></tr>
<tr><td>A5 1 5
M36</td><td>All participants will support dissemination of the project results to a range of standards bodies and seek feedback Targeted committees and working groups are listed below
<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>IEC TC 65 Industrial-process measurement, control and automation
SC 65B Measurement and control devices
WG5
Temperature sensors and instruments</td><td>NPL, PTB</td><td>IEC TC 65/SC 65B/WG5 meets annually The underlying work necessary to begin development of a new IEC standard(s) governing self-validating thermocouples and JNT, for which there are no existing frameworks, will be undertaken NPL and PTB contribute to this committee
Thermal imaging developments will ultimately feed into IEC/TS 62492-2 2013 which is due an update, IEC/TS 62492-1 2008, and indirectly IEC 62828-3 2018 [48]</td></tr>
<tr><td>Consultative Committee for Thermometry (CCT)</td><td>NPL, PTB, VTT, CMI, SMU, NSC-IM</td><td>CCT meets biennially The committee establishes the framework for improved temperature measurement and improved traceability to the International System of Units (SI)
Several of the NMI participants in this project are delegates to the world’s leading committee for temperature measurement, the Consultative Committee of Thermometry (CCT) The work of the CCT is very important for setting the framework for improved temperature measurement and is very supportive of all efforts to achieve and improve traceability to the International System of Units (SI) The outcomes of this project will be presented to the CCT mainly through its Working Groups and Task Groups which many of the NMI participants sit on and in one case chairs (NPL chairs WG5 on non-contact thermometry)</td></tr>
</table></td><td>STRATH, all participants</td></tr>
</table>

		Two briefing reports will be submitted to the CCT on the state of the art of • Practical Johnson noise thermometry (A2 3 4), which is of special interest to the international metrology community • Practical phosphor thermometry (A3 2 5), which is currently under-represented in CCT discussions and documentation
EURAMET Technical Committee for Interdisciplinary Metrology (TC-IM) Metrology for Digital Transformation (WG M4D)	**NPL**, PTB, VTT, CMI, SMU, DTI	This technical committee and the working group meet twice-yearly and often more frequently in the interim They will be kept up to date by NPL, PTB, VTT, CMI, SMU and DTI with the machine learning and sensor network metrology developments to inform wider discussion and consultation over applications of these to metrology in general
EURAMET Technical Committee on Thermometry (TC-T)	**NPL**, PTB, DTI, CMI, SMU, UL, VTT, NSC-IM	All the NMI participants in this project are members of the EURAMET TC Thermometry (TC-T) EURAMET TC-T will be used as a mechanism for dissemination of the outcomes of this project to the broader NMI temperature measurement community All of the EURAMET TC-T community will be kept informed about the progress of this project through regular reporting to the TC-T at the annual meeting Annual oral reports of the project progress will be presented to the committee and the participants will be asked for feedback on the work and results presented Peer-reviewed papers will also provide a reference for the committee The EURAMET TC-T is the natural place to identify possible secondees/trainees from other NMIs who wish to develop like capability or who may wish to participate in the research underway in this project
IEC/TC 65 UkrNDNC TK 65	**NSC-IM**	The Ukrainian Research and Training Center for Standardization, Certification and Quality Problems (UkrNDNC) committee on Industrial process measurement, control and automation meets biennially and often more frequently in the interim They establish the framework for improved temperature measurement and improved traceability to the International System of Units (SI) and promote excellence in instrumentation and control NSC-IM will disseminate project outputs to physicists, engineers and scientists involved in high value manufacturing and will ask for feedback on the work and results presented
IEC/TC 65 Ukrainian National Mirror Committee TK 85	**NSC-IM**	The UkrNDNC committee on Measuring Equipment for electrical and electromagnetic quantities meets biennially and often more frequently in the interim They establish the framework for improved temperature measurement and improved traceability to the International System of Units (SI) and promote excellence in instrumentation and control NSC-IM will disseminate project outputs to physicists, engineers and scientists involved in high value manufacturing and will ask for feedback on the work and results presented

	VDI – The Association of German Engineers	**PTB**	This association meets four times per year PTB is a member of the technical committee "FA 8 14 Radiation thermometry and thermography" PTB will disseminate projects outputs to the association and will ask for feedback on the work and results presented
	IMEKO TC12 Temperature and Thermal Measurements	**DTI**	The committee meets irregularly and will physically meet in 2025 It provides a forum for the organisation of international scientific events in temperature and thermal measurements TC12 organises a main symposium (TEMPMEKO) every three years and other specialist scientific events (workshops, seminars) DTI will promote the project and its work to this forum
	Nadcap/SAE	**CCPI**, NPL	Nadcap/SAE meets annually CCPI and NPL will endeavour to raise awareness of relevant developments and testing of self-validating thermocouples within the Nadcap community, with the ultimate goal of feeding developments into future updates of the AMS2750 standard CCPI is a member of the committee responsible for AMS2750
	The representatives on the corresponding committee or WG from the participants will jointly ask the chairperson to include a point in the agenda to briefly present the outputs of the project related to the WG activities and ask for comments Where appropriate a written report will be submitted for consideration by the committee or WG		
A5 1 6 M36	A project flyer as well as a project poster will be prepared addressing all relevant information about the project to maximise awareness The texts will be written for non-specialist audience The flyer and poster will be available for download on the website for all participants A 9-monthly e-newsletter will be produced and will be circulated to the Stakeholder Community The e-newsletter will also be available in the news section of the webpage The e-newsletter will cover general information about the project, participants, project results and upcoming events		**STRATH**, all participants
A5 1 7 M36	To enable other stakeholders to understand and have access to the results of the projects at least 8 articles will be written for the popular press or trade journals Examples of such journals are Precision, and Power and Process Engineering in the UK or Teknisk Nyt in Denmark		**STRATH**, all participants
A5 1 8 M36	The participants are linked with and are members of various scientific, metrological and industrial networks These networks will be used to gain additional contacts with potential stakeholders Therefore, participants will actively engage in various networking activities Links to the relevant user networks will be also sought and created or expanded The following networks were identified for further activities • European Metrology Network for Advanced Manufacturing • European Metrology Network for Climate and Ocean Observation • European Metrology Network for Mathematics and Statistics • Institute for Measurement and Control – Standards Policy Panel • Institute of Physics 'Instrument Science and Technology' (ISAT) committee		**NPL**, DTI, PTB
A5 1 9 M33	A one-day workshop will be held with the Stakeholder Community during the project The aim of the workshop will be to ensure that the end users of the technology developed are engaged and can influence the practical aspects of the project, and exploitation routes, throughout the programme This will be held in M33 (May 2027) at STRATH in Glasgow The workshop will showcase the project to the Stakeholder Community and share progress on the development of the various sensors and plans for testing and demonstration of those sensors The target number of participants at the workshop is 50 The workshop will be advertised through participants' contacts, the Stakeholder Community, the project's newsletter, social media and the website A free live webinar in a form of workshop will be organised (around M25 (September 2026)) by DTI to disseminate the progress and outcomes of the project to a wide audience The webinar will also be used to encourage participants to attend the workshop in M33		**STRATH**, DTI, all participants

A5 1 10 M36	At least one lecture per year will be given at a major European trade fair or industrially focused conference (examples of these are the Farnborough Airshow in the UK, Sensor and Test and Hannover Messe, New cast and Glasstec trade shows in Germany and the annual Nuclear Power Europe exhibition and conference)	**STRATH**, all participants
A5 1 11 M36	Several exchanges of staff between participants' institutes will take place during the project • OVGU will send staff members to NPL for 3 weeks to make use of the high temperature furnaces at NPL for phosphor temperature calibration in A3 2 2 • DTI will send a staff member to NPL for 2 weeks to collaborate on high temperature phosphor thermometry in A3 2 1 • NPL will send a staff member to DTU and PTB to work together on local commissioning of the portable standard flame in A4 3 3 • DTI will send a staff member to DTU to cooperate on thermometry for reformer tubes using DTU's emissivity facility in A3 3 2 NPL will deliver training on temperature metrology which will include developments in this project (and also from EMPIR projects 14IND04 EMPRESS and 17IND04 EMPRESS 2) as part of its regular temperature metrology training course This course is held every 18 months and is attended by delegates from across the globe Course will be held in December 2025	**STRATH**, all participants
A5 1 12 M36	General public exposure to the project developments and findings will be done through relevant social media platforms LinkedIn will be used to target followers and connections in the work-related settings Other social media may be used in conjunction with dissemination through the press, e g , popular articles, press releases at onset and end of project The consortium will tag EURAMET on 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 In addition, NPL maintains a LinkedIn group "Thermocouples in Industry", despite the title, stakeholders are interested in wider process control thermometry in industry This group will be used to disseminate project outputs, events etc There are 207 members	**STRATH**, all participants
A5 1 13 M36	Papers and reports produced by the project in technical WPs will be disseminated by the consortium Publications will be made available on the project website and distributed to the community for process control thermometry in industry and other potential end users by email This includes • Reference emissivity dataset for key engineering materials (A1 2 2) – PTB, NPL, M9 • Reference emissivity dataset for selected thermographic phosphors (A3 1 5) – PTB, NPL, M24 • Peer-reviewed publication on pre-key comparison of surface thermometry (A1 4 3) – PTB, NPL, CMI, M36 • Peer-reviewed publication on techniques developed for traceable quantitative thermal imaging (A1 4 4) – NPL, PTB, CMI, SMU, VTT, Beamex, M36 • Peer-reviewed publication on Johnson noise thermometry electronics with a technology readiness level of 6 for use in harsh industrial environments up to 1200 °C (A2 1 6) – PTB, NPL, Metrosol, UL, CMI, M27 • Report on a robust probe assembly for measuring Johnson noise in harsh environments (A2 2 5) – NPL, PTB, UL, CMI, Metrosol, STRATH, UoM, M34 • CCT briefing report on the state of the art of practical JNT (A2 3 3) – PTB, NPL, Metrosol, UL, CMI, UoM, M34 • Peer-reviewed publication on the robustness of phosphor thermometry up to 1250 °C (A3 1 7) – NPL, DTI, OVGU, STRATH, M30 • Peer-reviewed publication on the metrological evaluation of novel high temperature phosphor thermometry (A3 2 4) – NPL, DTI, OVGU, M30 • CCT briefing report on traceable phosphor thermometry including best practice in the preparation, application, and temperature measurement of phosphor coatings (A3 2 5) – NPL, DTI, M30 • Trade journal article on practical high temperature phosphor thermometry in high value manufacturing (A3 3 4) – NPL, STRATH, DTI, BAE, M34 • Trade journal article on the application of AI approaches to enable traceable	**NPL**, all participants

	in-situ temperature measurement in industrial applications (A4 3 7) – DTU, NPL, PTB, VTT, NSC-IM, STRATH, UL, B&W Volund, CCPI, Beamex, M33 • Peer-reviewed publication on the application of AI to enable in-situ traceable thermometry in industrial applications (A4 3 8) DTU, NPL, PTB, VTT, NSC-IM, STRATH, UL, B&W Volund, CCPI, Beamex, M36 • Peer-reviewed publication on the use of machine learning for automation of self-validating thermometers (A4 1 8) – NPL, UL, CCPI, NSC-IM, STRATH, M34 • Trade journal article describing applications of AI tools for retrievals of gas temperature from line-of-sight measurements (A4 2 8) – PTB, DTU, NPL, B&W Volund, M36 • Peer-reviewed publication describing the AI-driven reference surface (A4 3 6) – VTT, Beamex, NPL, PTB, M36	

