Publishable Summary for 18SIB02 Real-K
Realising the Redefined kelvin

Overview

On the 20th May 2019 the implementation phase of the redefinition of the international system of units (the SI) was completed and the new unit definitions came into force. This project has taken the kelvin redefinition, and its associated *mise-en-pratique* and began to turn it into a reality by: a) developing primary thermometry techniques at high and low temperatures which can be used to realise and disseminate the redefined kelvin b) perform research to ensure the on-going fitness of the current temperature scale the International Temperature Scale of 1990 (ITS-90), and c) undertake longer-term research for primary thermometry to be the basis of temperature traceability throughout the entire range.

Need

The kelvin redefinition and its associated *mise-en-pratique* (*MeP*-K-19) are essentially just a documentary framework that need significant work in the coming years if the experimental approaches to thermodynamic temperature realisation and dissemination given in that document are to become a reality. This was clearly recognised at the most recent Consultative Committee of Thermometry (CCT) meeting (CCT/28) in June 2017 where the explicit recommendation (recommendation T1) "that member state NMIs take full advantage of the opportunities for the realisation and dissemination of thermodynamic temperature afforded by the kelvin redefinition and the *mise en pratique* for the definition of the kelvin" was issued.

Currently nearly all temperature measurements performed around the world are traceable to one of the two defined scales (either the ITS-90 or the specialist low temperature scale, the Provisional Low Temperature Scale of 2000 (PLTS-2000)). With the impetus given by the redefinition there will be a rise in primary thermometry approaches for realising and disseminating temperature, *directly linked to the redefined kelvin*. Realising the redefined kelvin through primary thermometry will have a number of advantages compared to defined scales. Firstly, traceability will be directly linked to the redefined kelvin and not an intermediary defined scale. This over time will lead to practical primary thermometry being adopted by users with decreasing reliance on traceability to defined scales, improving the long-term reliability of measurements. Secondly, the low temperature part of the current scales could be replaced with simpler primary thermometry approaches, whilst the high temperature part will be replaced with more robust indirect primary radiometry. Thirdly in the long term practical primary thermometry could well be developed from the innovations under development in Real-K

This research supports the world metrology community in the realisation and dissemination of the redefined kelvin, with EURAMET continuing to lead in this important metrology field. Without this research the realisation and dissemination phase of the kelvin redefinition could falter.

Objectives

The overall goal of this project was to take the kelvin redefinition (and the *MeP*-K-19) and began to turn it into a reality. The following objectives were set at the beginning of the project and have been achieved:

1) To demonstrate and establish traceability directly to the redefined kelvin from ~1300 K to ~3000 K. Low uncertainty thermodynamic temperatures of four new High Temperature Fixed Points (HTFPs) will be determined. Then, through the *MeP*-K-19, HTFPs will be used to realise and disseminate thermodynamic temperature with uncertainties competitive with the defined scale (the ITS-90) (target Uncertainty [U]<0.05%).

2) To demonstrate practical primary thermometry for realisation and dissemination of thermodynamic temperature below 25 K and so demonstrate that primary thermometry can be used: to replace the currently complex ITS-90 scale realisation arrangement below 25 K and to ensure a smooth transition to the PLTS-2000 range below 1 K (target U = 0.2 mK at 25 K and <1% at 1 K).

3) To extend the life of the ITS-90 giving users continued access to low uncertainty realisations of the scale whilst allowing time for primary thermometry methods to mature. The troublesome issue of scale non-uniqueness will be investigated, with the objective of reducing its uncertainty by 30 %, and a

suitable fixed-point replacement for the mercury triple point identified, constructed and tested. Integration of the new fixed point within the ITS-90 will be addressed.

4) To reduce the uncertainty in a number of different primary thermometry methods, approved for use in the *MeP*-K-19, and so begin to facilitate an extension of their applicability for temperature realisation and dissemination into the temperature region 25 K and above. This long-term objective will be facilitated through reducing the uncertainties of the calculated thermophysical properties of gases (e.g. He, Ne, Ar) used as thermometric fluids in primary thermometers.

5) To work closely with the CCT to issue formal recommendations and definitive guidance on the realisation and dissemination of the redefined kelvin, to ensure rapid uptake of the results of this research. Engagement with the global thermometry community by regular briefings to Regional Metrology Organisation (RMO) Technical Committee for Thermometry (TC-Ts), papers and conference presentations. Wider user engagement through the stakeholder community and events.

