WP4 Update for April 2018

Ziad Melhem
Oxford Instruments Nanoscience

FuSuMaTech IP Workshop
19-20 April 2018
Ideas Square, CERN

WP4 Tasks

- T4.1: Quench analysis – from M1 to M18
  - *Task leader: Bernhard Auchmann (PSI) (– Participants: ELYTT, KIT*
- T4.2: Material properties database at Cryogenic temperature – from M1 to M18
  - Task leader: Simon Canfer (STFC) – Participants: CERN, Ox. Inst, KIT, PSI
- T4.3: Smart diagnostics – from M1 to M18
  - *Task leader: CERN Daniel Calcoen (CERN) – Participants: CEA*
- T4.4: Heat extraction and helium free cryogenics – from M1 to M18
  - *Task leader: Bertrand Baudouy (CEA) – Participants: Babcock Noell, ELYTT*
- T4.5: New high stress materials at cryogenic temperature – from M1 to M18
  - *Task leader: Klaus-Peter Weiss (KIT) – Participants: Ox Inst, CERN*

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WP4 Partners

- CEA
- CERN
- ASG
- Babcook Noell
- ELYTT
- Ox Inst
- Sigmaphi
- Tesla
- CNRS
- KIT
- PSI
- STFC

WP4 - Deliverables

- Define R&D or pilot programme for industrial and scientific members and how the programme will be achieved;
- Define required budget and intellectual property rules.
- Work out the WP 4 contribution to the FuSuMaTech EU grant proposal.

  - D4.1 – Development plan and schedule for generic R&D programme (Month 6)
  - D4.2 – Development plan for a test facility to test materials, components and coils (Month 18)
  - D4.3 – Rules for an IP management and dissemination (Month 18)
  - D4.4 – Budget for each package (Month 18)

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Status of WP4

Completed a Task Leaders meeting at Oxford Instruments ,Oxford on 4th April 2018

- Agreed plans for completion
  - Share draft proposals with the rest of project members 30th Apr 2018
  - Draft proposal from each task by Sep 2018 for internal review
  - Finalise proposal details and discussion by Dec 2018
  - Write final proposal for submission Mar 2019
  - Present proposal at the closing meeting Apr 2019

T4.1: Quench analysis

Task leader: Bernhard Auchmann (PSI) (– Participants: ELYTT, KIT

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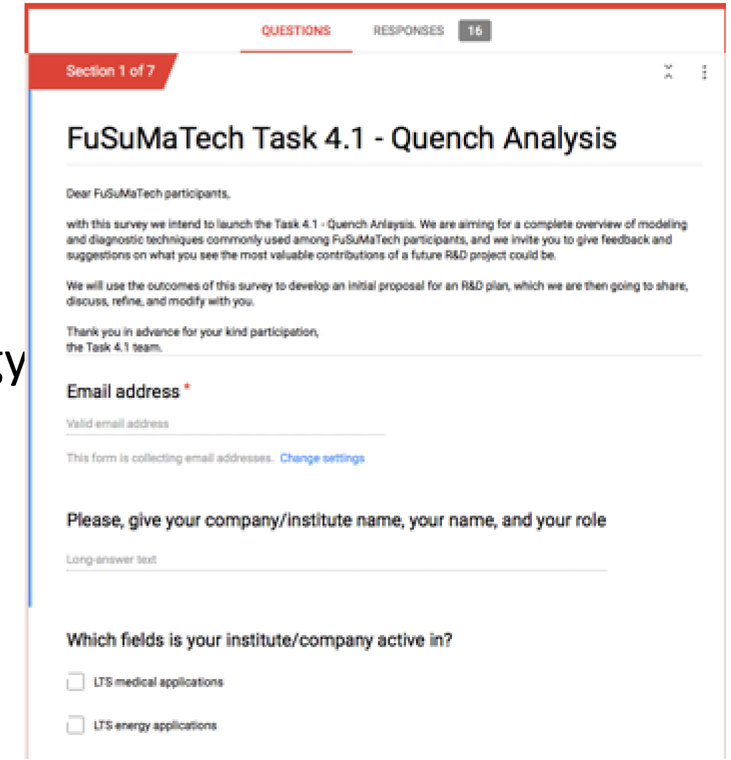
Task 4.1 Quench Analysis