C5.b Task 5.2: Exploitation and uptake

Activity number	Activity description	Participants (Lead in bold)
A5 2 1 M36	A dissemination, communication and exploitation plan (DCE) will be created at the beginning of the project by DTI, 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 expected results, such as • Expected result 1 – Practical quantitative thermal imaging using *in-situ* references, including spectral, angular and hemispherical emissivity datasets for several key engineering materials and selected phosphors • Expected result 2 – Elevated operational readiness of practical JNT for use in industrial environments at temperatures up to 1200 °C • Expected result 3 – Phosphor thermometry up to 1250 °C • Expected result 4 – AI tools for enhanced in-process thermometry	**DTI**, all participants
A5 2 2 M36	Expected result 1 – Practical quantitative thermal imaging using *in-situ* references (A1 4 4) and emissivity dataset for several key engineering materials and selected phosphors, including spectral, angular, and hemispherical emissivity (A1 2 9) The emissivity data published during the project will have immediate direct impact for practitioners by improving thermal imaging measurements, even without the *in-situ* references The new techniques using *in-situ* references will be disseminated through academic and trade journal articles They will also be available in the relevant participants' laboratories for use by customers in e g consultancies	**NPL**, CMI, DTI, PTB, SMU, VTT, STRATH, Beamex
A5 2 3 M36	Expected result 2 – Elevated operational readiness of practical JNT for use in industrial environments at temperatures up to 1200 °C (A2 1 6, A2 2 5) Johnson noise thermometry will be demonstrated by Metrosol/NPL, PTB, CMI and UL in industrial induction furnaces at STRATH, and by Metrosol/NPL, UoM and PTB in ionising radiation environments representative of nuclear waste storage and processing environments at NPL The exploitation route will be established through collaborators (e g , Magnicon, Isothermal Technology, TRM Limited)	**NPL**, CMI, PTB, UL, Metrosol, STRATH, UoM
A5 2 4 M36	Expected result 3 – Phosphor thermometry up to 1250 °C (A3 2 2) NPL, OVGU and DTI will implement the new validated phosphor thermometers This will provide NPL, OVGU and DTI the ability to offer calibrated surface temperature measurements up to 1250 °C (1200 °C for DTI) with an accuracy of 10 °C NPL will develop an exploitation route for phosphor thermometry This will include progress towards the commercialisation of the fibre-based thermometer system and the seeking of follow-on grant funding to assess market needs, design of a practical demonstrator instrument and networking with early adopters Its practicality and effectiveness will be demonstrated by trials in marine manufacturing with BAE Systems, and forming/forging at STRATH	**NPL**, DTI, OVGU, STRATH, BAE

A5 2 5 M36	Expected result 4 – AI tools for enhanced in-process thermometry *The use of machine learning for automation of self-validating thermometers, including case studies in industrial heat treatment plants* (A4 1 8) This will be included in the accredited procedure for the use of self-validating thermocouples Furthermore, the outcome will be presented to CCPI and their customers and collaborators (industrial instrumentation manufacturers, e g , Kambič), with the potential to be incorporated in the high temperature furnaces, and to collaborators who are end users (e g , Khmelnitsky Nuclear Power Plant and Rivne Nuclear Power Plant) Exploitation through licensing to CCPI and collaborators (e g , Kambič) will be pursued *Applications of AI tools for retrievals of gas temperature from line-of-sight measurements (A4 2 8)* This will be demonstrated through waste incineration process control trials at B&W Volund The outputs will be presented to relevant instrumentation manufacturers *AI-driven reference surface (A4 3 6)* VTT and Beamex will exploit the existing route to market for dry-block calibrator inserts to enable calibration of thermal imagers and phosphor thermometry with the neural network based flat-plate blackbody insert, via Beamex	**NPL**, UL, CCPI, NSC-IM, STRATH, B&W Volund, VTT, Beamex

All IP and potential licencing/exploitation will be handled in accordance with the Grant Agreement and the 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 DTI, who will be supported by the project management board (PMB) consisting of the coordinator and one representative from each participant including the work package leaders The coordinator will be strongly supported with the scientific and technical direction by NPL The members of the project management board will guide the project, identify upcoming risks and help with resolving them, organise and attend the project consortium meetings, and set up *ad-hoc* meetings if needed to ensure the overall project's success	**DTI**, all participants
A6 1 2 M36	The work package leaders will report on the on-going progress of the project to the coordinator by e-mail and web-meetings	**DTI**, NPL, PTB, DTU, STRATH
A6 1 3 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	**DTI**, all participants
A6 1 4 M36	The consortium will ensure that any ethics issues identified are addressed	**DTI**, all participants

C6.b Task 6.2: Project meetings

Activity number	Activity description	Participants (Lead in bold)
A6 2 1 M1	The kick-off meeting involving all participants will be held approximately one month after the start of the project, at DTI	**DTI**, all participants
A6 2 2 M36	There will be 5 formal project meetings These meetings include the kick-off meeting (A6 2 1), a meeting at NPL (M13 (September 2025)), a mid-term online meeting (around M18 (February 2026)), a meeting at STRATH (M25 (September 2026)) and a meeting at PTB (M34 (June 2027)) The meetings will review progress and be used to ensure participants are clear as to their role for the next period Members of the Stakeholder Community, and collaborators, will be invited to join a section in the meetings where appropriate	**DTI**, all participants

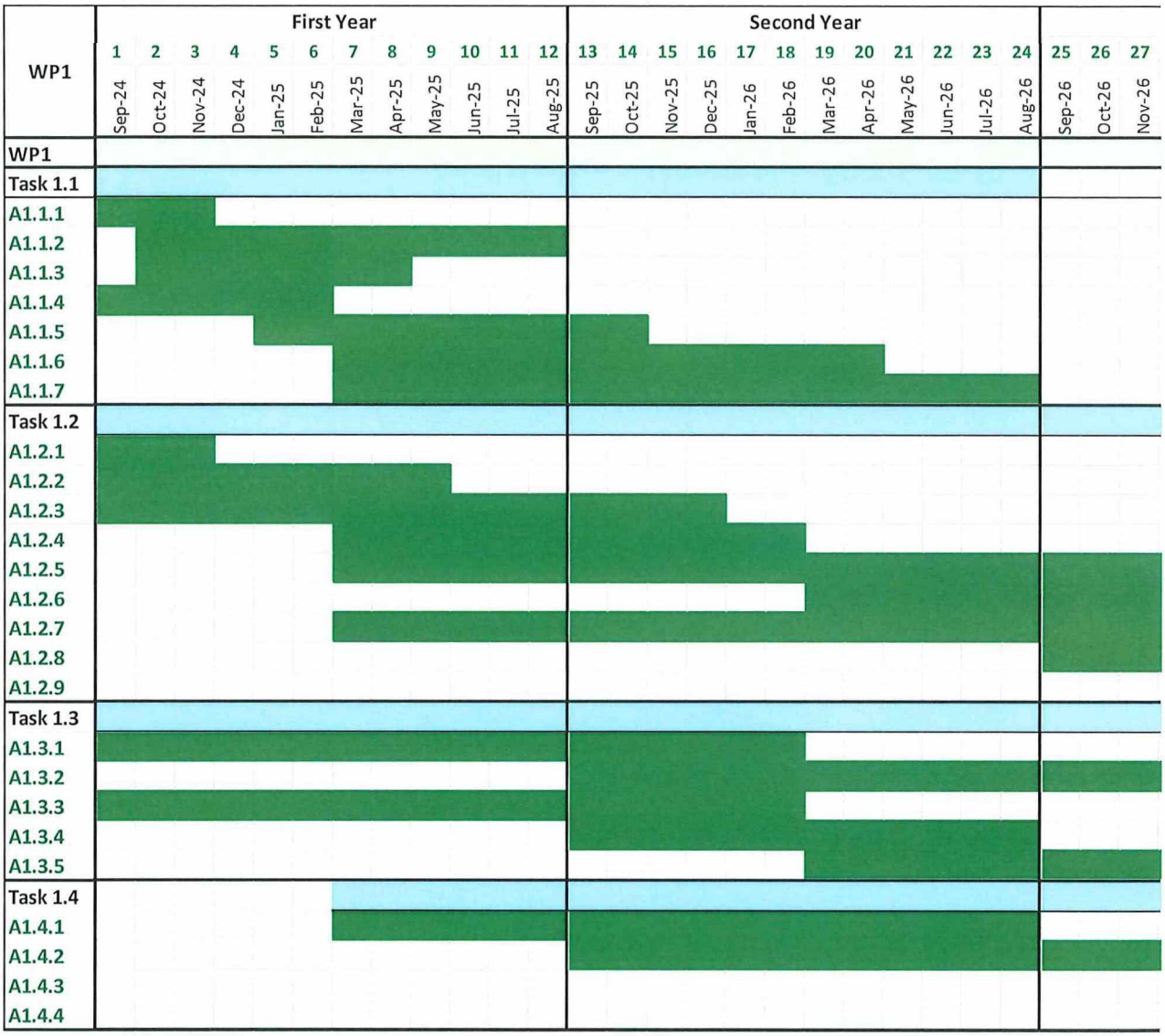
A6 2 3 M36	In addition, technical meetings of work package groups may be held whenever necessary and will be arranged on an ad hoc basis	**DTI**, all participants