Progress beyond the state of the art

This project has used primary thermometry for temperature realisation and dissemination at temperatures >1300 K (objective 1) and <25 K (objective 2). The project targeted reducing non-uniqueness uncertainties in the realisation of the ITS-90 by 30% and identified a replacement for the mercury triple point (objective 3). It has also undertaken low uncertainty *ab initio* calculations of thermophysical properties of He, Ne and Ar, confirmed by selected measurement (objective 4). All these developments are beyond the state of the art.

Results

Key results of the project are given, significant progress has been made in the state of the art of temperature metrology in all four areas. Note where the “current state of the art” is referred to it means what was possible at the beginning of the Real-K project.

Realisation and dissemination of the redefined kelvin >1300 K.

The *current state of the art* for temperature realisation and dissemination >1300 K is through the ITS-90. The state of the art was advanced by assigning definitive thermodynamic temperatures to the High Temperature Fixed Points (HTFPs): Fe-C (1426 K), Pd-C (1765 K), Ru-C (2226 K) and WC-C (3020 K), and by demonstrating the first practical outworking of the *MeP*-K-19 by indirect primary radiometry (>1300 K).

The following HTFPs were constructed in line with the construction protocol; 5 WC-C cells, 4 Ru-C cells, 6 Ru-C cells, 5 Pd-C cells and 4 Fe-C cells. These were compared and ranked according to agreed selection criteria such as melting range, repeatability, plateau shape and value of the inflection point. INRIM compared 7 Fe-C cells, CEM compared 5 Pd-C cells, NPL compared 5 Ru-C cells and LNE, Cnam compared 7 cells of WC-C.

The protocol for assigning thermodynamic temperature to the selected HTFPs was written. The measurements were performed into two loops. All the measurements have been analysed and a paper presented at the ITS-10 conference reporting preliminary thermodynamic temperatures of the new HTFPs.

The dissemination trials, including with a special large aperture HTFP cell of 6 mm made at have been undertaken. Traceability receiving partners (TUBITAK and CMI) received and measured the HTFP cells.

Objective 1 was completed. Direct traceability was demonstrated to the redefined kelvin from ~1300 K to ~3000 K. Low uncertainty thermodynamic temperatures of four new HTFPs was determined. HTFPs were used to realise and disseminate *T* with uncertainties competitive with the defined scale (the ITS-90), target [U]<0.05%.

Realisation and dissemination of the redefined kelvin <25 K.

The *current state of the art* for the temperature scale <25 K is complex. Traceable temperatures are referenced to ITS-90 or PLTS-2000. Scale realisation requires different sophisticated, time-consuming, experimental methods, which are only available in a few National Metrology Institutes (NMIs). The state of the art is being advanced through developing primary thermometers to cover the entire range from 1 K to 25 K for direct realisation and dissemination of temperature (target uncertainty <1%).

The Johnson Noise Thermometer, the primary Magnetic Field Fluctuation Thermometer (pMFFT), was redesigned leading to a factor 2 reduction in the uncertainty. Measurements were performed at the helium lambda point (2.1768 K) with good agreement between the pMFFT result and Dielectric Constant Gas Thermometry. In addition, the pMFFT demonstrated smooth overlap between ITS-90 and PLTS-2000 >0.6 K. The nanofabrication process for Al-and AlMn-based Coulomb Blockade Thermometers (CBTs) was modified and tunnel junction arrays manufactured. Al-based CBT devices were tested between 1.4 K and 25 K. Comparisons performed at PTB between pMFFT and CBT found good agreement between 2.5 K and 25 K. The CBT was found to deviate <2.5 K possibly caused by a partial disconnection of the CBT from its holder.

The pulse-tube cryostat with an Acoustic Gas Thermometer (AGT) was used to perform thermodynamic temperature measurements at T = 24.5561 K (Ne triple point). Classic AGT measurements between 4 K and 24 K were performed at several temperatures with fast-AGT and a single pressure refractive index thermometer (SP-RIGT) installed at TIPC-CAS. A comparison of both thermometers yielded good agreement.