PSI - Bernhard Auchman ELYTT – Julio Lucas KIT - Wilfried Goldacker

Task	Description
T4.1.1	Review of software tools for HTS and LTS applications.
T4.1.2	Review of diagnostic and detection tools for HTS and LTS applications.
T4.1.3	Identification of needs in industrial HTS and LTS applications such as magnets, current limiters, transformers, and rotating machinery.
T4.1.4	Identification of necessary improvements over the status quo in software tools and definition of an R&D roadmap.
T4.1.5	Identification of potential novel or improved routes for quench diagnostics and detection, including joint R&D with conductor developers, and definition of a roadmap.

Online Survey

- ❑ **Online Survey** among FuSuMaTech participants launched in Jan. ‘18..
  - ✓ Sixteen responses from:
    - Bilfinger Noell, CEA (2x), CERN (3x), CNRS, Elytt, INFN, KIT (2x),
    - Oxford Instruments, PSI, SigmaPhi, Tesla (2x)
  - Missing response from:
    - AS-G, Alstom, STFC.
  - Industries (ordered by multiplicity)
    - LTS accelerators, LTS medical, HTS energy, HTS accelerator, LTS energy
  - Typical geometries (ordered by multiplicity):
    - Solenoids, long accelerator, short accelerator


QUESTIONS RESPONSES 16

Section 1 of 7

FuSuMaTech Task 4.1 - Quench Analysis

Dear FuSuMaTech participants,

with this survey we intend to launch the Task 4.1 - Quench Anlaysis. We are aiming for a complete overview of modeling and diagnostic techniques commonly used among FuSuMaTech participants, and we invite you to give feedback and suggestions on what you see the most valuable contributions of a future R&D project could be.

We will use the outcomes of this survey to develop an initial proposal for an R&D plan, which we are then going to share, discuss, refine, and modify with you.

Thank you in advance for your kind participation,
the Task 4.1 team.

Email address *

Valid email address

This form is collecting email addresses. Change settings

Please, give your company/institute name, your name, and your role

Long-answer text

Which fields is your institute/company active in?

- [ ] LTS medical applications
- [ ] LTS energy applications

Survey Results

❑Some questions and answers:

- Software used: ANSYS 2D, COMSOL 2D, Opera vector fields, QLASA, ROXIE, STEAM, other in-house
- Comm. software limitations/potential:
  - (+) support, rather flexible, HPC,
  - (–) workarounds necessary for superconductivity, setup time, licenses, computation time, blackboxes
- Largest needs:
  - Materials data base working with commercial tools, HTS support, efficient 3D, easy generic workflows, coupling to helium fluid dynamics
- HPC: >50% of participants would benefit from better HPC support
- Validation: 94% would benefit or benefit a lot from documented and measured bench-mark cases for code validation.
- Material parameters: strong support for generic mat. database to interface with multiple softs., list of “missing” data for LTS and HTS data.
- Diagnostics needs: improved conductor temperature meas. Fast and distributed sensing, detection and diagnostics for HTS