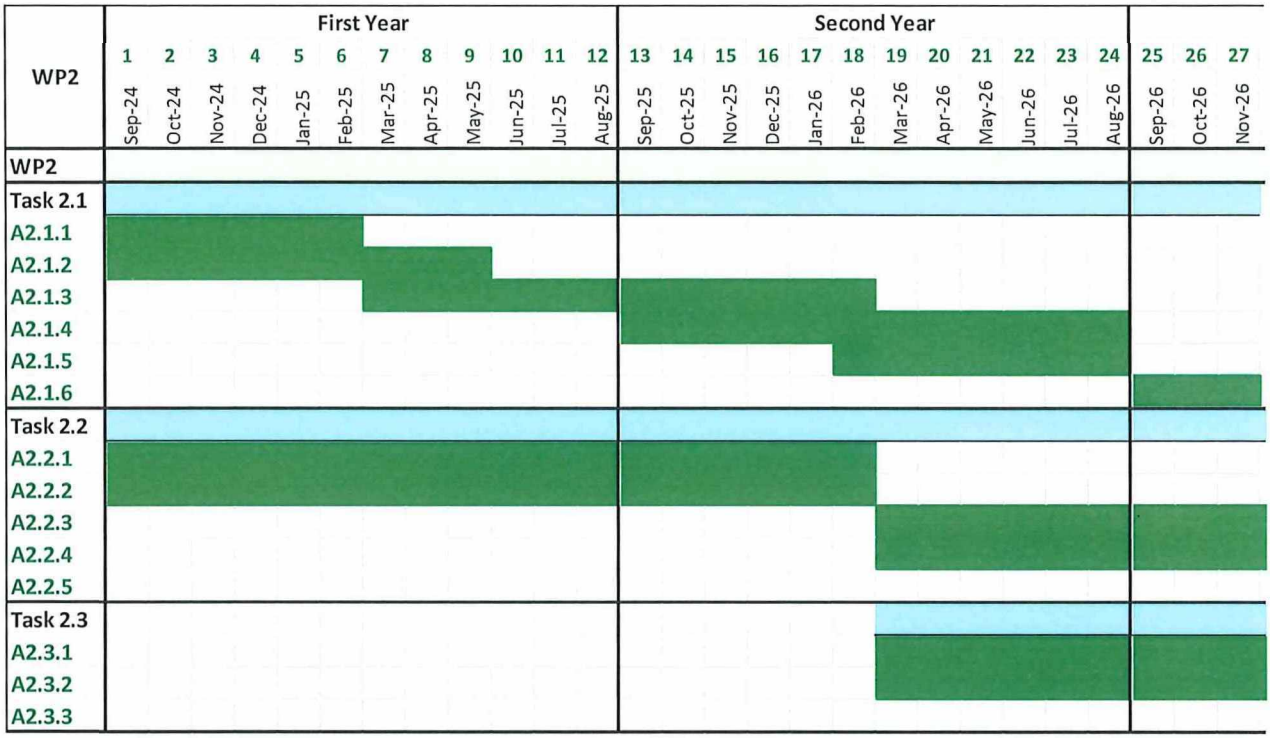
C6.c Task 6.3: Project reporting

Activity number	Activity description	Participants (Lead in bold)
A6 3 1 M1	One month after the start of the project a publishable summary will be produced and submitted to EURAMET	**DTI**, all participants
A6 3 2 M6	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	**DTI**, all participants
A6 3 3 M36 +60 days	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 (May 2025, November 2026 + 45 days), 18, 36 (February 2026, August 2027 + 60 days) - Outcomes and Impact 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	**DTI**, all participants
A6 3 4 M36 +60 days	Periodic Reports (including financial reports, updated data management plan, and updated dissemination, communication and exploitation plan) will be delivered at months 18 and 36 (February 2026, August 2027 + 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	**DTI**, all participants
A6 3 5 M36 +60 days	Final Reports will be delivered at month 36 (February 2026, August 2027 + 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	**DTI**, all participants
A6 3 6 M20	Some projects will be subject to a midterm review in Spring 2026 Where projects are selected for a midterm review, reports (project self-assessment, updated publishable summary and presentation) will be delivered prior to the midterm reviews for Call 2023, 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	**DTI**, 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