In summary the aims of objective 2 were met. Practical primary thermometry for the potential for realisation and dissemination of thermodynamic temperature below 25 K using pMFFT, CBT and fast-AGT (and SP-RIGT) has been demonstrated. A smooth transition to the PLTS-2000 range below 1 K has been demonstrated. The target uncertainties of 0.2 mK at 25 K and <1% at 1 K were largely met.

Extending the life of the International Temperature Scale of 1990.

The current state of the art leaves Type 1[1] and 3[2] non-uniqueness among the dominant uncertainties in ITS-90 calibrations. However significant data to support uncertainty assignment is only available in limited sub-ranges of the ITS-90 e.g. 0 ºC to 420 ºC. There are three candidates for replacing the hazardous mercury triple point, namely Xe, CO_2 or SF_6. The state of the art was advanced through substantially increasing knowledge of Type 1 and 3 non-uniqueness and in characterising two replacements for the Hg triple point.

Robust evaluation of the non-uniqueness of SPRTs over a wide range of temperatures was performed over the temperature ranges from 178 K to 302 K (NPL) and from 273 K to 353 K (CEM). Measurements were performed at the ITS-90 fixed points: Ar, Hg, H_2O and Ga, and secondary triple points; SF_6, CO_2 and Xe. The results showed a significant improvement over previous comparisons using long-stem SPRTs. INRIM completed the Type 3 non-uniqueness evaluation (NU3) at high temperatures and the results were in very good agreement with previous determinations of the NU3 performed using completely different apparatus. The type 1 non-uniqueness (subrange inconsistency, SRI) of many long-stem SPRTs was investigated for all pairs of overlapping ITS-90 subranges these results importantly showed that the currently calculated differences are likely a substantial overestimate of the true SRI.

The results by UL of a least-squares (lsq) approach to SPRT interpolation were submitted for publication. One significant benefit of lsq over exact interpolation is the reduction in uncertainty propagated from the fixed points.

Cnam & LNE completed the measurements on the SF_6 cells with the results in excellent agreement with a previous SF_6 cell (within 0.1 mK). Cnam & LNE assembled a dedicated SF_6 calorimeter and installed a SF_6 triple point cell. The new system was characterised and then used to perform SF_6 triple point realization. The results with capsule-type SPRTs showed excellent agreement with previous data. However long-stem SPRTs were affected by heat conduction along the stem at the 1 mK level. TUBITAK constructed and characterised two CO_2 cells then plateau duration and reproducibility and phase transition width were measured. Comparison measurements carried out over several months indicated very consistent triple point temperature lying within 0.1 mK, with plateaus lasting >10 hours with a 0.3 mK width. These results were confirmed by repeat measurements. A comparison between cells containing 6N and 5N purity CO_2 samples was performed with a temperature difference of 0.15 mK. In conclusion this work shows that CO_2 cells can calibrate long stem SPRTs with an uncertainty <0.5 mK and the triple point of CO_2 is a very credible alternative to the mercury point.

SMU investigated the effect of replacing the Hg triple point in the sub-range of ITS-90 with SF_6, CO_2 and Xe. Xe yields superior performance to SF_6 and CO_2, **but** Xe (~160 K) is too low to be used with long-stem SPRTs. NPL analysed alternative interpolations for long-stem SPRTs below TPW to the argon point, without including the Hg point. A surprising conclusion is that the U<0.5 mK, <u>similar to current uncertainties for long-stem SPRTs</u>.

The overall aims of objective 3 were achieved. Scale non-uniqueness was comprehensively investigated and reducing its uncertainty by >30 % was met. Two possible alternative triple points to that of Hg were identified, constructed and tested, namely the SF_6 and CO_2. Integration of either of these fixed points within the ITS-90 was addressed. This work will extend the useful life of the ITS-90 to the end of the 2020s, and beyond.

Facilitating full range primary thermometry.
The *current state of the art* in establishing traceable temperatures is through calibration to, e.g. the ITS-90. For primary thermometry to be practical for kelvin dissemination between 25 K and 1300 K, gas-based methods,

[1] Type 1 non-uniqueness – arises from the use of different equations in overlapping ranges, using the same thermometer

[2] Type 3 non-uniqueness – arises from the use of different interpolating thermometers of the same kind in the same range

i.e. AGT, Dielectric Constant Gas Thermometry (DCGT) and RIGT, need to be substantially simplified. The state of the art for gas based primary thermometry will be advanced through reducing the *ab initio* calculation uncertainty of the non-ideality of monatomic gases He, Ar and Ne, with the calculations validated by low-uncertainty measurements over a temperature range of (10 K to 350 K) and pressures (<100 MPa).

Calculation of interaction potentials and thermophysical properties of thermometric gases

Excellent progress has been made in the calculation of thermophysical properties of thermometric gases. These are now sufficiently known to facilitate practical gas-based thermometry. Highlights include:

- for He, six-fold improvement in the 2nd density and acoustic virial coefficients, a factor of 3 to 5 improvement in the 3rd density and acoustic virial coefficients
- for Ne, 5-10 level of improvement in the calculation of the 2nd density and acoustic virial coefficients and improved estimates of the 3rd and 4th density and acoustic virials,
- for Ar, the calculation of an improved 2-body potential leading to significantly more accurate calculated estimates of the thermophysical properties.

Measurement of selected thermophysical properties of gases

The progress of theoretical calculations of thermophysical quantities of thermometric gases have been selectively validated by means of state-of-the-art experiments. These include:

- For He: The 2nd and 3rd density virial coefficients of helium were determined and found to closely agree with the most accurate theoretical values currently available. The 2nd and 3rd acoustic virial coefficients of He were determined and agreed with the best theoretical estimates.
- For Ne: The 2nd acoustic virial coefficient of Ne was measured. Speed-of-sound measurements in supercritical neon were carried out between 80 K and 420 K between 20 MPa and 100 MPa (U(k=2) = 0.007%). From this the 4th order acoustic virial and 2nd acoustic virial coefficient were determined.
- For Ar: Analysis of speed of sound measured yielded low uncertainty values of the second acoustic virial coefficient of argon, these results were in close agreement with accurate *ab-initio* calculations.

Preparing for improved primary thermometry

Given the new theoretical values for thermophysical gas properties, validated by key experimental evaluations the path is now open for improved primary thermometry. Here we performed preliminary demonstrations. But this will be extensively demonstrated in the Disseminating the Redefined Kelvin (DireK-T) project.

The aims of this objective were achieved. The uncertainties of the calculated thermophysical properties of gases (e.g. He, Ne, Ar) used in primary thermometers have more than been sufficiently reduced to facilitate reduction in uncertainty of the gas-based primary thermometry methods given in the *MeP*-K-19.

Impact

General outreach: This has been through the project website and circulation of five newsletters to stakeholders. An introductory article was published in the British Cryogenics Council newsletter. Written progress reports have been circulated to the CCT and all the RMO TC-Ts.

Seminars/talks/conferences: The coordinator gave invited seminars about Real-K at 7 European universities. The coordinator gave eight invited plenary/papers on Real-K during the project. Of particular note were; an invited keynote in Jan 2022, NPL India 75th anniversary celebration, “The kelvin redefinition and its implications” (based on Real-K results) and in April 2023 the James Schooley Plenary Lecture at the prestigious tenth International Temperature Symposium (ITS-10) “Progress with the redefined kelvin”. Oral presentations on Real-K were given at the virtual Euramet TC-T meeting in 2020 and in Apr 2022. On 19th April 2023 an international workshop on “Realising the redefined kelvin: Turning the *MeP*-K into reality”, was hosted by SMU.

Papers: There are currently 19 refereed articles published with at least 18 more awaiting publication.

Stakeholder community: The project stakeholder committee is comprised of 39 members. A wide spectrum of organisations is represented from industry bodies such as the British Cryogenics Council, Accreditation Bodies, Universities, RMOs and NMIs outside Europe, as well as 12 companies.

Impact on industrial and other user communities

Temperature is one of the most measured parameters in both industry and science. As such these developments will have significant impact in bott areas of human activity. *At low temperatures* (<25 K) cryogenic equipment manufacturers will welcome the possibility of direct traceability to the redefined kelvin through a simplified calibration route. Contact has been made with companies in Finland and Germany that specialise in the manufacture of cryogenic equipment. *At high temperatures*, (>1300 K) these developments impact wide spectrum of industries, e.g. materials processing and aerospace. More reliable traceability directly to thermodynamic temperature will be established through known temperature HTFPs, with NMI-like uncertainties available closer to the point of measurement. *In the mid-temperature range*, one early impact would potentially be the commercial exploitation of the mercury (Hg) fixed triple point replacement. End users will, for the first time, have reliable estimates for Type 1 and Type 3 non-uniqueness uncertainties.