WP2
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Second Year
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Sep-24 Oct-24 Nov-24 Dec-24 Jan-25 Feb-25 Mar-25 Apr-25 May-25 Jun-25 Jul-25 Aug-25 Sep-25 Oct-25 Nov-25 Dec-25 Jan-26 Feb-26 Mar-26 Apr-26 May-26 Jun-26 Jul-26 Aug-26 Sep-26 Oct-26 Nov-26
WP2
Task 2.1
A2.1.1
A2.1.2
A2.1.3
A2.1.4
A2.1.5
A2.1.6
Task 2.2
A2.2.1
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Task 2.3
A2.3.1
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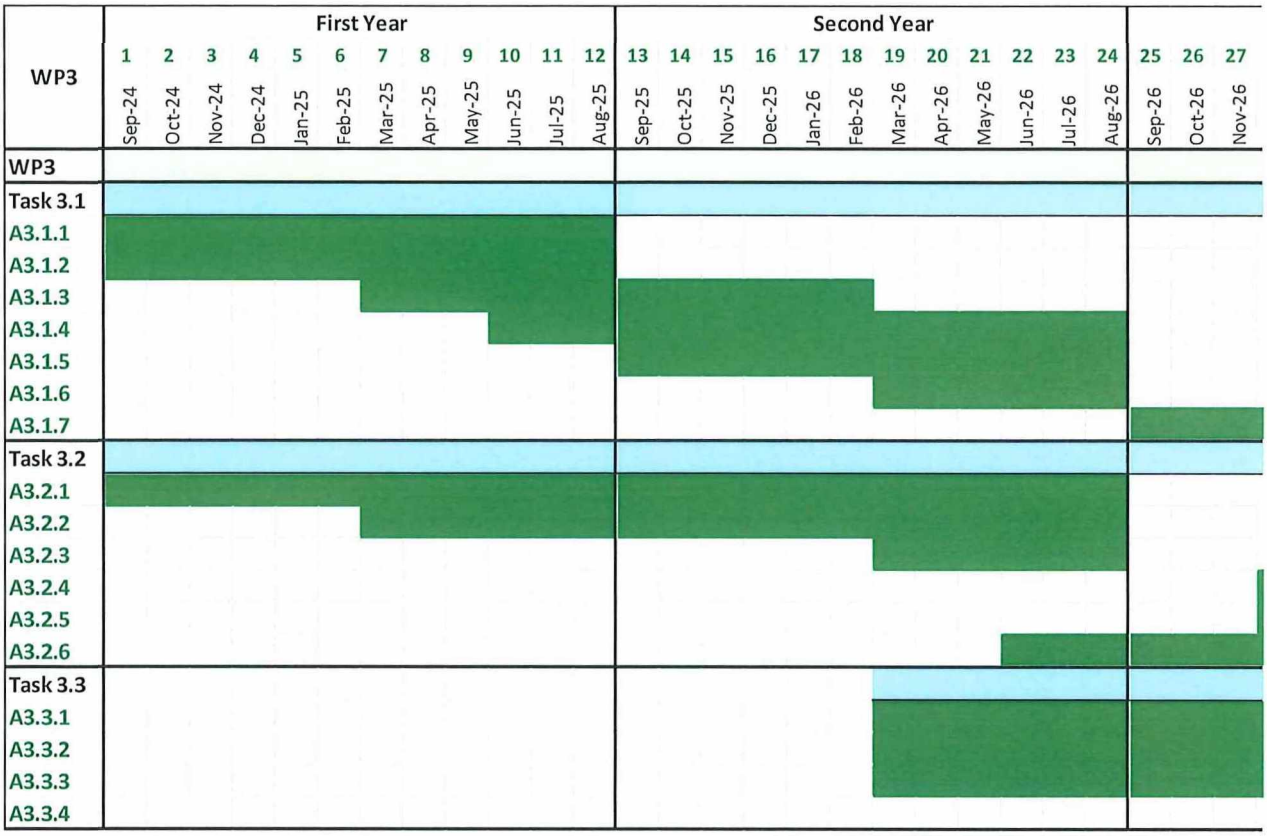
A2.3.3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Second Year
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WP3
Task 3.1
A3.1.1
A3.1.2
A3.1.3
A3.1.4
A3.1.5
A3.1.6
A3.1.7
Task 3.2
A3.2.1
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Task 3.3
A3.3.1
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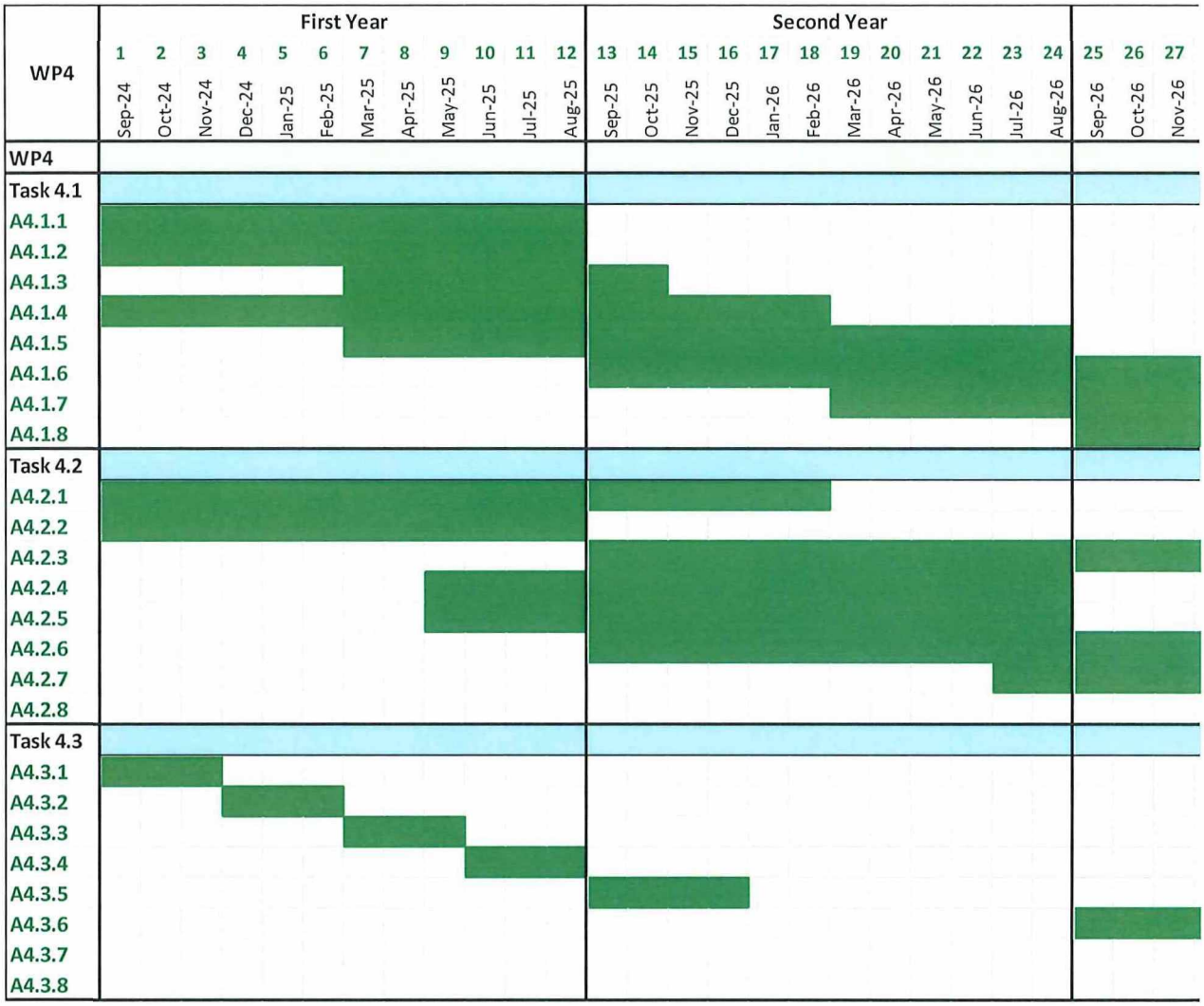
A3.3.4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WP4
Task 4.1
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A4.1.3
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A4.1.8
Task 4.2
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A4.2.2
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Task 4.3
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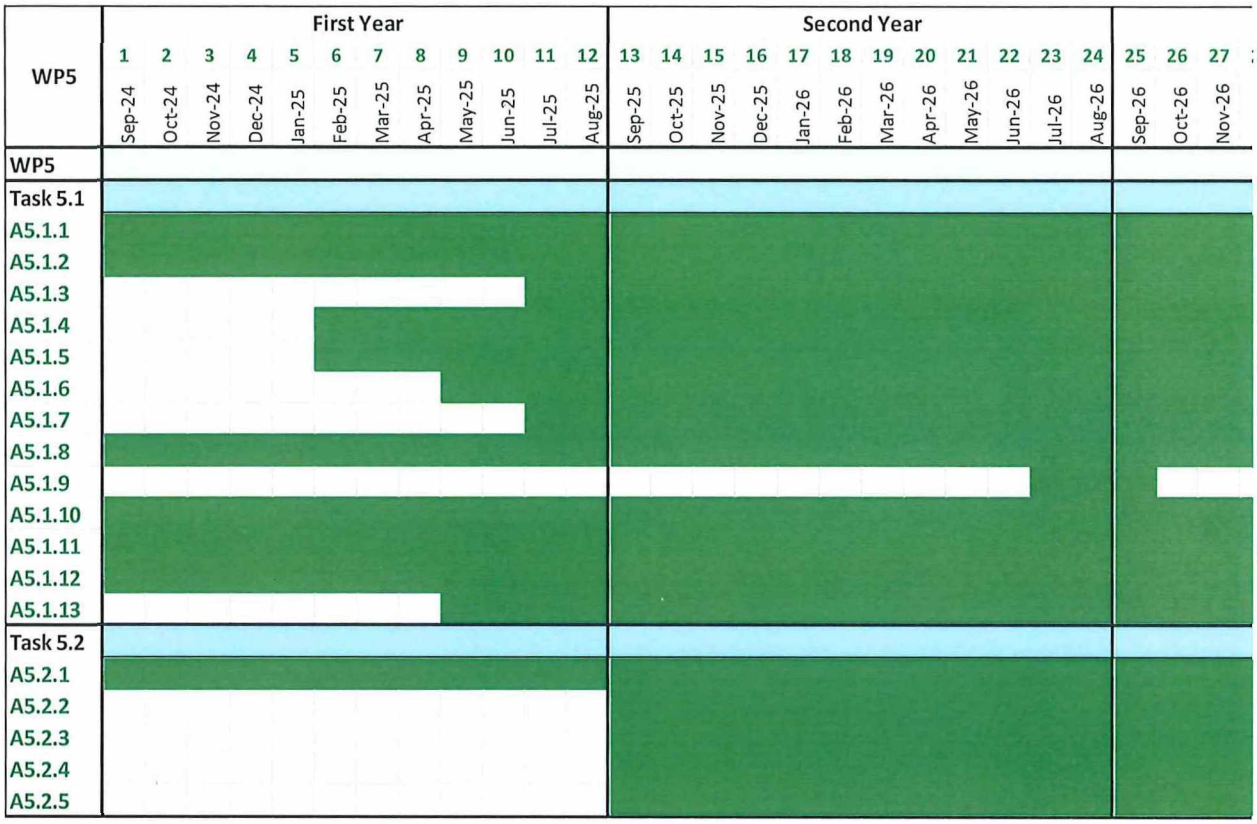
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WP5
Task 5.1
A5.1.1
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Task 5.2
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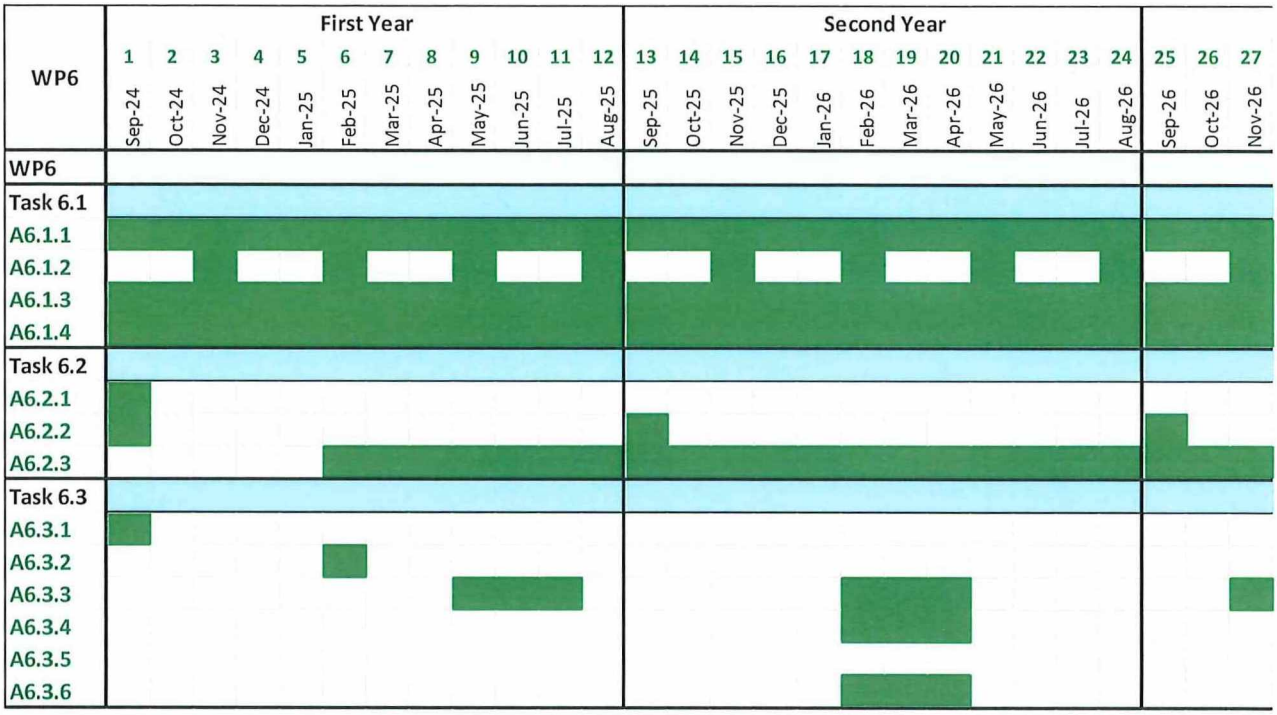
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Second Year
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WP6
Task 6.1
A6.1.1
A6.1.2
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Task 6.2
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Task 6.3
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Section 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 Difficulty in optimising binder/phosphor recipe in terms of adhesion, calibration cycle stability, durability, and temperature sensitivity	Likelihood after mitigation Low Impact The lower temperature cannot be reached reliably Level of severity Medium	Previous work has been done on low temperature phosphors which renders this outcome unlikely	The minimum temperature range will be reduced
Task 1 1 Difficulty in obtaining a suitable phosphor for furnace trials	Likelihood after mitigation Low Impact Delays in the delivery of Task 1 1 Level of severity Medium	All participants have highly competent staff with a high level of expertise in phosphor thermometry There is a wide range of potential suppliers of phosphors	Participants will draw on contacts to obtain access to another suitable phosphor In worst case, project plan might be modified to account for the delay
Task 1 2 The existing phosphor thermometer (fibre coupled or camera based) cannot be modified to operate below 0 °C	Likelihood after mitigation Low Impact The operation over the full temperature range (-100 °C to 500 °C) cannot be demonstrated Level of severity Medium	Previous work has been done on phosphor thermometers Since several technical approaches are possible to achieve this goal, this outcome is unlikely	The minimum temperature range will be reduced
Task 1 3 The scene-based non-uniformity correction method for thermal imager cannot be applied on the reference scene	Likelihood after mitigation Low Impact The overall uncertainty of the quantitative thermal imaging temperature measurement is increased Level of severity Medium	Previous work has shown that the ex-situ use of scenes without sharp-knife style temperature changes can be used to obtain a non-uniformity correction for thermal imagers	The internal non-uniformity correction of the thermal imager will be used
Task 1 3 The scene-based non-uniformity correction cannot be implemented into the thermal imager provided by the collaborators	Likelihood after mitigation Low Impact Only the internal nonuniformity correction of the thermal imagers can be used Level of severity Medium	The scene-based non-uniformity correction will be applied in a postprocessing of the thermal image	The internal non-uniformity correction of the thermal imager will be used
Task 1 4 The different surface thermometry techniques are not consistent within the uncertainty	Likelihood after mitigation Low Impact A wider CCT intercomparison is not viable Level of severity Medium	This will be useful information with which the uncertainty estimates can be improved	Any anomalous techniques will be identified and associated uncertainties expanded or otherwise further explored
Task 2 1 Difficulty in obtaining traceability to electrical standards, particularly for absolute power spectral density	Likelihood after mitigation Medium Impact Reduction in accuracy of traceability to electrical standards Level of severity Medium	The consortium will use their experience in methods of traceable AC measurements, use precise AC source (e g Josephson array)	The participants will settle for traceability to temperature standards, where they can definitely obtain traceability to the required accuracy (though electrical traceability is conceptually preferred)