Impact on the metrology and scientific communities

Significant impact on the global temperature metrology community is envisaged through step changes in the SI system in approaches to realisation of the kelvin in the NMI/Designated Institute (DI) community, egs are:

- The processes and equipment in place for temperature realisation and dissemination through the *MeP*-K-19, at temperatures >1300 K and <25 K, and mature enough for wide adoption
    - For T>1300 K: By the mid-2020s, the current ITS-90 could be supplanted, in several leading NMIs, by direct traceability to thermodynamic temperature through HTFPs.
    - For T<25 K: By the mid-2020s replacement of ITS-90 <25 K underway through the primary thermometry methods developed here, leading to more robust traceability and dissemination.
- The life extension research for the ITS-90 will impact the NMI thermometry community worldwide by:
    - The reduction in uncertainties due to scale non-uniqueness effects, enabling all NMIs to improve their realisation of the ITS-90.
    - The identification of a viable replacement for the mercury triple point, ensuring the ITS-90 will be able to continue well into the 2020s.

The NMI thermometry and wider scientific community will benefit from the "facilitating full range primary thermometry" activity. A reliable and comprehensive set of *ab initio* values of key thermophysical properties for thermometric gases (e.g. Ar, Ne, He) are now available. These values will facilitate the use of primary thermometry for traceability, demonstration of which to 300 K is one of the key objectives of the follow-on project Dissemination of the Redefined Kelvin (DireK-T).

Impact on relevant standards

This project will have a profound impact on the whole thermometry community. This will be affected chiefly through the CCT, the global authority on temperature, and the relevant standards body for this research.

Key inputs to the CCT, which will influence its guides and recommendations are:

- Definitive thermodynamic temperatures of new HTFPs, namely Co-C, Pd-C, Ru-C and WC-C
- Recommendations on the realisation and dissemination of thermodynamic temperature >1300 K
- Report on the realisation and dissemination of thermodynamic temperature from ~1 K to 25 K
- Synthesis report on characterisation and reduction of uncertainties due to scale non-uniqueness
- Recommendation report on the replacement the mercury triple point
- Recommendation report of uncertainties for primary thermometry methods, for the next version of the *MeP*-K
- Summary report to CCT-WG-SP (Strategic Planning) of the findings of Real-K

Longer-term economic, social, and environmental impacts

Thermometry is the most widely measured physical parameter so any change will have far reaching impacts in all areas of human endeavour. This project will begin a paradigm shift in the practice of thermometry. *From an economic perspective*. This change will first occur at the NMI level, but over time will be established in accredited laboratories. The effect of this will be to reduce the dependency on NMIs, providing traceability at reduced cost to the user. *From a social perspective*. These developments will stimulate new industries, protecting high-value manufacturing employment. *From an environmental perspective.* As practical primary thermometry becomes a reality then *any* industrial process requiring reliable temperature measurement will, through the deployment of such sensing techniques, always be able to run optimally minimising energy use and harmful emissions. Any user requiring long-term reliable thermometry will benefit from the availability of *in-situ* practical primary thermometry having significant *social and environmental impact*.

List of Publications

A. Peruzzi, *et al*, Survey of Subrange Inconsistency of Long-Stem Standard Platinum Resistance Thermometers *Metrologia* https://doi.org/10.1088/1681-7575/abe8c1

C Gaiser, B Fellmuth, Primary thermometry at 4 K, 14 K, and 25 K applying dielectric-constant gas thermometry *Metrologia* https://doi.org/10.1088/1681-7575/ac0d4a

Bo Gao, *et al* Measurement of thermodynamic temperature between 5 K and 24.5 K with single-pressure refractive-index gas thermometry *Metrologia* https://doi.org/10.1088/1681-7575/ab84ca

D. Madonna Ripa *et al* Refractive index gas thermometry between 13.8 K and 161.4 K *Metrologia* https://doi.org/10.1088/1681-7575/abe249

Changzhao Pan *et al* Acoustic measurement of the triple point of neon T_{Ne} and thermodynamic calibration of a transfer standard for accurate cryogenic thermometry *Metrologia* https://doi.org/10.1088/1681-7575/ac0711

O.M. Hahtela *et al* Coulomb Blockade Thermometry on a Wide Temperature Range *CPEM 2020 Proceedings* https://doi.org/10.1109/CPEM49742.2020.9191726

C. Pan *et al*, Direct comparison of ITS-90 and PLTS-2000 from 0.65 K to 1 K at LNE-CNAM, *Metrologia*, **58** (2021), 025005, https://doi.org/10.1088/1681-7575/abd845

G. Machin *et al* Progress in realising the Redefined Kelvin, SMSI 2021 Conference Proceedings, AMA Service GmbH, ISBN 978-3-9819376-4-0, 2021, p. 29-30 (2021) https://doi.org/10.5162/SMSI2021/PT4

Giovanni Garberoglio *et al* Path-integral calculation of the fourth virial coefficient of helium isotopes *The Journal of Chemical Physics* https://doi.org/10.1063/5.0043446

D. Imbraguglio *et al* Comparison of ITS-90 realizations from 13 K to 273 K between LNE-CNAM and INRIM *Measurement* https://doi.org/10.1016/j.measurement.2020.108225

M. J. Martín *et al* Construction, Characterization and Measurement of Fe–C and Pd–C HTFPs at CEM *International Journal of Thermophysics* https://doi.org/10.1007/s10765-022-02978-2

D. Madonna Ripa *et al* Corrigendum: Refractive index gas thermometry between 13.8 K and 161.4 K *Metrologia* https://doi.org/10.1088/1681-7575/ac2d9e

P. Czachorowski *et al* Second virial coefficients for 4He and 3He from an accurate relativistic interaction potential *Physical Review A* https://arxiv.org/abs/2007.09767

G Machin, The Kelvin Redefinition and Practical Primary Thermometry: Implications for temperature traceability and sensing, Johnson Matthey Technology Review, https://doi.org/10.1595/205651323X16620342873795

J. P. Pekola, Influence of device non-uniformities on the accuracy of Coulomb blockade thermometry, Metrologia, https://doi.org/10.1088/1681-7575/ac79e8

G. Machin *et al* Towards realising the redefined kelvin Measurement https://doi.org/10.1016/j.measurement.2022.111725

A. Kirste *et al*, Comparison of Different Johnson Noise Thermometers From Millikelvin Down to Microkelvin Temperatures, JPS Conference Proceedings, https://doi.org/10.7566/JPSCP.38.011198

R. Veltcheva *et al*, Investigations of Type 3 non-uniqueness in Standard Platinum Resistance Thermometers between 83 K and 353 K, Measurement, https://doi.org/10.1016/j.measurement.2023.112863

C.Gaiser *et al*, 2022 Update for the Differences Between Thermodynamic Temperature and ITS-90 Below 335 K, Journal of Physical and Chemical Reference Data, https://doi.org/10.1063/5.0131026

This list is also available here: Research Publications Repository Link - EURAMET

Project start date and duration:1 September 2019	44 months (originally 36)	
Coordinator: Professor Graham Machin Tel: +44 20 8943 6742 E-mail:graham.machin@npl.co.uk Project website address: https://real-k.aalto.fi		
Internal Funded Partners: 1. NPL, United Kingdom 2. CEM, Spain 3. CMI, Czech Republic 4. CNAM, France 5. INRIM, Italy 6. INTiBS, Poland 7. IPQ, Portugal 8. LNE, France 9. PTB, Germany 10. SMU, Slovak Republic 11. TUBITAK, Turkey 12. UL, Slovenia 13. VSL, The Netherlands (withdrew Autumn 2020) 14. VTT, Finland	External Funded Partners: 15. Aalto, Finland 16. FBK, Italy 17. HSU, Germany 18. UW, Poland	Unfunded Partners: 19. NIM, China 20. TIPC-CAS, China 21. VNIIOFI, Russia (suspended 25/03/2022 on recommendation of Euramet BoD and consortium vote)
RMGs: RMG1: INRIM, Italy (Employing organisation); CNAM, France (Guestworking organisation) RMG2: SMU, Slovakia (Employing organisation); CNAM, France (Guestworking organisation) RMG3: INRIM, Italy (Employing organisation); CNAM, France (Guestworking organisation) RMG4: CMI, Czech Republic (Employing organisation); INRIM, Italy (Guestworking organisation)		