Task 2 2 The layout design and format for a robust probe assembly under harsh environments requires different materials for electrodes or different thickness of boron nitride dielectric in the fabrication of the graphene sensing element	Likelihood after mitigation Medium Impact Delays in development of the probe assembly needed for JNT Level of severity Medium	Best practice for electrode materials and dielectric encapsulation for robust operation will be exchanged between all participants from the start of the project, to anticipate such design considerations	The timeline is arranged to allow for iterations of the probe fabrication, so the design and assembly will already include reliable electrode materials and encapsulation before moving to tests under harsh environments
Task 2 2 Difficulty in identifying suitable probe materials	Likelihood after mitigation Low Impact Reduction in accuracy of temperature measurement, increase in calculation complexity Level of severity Medium	The consortium will use knowledge from some preliminary tests already conducted and alter physical layout and temperature profile of probe to reduce effect	The consortium will calculate effect and alter other parameters to minimise, for example change sensor resistance
Task 2 2 Difficulty in fabricating a suitable graphene sensor resistor within the required timeframe	Likelihood after mitigation Medium Impact Delays in development of the practical sensing element for Johnson noise thermometers Level of severity Medium	The project has planned several rounds of fabrication to account for optimisation of the fabrication process Additionally, the required design has been simplified to reduce fabrication risks	There are commercially available graphene devices that can be adapted to the task after the graphene is properly encapsulated The consortium can purchase these and focus the work onto the encapsulation alone
Task 2 2 Difficulty in incorporating the graphene sensor resistor into a practical probe assembly	Likelihood after mitigation Medium Impact Delays in development of the probe assembly needed for Johnson noise thermometers Level of severity Medium	The project has planned an early start to allow for several iterations of the probe design and assembly The design will be kept as simple as possible	The participants have close links with several thermometry probe manufacturers with considerable expertise and fabrication facilities for a wide range of different types of probe assembly The consortium can draw on this expertise if necessary
Tasks 2 2, 2 3, 3 3, 4 1, 4 2 Unable to obtain access to unfunded participants' / collaborators'/ end-users' facilities to evaluate the project devices	Likelihood after mitigation Low Impact Trialling of the sensors in the actual high-value manufacturing process environments concerned would be impossible Level of severity Low	There is a sufficient number of project participants and collaborators who are high-value manufacturing organisations to re-distribute tasks should it be necessary	Participants will draw on contacts to obtain access to another industrial site and test the devices
Tasks 2 2, 2 3, 3 3, 4 1, 4 2 Industrial equipment to test out project devices go out of service or not available	Likelihood after mitigation Medium Impact This will cause the delay with experiments and project delivery Level of severity Medium	Regular checks of the machines will be carried out The consortium will ensure early planning to avoid clash between experiments and maintenance services	Participants will draw on contacts to obtain access to replacement equipment Industrial testing will be reviewed and limited
Task 2 3 The different JNT techniques are not consistent within the uncertainty	Likelihood after mitigation Low Impact One or more of the JNTs cannot be used with confidence Level of severity Medium	This will be useful information with which the uncertainty estimates can be improved	Any anomalous techniques will be identified and associated uncertainties expanded or otherwise further explored
Task 3 1 Phosphor cannot be used up to 1250 °C	Likelihood after mitigation Low Impact Target uncertainty of phosphor-based thermometry cannot be achieved Level of severity Medium	Previous work has been done on high temperature phosphors which renders this outcome unlikely	The maximum temperature will be reduced

Task 3 1 Phosphor decay time versus temperature calibration uncertainty is too large at higher temperatures > 500 °C	Likelihood after mitigation Low Impact Target uncertainty of phosphor-based thermometer cannot be achieved Level of severity Medium	Alternative phosphors may be used, investigate alternative laser/LED light sources A number of experts are involved in this work package and it is expected that a solution can be found	Uncertainty can be expanded
Task 3 1 The phosphor intensity ratio technique is new to the principal investigators	Likelihood after mitigation Low Impact Target uncertainty of phosphor-based thermometer cannot be achieved Level of severity Medium	Preliminary trials using a single spot intensity ratio phosphor thermometer will be carried out independently of the project This will improve the prospects of meeting the target uncertainty and mitigate non-compliance	The temperature range will be restricted and/or the stand-off distance reduced
Task 3 1 Difficulty in selecting a suitable phosphor/binder combination for operation up to 1250 °C	Likelihood after mitigation Medium Impact Delays in development of phosphor thermometer system Level of severity Medium	All participants have highly competent staff with a high level of expertise in phosphor thermometry Access to experts in the field who are not directly involved in the project will increase the pool of knowledge and minimise risks	The development of the fibre-based phosphor thermometers may be delayed but not halted
Task 3 2 Measurement challenges due to high temperature (1250 °C) and extreme conditions in the reheat furnace	Likelihood after mitigation Low Impact Target uncertainty of phosphor-based thermometer cannot be achieved Level of severity Medium	Previous work has been done on high temperature phosphors indicating that materials with suitable temperature ranges and host compounds with suitable chemical stability exist which render this outcome unlikely	The maximum target temperature will be reduced
Task 3 3 The phosphor does not survive for long enough in the industrial harsh environments for sufficient measurements to be made	Likelihood after mitigation Low Impact Phosphor cannot be demonstrated in industrial applications Level of severity Medium	Several different industrial trials are planned so the risk is well spread Development and testing in Tasks 3 1 and 3 2 should mitigate this risk	The range of target industrial applications will be narrowed
Task 4 1 Machine learning algorithm cannot be made to work with the available temperature-time data	Likelihood after mitigation Low Impact Self-validating thermocouples cannot be automated Level of severity Medium	Previous work has been done on machine learning algorithms for this application [39] which suggests at least one envisaged approach is feasible	A wide range of approaches are available and will serve as backup methods
Task 4 2 Equipment damage/loss during transportation to participants' facilities	Likelihood after mitigation Low Impact Damage or de-calibration of the NPL standard flame will make comparison measurements between the participants' facilities unreliable Level of severity Medium	NPL staff will travel with all sensitive equipment during transit to ensure its condition on arrival at the participant's facility	Pre-installation tests will identify whether damage has occurred Spare parts including a complete burner and flow controllers will be available to repair the system if required
Task 4 2 Failure of flame burner systems at participants' laboratories	Likelihood after mitigation Low Impact Delay in commissioning of flame standards resulting in delay in task completion Level of severity Medium	All participants have internal procedures to ensure facilities are fit-for-purpose and age/performance is monitored Some margin on the time required for undertaking the task has been included in the planned test schedule	Participants have access to replacement burners and associated fuel mixing/control equipment

Task 4 2 High degree of technical challenge Measuring flame temperatures with a target uncertainty of 0 5 % requires a high degree of technical knowhow	Likelihood after mitigation Medium Impact The uncertainty of the optical thermometry techniques does not reach the required level Level of severity Medium	All participants have highly competent staff with substantial expertise in flame temperature measurement The collaboration between participants will provide opportunities to share knowledge and best practice	More than one optical diagnostic technique is available at the participants' facilities This provides good contingency as it is highly unlikely that all methods would be unsuccessful
Task 4 2 A line-of-sight IR emission system may fail to achieve the challenging overall temperature measurement uncertainty because of a low sensitivity of the IR spectrometer	Likelihood after mitigation Low Impact The uncertainty of the optical thermometry techniques does not reach the required level Level of severity Medium	All participants have highly competent staff with substantial expertise in flame temperature measurement A low-resolution FTIR will be used instead as a back-up to the IR spectrometer The collaboration between participants will provide opportunities to share knowledge and best practice	The combined uncertainty will be expanded
Task 4 3 The neural network does not provide an adequate prediction of the insert plate surface temperature	Likelihood after mitigation Low Impact The uncertainty of the surface thermometry calibration artefact is too large Level of severity Medium	The team is highly experienced at developing high quality reference thermometry instrumentation and high quality neural network algorithms	The uncertainty of the reference temperature and its areal distribution will be expanded

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	Likelihood after mitigation Medium Impact The loss of key team members could result in delay of deliverables and the project or in worst case that specific tasks cannot be delivered Level of severity Medium	None of the team members are planning to leave or retire within the project, although the possibility of ill-health or accidents cannot be discounted Although each team member has valuable experience that is not replicated exactly by other team members, the grouping of European experts within the consortium should minimise the technical areas where knowledge is held by a single person 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	If a key member leaves the project, then the participant concerned will be responsible for appointing a replacement In extreme cases work will be re-allocated between participants
Complexity of financially and technically managing a large consortium of participants	Likelihood after mitigation Medium Impact Failure to fully cooperate or communicate effectively within the consortium could endanger efficient delivery of the project Level of severity Medium	The project is led by an experienced coordinator and experienced WP leaders They will regularly communicate both in connection with the project meetings and in between This will ensure that potential problems are identified early and that all participants are clear on their roles	WP leaders will play an important role in flagging up potential problems to the coordinator and the Project Management Board, who will then decide on the best course of action to take If necessary, work will be reassigned to an alternative participant, or parts of the work re-scoped in agreement with EURAMET

Inter-dependencies between technical activities and tasks are too complex	Likelihood after mitigation Medium Impact Tasks are delayed, or it is not possible to deliver them Level of severity Medium	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
Problems dealing with Intellectual Property (IP) ownership and/or exploitation might occur and could be a source of potential conflict	Likelihood after mitigation Medium Impact Disagreement between project 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 IP will be handled accordingly	Independent arbitrators will be used in the event of disagreement between participants
A collaborator fails to provide access to facilities/site or equipment	Likelihood after mitigation Medium Impact The consortium may not be able to complete the planned work, or the work might need to be delayed until another collaborator or alternative access to facilities or equipment is found The consortium may not be able to perform the industrial validation in WP3 Level of severity Medium	The coordinator or relevant participant will liaise with the collaborator early in the project regarding access to facilities/site or equipment All collaborators are professional companies or organisations and experienced in project-work Any issues will be discussed at the regular technical web-meetings and taken care of	The WP leaders will together with the coordinator identify and approach alternative collaborator with suitable facilities/ site or equipment
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 High 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 have been scheduled to have some overlap in time and thus a delay in the output of one activity will not necessarily cause an immediate delay in another	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 and joint demonstrator activities in a post- or trans-COVID world	Likelihood after mitigation Medium Impact Failure to show the outputs at workshops or through joint demonstrator activities risks reducing the knowledge transfer and impact from the project Level of severity Low	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

D3 Ethics

The Partnership Ethics Review 2023 has given JRP 23IND11 ThermoSI "Ethics clearance".

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.

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.

Artificial intelligence

The ethics screening identified that there are issues arising from project work involving artificial intelligence.

By signing or acceding to this grant agreement each participant asserts that any work involving artificial intelligence is carried out in agreement with ethical principles and relevant legislations. The project will use AI as a mathematical tool to enhance industrial temperature measurement systems. Machine learning based sensors consist of a conventional sensor and a machine learning model embedded in their measurement system. The model allows the sensors to detect measurement drift, but it does not influence the machine-human interaction. AI tools to be used in this project shall not interact with, replace or influence human decision-making processes.

The consortium will ensure that any AI methods used and/or developed in the project comply with the prerequisites for ethically sound AI systems in accordance with the '*Ethics Guidelines for Trustworthy AI*'.

Section E: References

[1] In the case of Johnson noise thermometry, traceability is to electrical standards, giving a reference to electrical energy which is directly related to thermal energy and hence temperature in the new SI with the definition of *e*, *h* and *k* (electronic charge, Planck constant and Boltzmann constant respectively)

[2] Following the redefinition of the kelvin in 2019, Johnson noise thermometry is one of the practical primary thermometry types recommended for further development by the CCT https //www bipm org/utils/en/pdf/si-mep/SI-App2-kelvin pdf, for more details on the kelvin redefinition see G Machin, The Kelvin redefined, Meas Sci Technol 29 022001 (2018) https //doi org/10 1088/1361-6501/aa9ddb

[3] H Preston-Thomas, The International Temperature Scale of 1990 (ITS-90), Metrologia 27 (1990) 3-10, erratum Metrologia 27 (1990) 107 https //iopscience iop org/article/10 1088/0026-1394/27/1/002/pdf

[4] 14IND04 EMPRESS and 17IND04 EMPRESS 2 were the first "Enhancing process efficiency through improved temperature measurement" projects, which ran from May 2015 to April 2021 These ground-breaking projects brought together NMIs, universities, sensor manufacturers and industrial end-users in high value manufacturing to solve a suite of specific, documented process control challenges in real-world high value manufacturing applications EMPRESS 2 has an associated Stakeholder Community numbering more than 140 organisations with an interest in high value manufacturing Outcomes were reported at industry-focused Stakeholder Community workshops (one featuring a keynote speech from Rolls-Royce on the importance of EMPRESS developments to the development of gas turbines for propulsion)

[5] A published progress report is at J V Pearce, F Edler, C J Elliott, L Rosso, G Sutton, A Andreu, G Machin, "EMPRESS A European Project to Enhance Process Control Through Improved Temperature Measurement", Int J Thermophys (2017) 38 118 http //drcu be/tdbc, see also J V Pearce, EMPRESS A pan-European project to enhance manufacturing process efficiency through improved temperature control, Measurement and Control, Vol 49 No 8 pp 252-255, October 2016 http //mac sagepub com/content/49/8/252 short

[6] Enhancing process efficiency through improved temperature measurement the EMPRESS projects, J V Pearce, A Heyes, F Edler, A Fateev, G Sutton, A Andreu, G Machin, proc Tempmeko 2019, Journal of Physics Conference Series 2554 012003 (2023) https //doi org/10 1088/1742-6596/2554/1/012003 See also J V Pearce, Measurement and control in the NPL temperature metrology group, Precision, September 2022, page 6 https //tinyurl com/2583b36t

[7] The Institute of Measurement and Control (InstMC) is the UK professional body concerned with promoting measurement and control across the full spectrum of technologies https //www instmc org/

[8] BS EN 13445-1 2009 Unfired pressure vessels Part 1 General & BS EN 13445-4 2009+A1 2011 Unfired pressure vessels Part 4 Fabrication

[9] ASME Boiler and Pressure Vessel Code (BPVC) Section VIII – Rules for Construction of Pressure Vessels

[10] PD 5500 2012+A2 2013 Specification for unfired fusion welded pressure vessels

[11] ISO 15614-1 (2004) Specification and qualification of welding procedures for metallic metals – Welding procedure test – Part 1 Arc and gas welding of steels and arc welding of nickel and nickel alloys

[12] BS EN ISO 8502-4 2000 Preparation of steel substrates before application of paints and related products – Tests for the assessment of surface cleanliness – Part 4 Guidance on the estimation of the probability of condensation prior to paint application

[13] AMS2750F is an aerospace manufacturing standard covering temperature sensors, instrumentation, thermal processing equipment, correction factors and instrument offsets, system accuracy tests, and temperature uniformity surveys These are necessary to ensure that parts or raw materials are heat treated in accordance with the applicable specification(s)

[14] High value manufacturing is the application of leading-edge technical knowledge and expertise to the creation of products, production processes, and associated services which have strong potential to bring sustainable growth and high economic value to the EU It is often associated with extensive supply and value chains

[15] Advanced manufacturing involves versatile production methods that fully utilise capital plant and are more efficient, effective and responsive – as opposed to traditional manufacturing which is based on the use of dedicated plant and production lines with little or no flexibility It has the capacity to accommodate the

varying production requirements and mass customisation commonly encountered by industry, without the need for excessive capital investment.

[16] Key figures on Europe 2023 Edition, Eurostat, ISBN 978-92-68-04392-9 https://op.europa.eu/en/publication-detail/-/publication/946f95e0-3274-11ee-83b8-01aa75ed71a1/language-en

[17] EC communication COM(2011) 109 final, Energy Efficiency Plan 2011 https://tinyurl.com/y6vdrkm9

[18] E. Westkämper: Towards the Re-Industrialization of Europe - A Concept for Manufacturing for 2030, Springer-Verlag 2014

[19] COM(2017) 479 final: Investing in a smart, innovative and sustainable Industry – A renewed EU Industrial Policy Strategy https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52017DC0479

[20] COM(2014) 14 final: For a European industrial renaissance https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0014&from=ET

[21] For both electricity and gas, the price differential with most other regions is increasing.

[22] All EMN Advanced Manufacturing Strategic Research Agenda documents are available at https://www.euramet.org/european-metrology-networks/advanced-manufacturing/strategic-research-agenda

[23] http://www.johnson-noise-thermometer.com/

[24] D. Drung, M. Kraus, C. Krause, Calibration of the dual-mode auto-calibrating resistance thermometer with few-parts-per-million uncertainty, Meas. Sci. Technol. 33(1) 015008 https://doi.org/10.1088/1361-6501/ac2c48

[25] There are two key types of requirements for Johnson noise thermometry, namely industrial (harsh environments, very long-term measurements where mitigation of drift is crucial) where measurement uncertainties of 1 °C are acceptable, and metrological, i.e. for standards and calibration laboratories, where mitigation of drift is important but also very low measurement uncertainties approaching 1 mK; here the requirement for robustness in harsh environments is less stringent.

[26] Nyquist's equation relates the temperature T of a sensing element (e.g. resistor) to the Johnson noise voltage $\overline{V_T^2}$ and the resistance R: $\overline{V_T^2} = 4kTR\Delta f$, where k is Boltzmann's constant and Δf is the bandwidth over which the measurements are performed. It is evident that if $\overline{V_T^2}$ and R are periodically measured, then T can always be determined, even if the sensor is damaged by harsh environments.

[27] Bolometry and calorimetry has already been shown to be viable using graphene at cryogenic temperatures. See e.g. K.C. Fong & K.C. Schwab, Ultrasensitive and Wide-Bandwidth Thermal Measurements of Graphene at Low Temperatures. Phys. Rev. X 2, 031006 (2012) https://doi.org/10.1103/PhysRevX.2.031006

[28] The EMN Metrology Network for Mathematics and Statistics (MATHMET) Strategic Research Agenda is available at https://www.euramet.org/european-metrology-networks/mathmet/strategy

[29] Machin G, Vuelban E, Sadli M, Edler F, Strnad R, Anhalt K, Pearce J, Siefert M, The research outcomes of the European Metrology Research Programme Project: HiTeMS – High Temperature Measurement Solutions for Industry, Measurement 78 168 (2016) https://doi.org/10.1016/j.measurement.2015.09.033

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[31] Sutton, G., Korniliou, S., Andreu, A. *et al.* Imaging Luminescence Thermometry to 750 °C for the Heat Treatment of Common Engineering Alloys and Comparison with Thermal Imaging. *Int J Thermophys* **43**, 36 (2022). https://doi.org/10.1007/s10765-021-02963-1

[32] Vuelban, E. & Girard, Ferruccio & Battuello, M. & Nemeček, P. & Maniur, M. & Pavlasek, Peter & Paans, T., Radiometric Techniques for Emissivity and Temperature Measurements for Industrial Applications. International Journal of Thermophysics. 36 1545-1568 (2015) https://doi.org/10.1007/s10765-015-1901-8 .

[33] Final report of EUROMET.T-S1 (EUROMET project 658): The examination of base parameters for ITS-90 scale realization in radiation thermometry, Metrologia 45 03002 (2008) https://doi.org/10.1088/0026-1394/45/1A/03002

[34] P. Bramley, D. Cruickshank, J.V. Pearce, The development of a practical, drift-free, Johnson noise thermometer for industrial applications, Int. J. Thermophys. 38, 25 (2017) https://doi.org/10.1007/s10765-016-2156-8

[35] P. Bramley, D. Cruickshank, J. Aubrey, Developments towards an industrial Johnson noise thermometer, Meas. Sci. Technol. 31(5) 054003 (2020) https://doi.org/10.1088/1361-6501/ab58a6

[36] Graphene is an allotrope of carbon in the form of a single layer of atoms in a 2D hexagonal lattice, with a wide range of remarkable properties that offer potential for disruptive improvements in microelectronics. An authoritative roadmap is given by Ferrari, A. C. et al. Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems. Nanoscale 7, 4598–4810 (2015) https://doi.org/10.1039/c4nr01600a

[37] F. Luo et al., Graphene Thermal Emitter with Enhanced Joule Heating and Localized Light Emission in Air, ACS Photonics 2019, 6, 8, 2117-2125 https://pubs.acs.org/doi/10.1021/acsphotonics.9b00667

[38] ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories

[39] A machine learning approach to automation and uncertainty evaluation for self-validating thermocouples, S. Bilson, A. Thompson, D. Tucker, J. Pearce, NIST Special Publication 2100, NIST SP 2100-05, ITS10 Conference Digest, Tenth International Temperature Symposium, Anaheim, CA USA, April 3-7, https://doi.org/10.6028/NIST.SP.2100-05 p. 85 (2023); Additionally, full paper now accepted for publication in the American Institute of Physics (AIP) Conference Proceedings.

[40] https://ec.europa.eu/eurostat/databrowser/view/ILC_MDES01/default/table?lang=en

[41] https://www.eesc.europa.eu/en/news-media/news/energypoverty-women-more-likely-be-affected-men

[42] JCGM 100 – Evaluation of measurement data – Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3) https://www.iso.org/sites/JCGM/GUM-introduction.htm

[43] BS EN 60584-1:2013 Thermocouples – Part 1: EMF specifications and tolerances

[44] IEC/TS 62492-2:2013 Industrial process control devices – Radiation thermometers – Part 2: Determination of the technical data for radiation thermometers

[45] IEC/TS 62492-1:2008 Industrial process control devices – Radiation thermometers – Part 1: Technical data for radiation thermometers

[46] Special Process: Heat Treat System Assessment 4th edition (CQI-9) is a comprehensive audit covering the most common heat treat processes employed by the automotive industry, intended to provide a common approach to a heat treat management system for automotive production and service part organizations. https://www.aiag.org/quality/special-process-assessments/heat-treat https://www.aiag.org/quality/special-process-assessments/heat-treat

[47] Nadcap (National Aerospace and Defense Contractors Accreditation Program) is an industry-managed approach to conformity assessment of 'special processes' that brings together technical experts from prime contractors, suppliers and representatives from government to work together and establish requirements for approval of suppliers using a standardized approach. Unlike traditional third party programs, Nadcap approval is granted based upon industry consensus. https://p-r-i.org/nadcap/

[48] IEC 62828-3:2018 Reference conditions and procedures for testing industrial and process measurement transmitters – Part 3: Specific procedures for temperature transmitters

[49] Including manufacturing, extractive industries and utilities industries, but excluding business services and construction. See COM(2017) 479 final, Investing in a smart, innovative and sustainable Industry – A renewed EU Industrial Policy Strategy https://tinyurl.com/yyjp44gb

[50] For every 100 jobs created in industry, it is estimated that between 60 and 200 new jobs are created in the rest of the economy. See COM(2012) 582 final, A Stronger European Industry for Growth and Economic Recovery https://tinyurl.com/y5hwnla4

[51] Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3.

[52] Air pollution accounted for 5.4% of deaths in the EU in 2017, although this has been decreasing steadily, from 6.99% in 1990 https://tinyurl.com/yamhdewh

[53] The EU currently accounts for 9.8% of global CO2 emissions, and is a large historical contributor with 22% of cumulative CO2 emissions, second only to the USA https://tinyurl.com/yy4p4w34

[54] A Markandya and P Wilkinson, Electricity generation and health, The Lancet 370(9591), 979-990 (2007) https //doi org/10 1016/S0140-6736(07)61253-7

[55] COM(2014) 15 final, A policy framework for climate and energy in the period from 2020 to 2030 https //tinyurl com/y4xt5qtj

[56] Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control (no longer in force) https //eur-lex europa eu/legal-content/EN/ALL/?uri=CELEX%3A32008L0001

[57] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (recast) https //eur-lex europa eu/LexUriServ/LexUriServ do?uri=OJ L 2010 334 0017 0119 en PDF

[58] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency https //eur-lex europa eu/LexUriServ/LexUriServ do?uri=OJ L 2012 315 0001 0056 en PDF

[59] All EMN for Climate and Ocean Observation Strategic Research Agenda documents are available at https //www euramet org/climate-and-ocean-observation/strategy

[60] European Platform on Life Cycle Assessment https //eplca jrc ec europa eu/

[61] S O Rice, "Mathematical analysis of random noise," Bell systems technical journal, vol 23, pp 282-332, 1944 https //doi org/10 1002/j 1538-7305 1944 tb00874 x

Version 1.0
21/05/2024

ANNEX 2 of EUROPEAN PARTNERSHIP ON METROLOGY GA 23IND11 ThermoSI

ESTIMATED BUDGET FOR THE ACTION

	Estimated eligible[1] costs (per budget category)												Estimated EU contribution[2]			
	Direct costs										Indirect costs	Total costs	EU contribution to eligible costs			Maximum grant amount[6]
	A. Personnel costs				B. Subcontracting costs	C. Purchase costs			D. Other cost categories		E. Indirect costs[3]		Funding rate %[4]	Maximum EU contribution[5]	Requested EU contribution	
	A.1 Employees (or equivalent) A.2 Natural persons under direct contract A.3 Seconded persons		A.4 SME owners and natural person beneficiaries	A.6 Personnel unit cost	B. Subcontracting	C.1 Travel and subsistence	C.2 Equipment	C.3 Other goods, works and services	D.1 Financial support to third parties	D.2 Internally invoiced goods and services	E. Indirect costs					
Forms of funding	Actual costs	Unit costs (usual accounting practices)	Unit costs[7]	Unit costs[7]	Actual costs	Actual costs	Actual costs	Actual costs	Unit costs (usual accounting practices)	Unit costs (usual accounting practices)	Flat-rate costs[8]					
	a1	a2	a3	a5	b	c1	c2	c3	d1	d2	e = 0,25 * (a1 + a2 + a3 + a5 + c1 +c2 + c3)	f = a+b+c+d+e	U	g = f*U%	h	m
1: DTI	271,000	-	-	-	-	22,000	-	27,000	-	-	80,000	400,000.00	100%	400,000.00	400,000.00	400,000.00
2: CMI	43,000	-	-	-	-	3,000	-	2,000	-	-	12,000	60,000.00	100%	60,000.00	60,000.00	60,000.00
3: PTB	269,500	-	-	-	-	15,000	-	11,500	-	-	74,000	370,000.00	100%	370,000.00	370,000.00	370,000.00
4: SMU	12,000	-	-	-	-	4,500	-	3,500	-	-	5,000	25,000.00	100%	25,000.00	25,000.00	25,000.00
5: UL	166,000	-	-	-	-	18,000	-	30,000	-	-	53,500	267,500.00	100%	267,500.00	267,500.00	267,500.00
6: VTT	-	36,783	-	-	-	6,100	-	4,495	-	20,777	11,845	79,999.50	100%	79,999.50	79,999.50	79,999.50
7: DTU	102,707	-	-	-	-	8,253	-	17,040	-	-	32,000	160,000.00	100%	160,000.00	160,000.00	160,000.00
8: NSC-IM	37,000	-	-	-	-	7,000	-	4,000	-	-	12,000	60,000.00	100%	60,000.00	60,000.00	60,000.00
9: OVGU	37,050	-	-	-	-	3,950	-	3,000	-	-	11,000	55,000.00	100%	55,000.00	55,000.00	55,000.00
10: B&W Volund	10,000	-	-	-	-	2,000	-	-	-	-	3,000	15,000.00	0%	-	-	-
11: Beamex	25,000	-	-	-	-	10,000	30,060	5,000	-	-	17,515	87,575.00	0%	-	-	-
12: BAE																
13: CCPI																
14: Metrosol																
15: NPL																
16: STRATH																
17: UoM																
Total consortium	973,257	36,783	-	-	-	99,803	30,060	107,535	-	20,777	311,860	1,580,074.50		1,477,499.50	1,477,499.50	1,477,499.50

[1] See Article 6 for the eligibility conditions. All amounts must be expressed in EUR (see Article 21.3 for the conversion rules).

[2] The consortium remains free to decide on a different internal distribution of the EU funding (via an amendment request).

[3] Indirect costs already covered by an operating grant (received under any EU funding programme) are ineligible (see Article 6.3). Therefore, a beneficiary/affiliated entity that receives an operating grant during the action duration cannot declare indirect costs for the year(s)/reporting period(s) covered by the operating grant, unless they can demonstrate that the operating grant does not cover any costs of the action. This requires specific accounting tools. Please immediately contact EURAMET for details.

[4] See Data Sheet of the GA for the funding rate(s).

[5] This is the *theoretical* amount of the EU contribution to costs, if the reimbursement rate is applied to all the budgeted costs. This theoretical amount is then capped by the 'maximum grant amount'.

[6] The 'maximum grant amount' is the maximum grant amount decided by the EU. It normally corresponds to the requested grant, but may be lower.

[7] See Annex 2a 'Additional information on the estimated budget' for the details (units, cost per unit).

ANNEX 3

ACCESSION FORM FOR BENEFICIARIES

Cesky Metrologicky Institut (CMI), established in Okružní 31, CZ-638 00 Brno, Czechia, PIC no. 993266033, VAT no CZ00177016, ('the beneficiary'), represented for the purpose of signing this Accession Form by its legal authorised representative (person legally authorised to act on behalf of the legal entity),

hereby agrees

to become a beneficiary

in Agreement 23IND11 ThermoSI ('the Agreement')

between Teknologisk Institut (DTI) **and** EURAMET e.V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority') under the powers delegated by the European Commission ('European Commission') **and mandates the coordinator** to submit and sign in its name and on its behalf any amendments to the Agreement, in accordance with Article 39.

By signing this Accession Form, the beneficiary accepts the grant and agrees to implement it in accordance with the Agreement, with all the obligations and terms and conditions it sets out as from the date of the signature of the accession form (**'accession date'**)

For the beneficiary:

Name of authorised representative

Function of authorised representative

Signature of authorised representative

Date

Done in English

ANNEX 3

ACCESSION FORM FOR BENEFICIARIES

Physikalisch-Technische Bundesanstalt (PTB), established in Bundesallee 100, DE-38116 Braunschweig, Germany, PIC no 999596544, VAT no DE811240952, ('the beneficiary'), represented for the purpose of signing this Accession Form by its legal authorised representative (person legally authorised to act on behalf of the legal entity),

hereby agrees

to become a beneficiary

in Agreement 23IND11 ThermoSI ('the Agreement')

between Teknologisk Institut (DTI) **and** EURAMET e V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority') under the powers delegated by the European Commission ('European Commission') **and mandates the coordinator** to submit and sign in its name and on its behalf any amendments to the Agreement, in accordance with Article 39

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For the beneficiary

_____

Name of authorised representative

_____

Function of authorised representative

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INc

_____

Signature of authorised representative

_____

Date

Done in English

ANNEX 3

ACCESSION FORM FOR BENEFICIARIES

Slovenský Metrologický Ústav (SMU), established in Karloveská 63, SK-842 55 Bratislava 4, Slovakia, PIC no. 994207903, VAT no SK2020908230, ('the beneficiary'), represented for the purpose of signing this Accession Form by its legal authorised representative (person legally authorised to act on behalf of the legal entity),

hereby agrees

to become a beneficiary

in Agreement 23IND11 ThermoSI ('the Agreement')

between Teknologisk Institut (DTI) **and** EURAMET e.V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority') under the powers delegated by the European Commission ('European Commission') **and mandates the coordinator** to submit and sign in its name and on its behalf any amendments to the Agreement, in accordance with Article 39

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For the beneficiary.

_____

Name of authorised representative

_____

Function of authorised representative

_____

Signature of authorised representative

_____

Date

Done in English.

ANNEX 3

ACCESSION FORM FOR BENEFICIARIES

Univerza v Ljubljani (UL), established in Kongresni trg 12, SI-1000 Ljubljana, Slovenia, PIC no 999923240, VAT no SI54162513, ('the beneficiary'), represented for the purpose of signing this Accession Form by its legal authorised representative (person legally authorised to act on behalf of the legal entity),

hereby agrees

to become a beneficiary

in Agreement 23IND11 ThermoSI ('the Agreement')

between Teknologisk Institut (DTI) **and** EURAMET e V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority') under the powers delegated by the European Commission ('European Commission') **and mandates the coordinator** to submit and sign in its name and on its behalf any amendments to the Agreement, in accordance with Article 39

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For the beneficiary

_____

Name of authorised representative

_____

Function of authorised representative

_____

Signature of authorised representative

_____

Date

Done in English

ANNEX 3

ACCESSION FORM FOR BENEFICIARIES

Teknologian tutkimuskeskus VTT Oy (VTT), established in Tekniikantie 21, 02150, Espoo, Finland, PIC no 932760440, VAT no FI26473754, ('the beneficiary'), represented for the purpose of signing this Accession Form by its legal authorised representative (person legally authorised to act on behalf of the legal entity),

hereby agrees

to become a beneficiary

in Agreement 23IND11 ThermoSI ('the Agreement')

between Teknologisk Institut (DTI) **and** EURAMET e V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority') under the powers delegated by the European Commission ('European Commission') **and mandates the coordinator** to submit and sign in its name and on its behalf any amendments to the Agreement, in accordance with Article 39

By signing this Accession Form, the beneficiary accepts the grant and agrees to implement it in accordance with the Agreement, with all the obligations and terms and conditions it sets out as from the date of the signature of the accession form ('**accession date**')

For the beneficiary

_____

Name of authorised representative

_____

Function of authorised representative

_____

Signature of authorised representative

_____

Date

Done in English

ANNEX 3

ACCESSION FORM FOR BENEFICIARIES

Danmarks Tekniske Universitet (DTU), established in Anker Engelunds Vej 1, Bygning 101A, DK-2800 Kongens Lyngby, Denmark, PIC no. 999990655, VAT no. DK30060946, ('the beneficiary'), represented for the purpose of signing this Accession Form by its legal authorised representative (person legally authorised to act on behalf of the legal entity),

hereby agrees

to become a beneficiary

in Agreement 23IND11 ThermoSI ('the Agreement')

between Teknologisk Institut (DTI) **and** EURAMET e.V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority') under the powers delegated by the European Commission ('European Commission') **and mandates the coordinator** to submit and sign in its name and on its behalf any amendments to the Agreement, in accordance with Article 39

By signing this Accession Form, the beneficiary accepts the grant and agrees to implement it in accordance with the Agreement, with all the obligations and terms and conditions it sets out as from the date of the signature of the accession form ('**accession date**').

For the beneficiary:

Name of authorised representative
Mette Bjørnlund

Function of authorised representative
Head of administration

Signature of authorised representative

Date

Done in English.

ANNEX 3

ACCESSION FORM FOR BENEFICIARIES

National Scientific Centre Institute of Metrology (NSC-IM), established in 42 Mironositskaya Str., UA-61002 Kharkov, Ukraine, PIC no. 952600335, VAT no. UA025683220315, ('the beneficiary'), represented for the purpose of signing this Accession Form by its legal authorised representative (person legally authorised to act on behalf of the legal entity),

hereby agrees

to become a beneficiary

in Agreement 23IND11 ThermoSI ('the Agreement')

between Teknologisk Institut (DTI) **and** EURAMET e.V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority') under the powers delegated by the European Commission ('European Commission') **and mandates the coordinator** to submit and sign in its name and on its behalf any amendments to the Agreement, in accordance with Article 39.

By signing this Accession Form, the beneficiary accepts the grant and agrees to implement it in accordance with the Agreement, with all the obligations and terms and conditions it sets out as from the date of the signature of the accession form (**'accession date'**).

For the beneficiary:

_____

Name of authorised representative

Function of authorised representative

_____

Signature of authorised representative

_____ _____

Date

Done in English.

ANNEX 3

ACCESSION FORM FOR BENEFICIARIES

Otto-von-Guericke-Universitaet Magdeburg (OVGU), established in Universitaetsplatz 2, 39106 Magdeburg, Germany, PIC no. 999873285, VAT no. DE139238413, ('the beneficiary'), represented for the purpose of signing this Accession Form by its legal authorised representative (person legally authorised to act on behalf of the legal entity),

hereby agrees

to become a beneficiary

in Agreement 23IND11 ThermoSI ('the Agreement')

between Teknologisk Institut (DTI) **and** EURAMET e.V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority') under the powers delegated by the European Commission ('European Commission') **and mandates the coordinator** to submit and sign in its name and on its behalf any amendments to the Agreement, in accordance with Article 39.

By signing this Accession Form, the beneficiary accepts the grant and agrees to implement it in accordance with the Agreement, with all the obligations and terms and conditions it sets out as from the date of the signature of the accession form (**'accession date'**).

For the beneficiary:

Name of authorised representative

Function of authorised representative

Signature of authorised representative

Date

Done in English.

ANNEX 3

ACCESSION FORM FOR BENEFICIARIES

Beamex Oy Ab (Beamex), established in Ristisuonraitti 10, 68600, Pietarsaari, Finland, PIC no 892954938, VAT no FI0181602-8, ('the beneficiary'), represented for the purpose of signing this Accession Form by its legal authorised representative (person legally authorised to act on behalf of the legal entity),

hereby agrees

to become a beneficiary

in Agreement 23IND11 ThermoSI ('the Agreement')

between Teknologisk Institut (DTI) **and** EURAMET e V, Bundesallee 100, 38116 Braunschweig, Germany, ('the granting authority') under the powers delegated by the European Commission ('European Commission') **and mandates the coordinator** to submit and sign in its name and on its behalf any amendments to the Agreement, in accordance with Article 39

By signing this Accession Form, the beneficiary accepts the grant and agrees to implement it in accordance with the Agreement, with all the obligations and terms and conditions it sets out as from the date of the signature of the accession form ('**accession date**')

For the beneficiary

Name of authorised representative

Function of authorised representative

Signature of authorised representative

Date

Done in English

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Final Audit Report 2024-05-27

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