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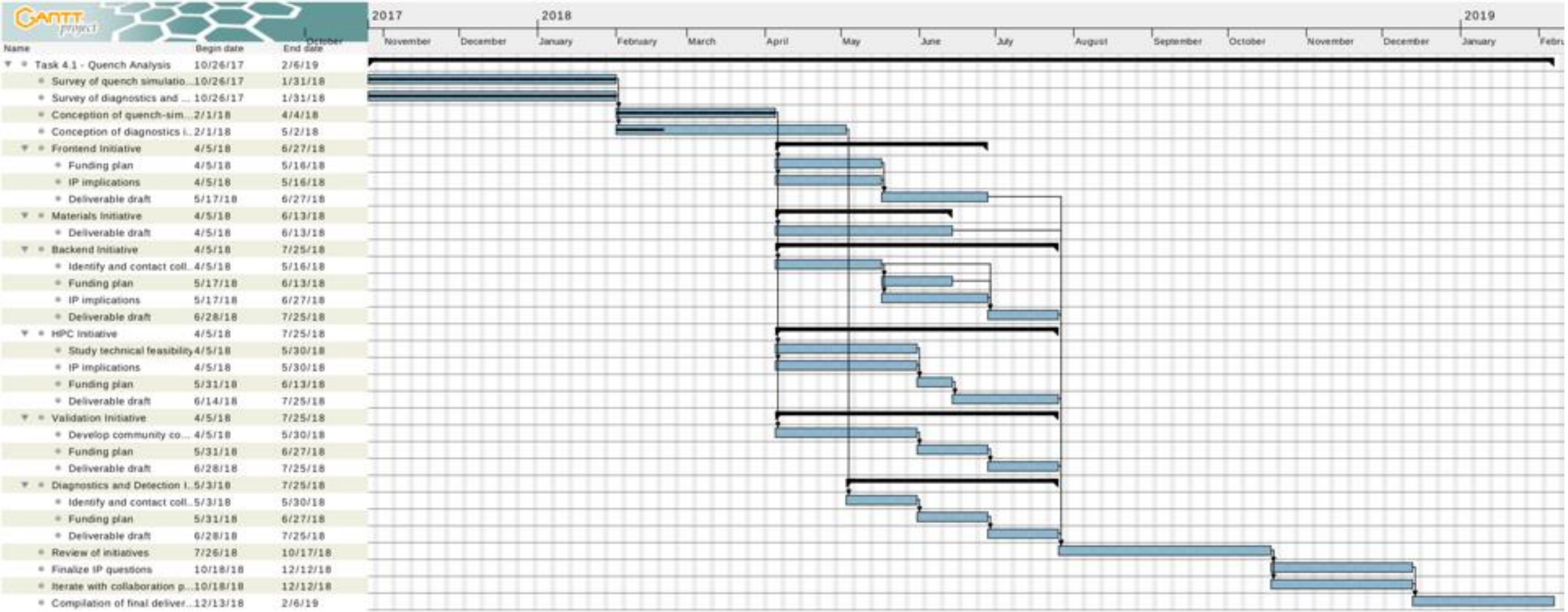
Planning



Explore if diagnostics & detection should be incorporated in Task 4.3?

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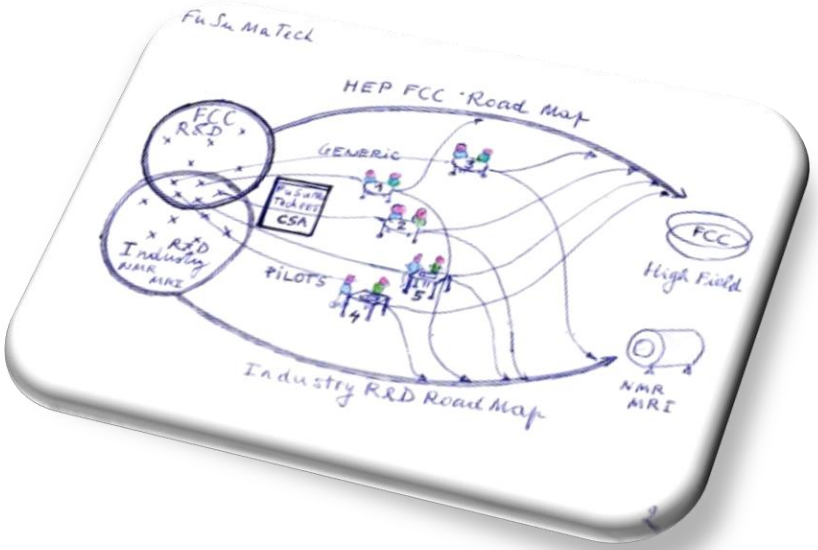
Next Steps

- **Next five months**:
  - Refine (as task team) the list of R&D initiatives .
    - Assign each initiative to two or more team members.
    - Present the status to the community at the April 19 FuSuMaTech workshop in form of a ppt and a 2-3 page doc.
  - Prepare a detailed plan for the task initiatives, to circulate among participants, including:
    - organizational structure of each initiative,
    - time range and resources,
    - integration with WP5 as pilot project,
    - feedback to road maps (e.g. FCC Roadmap, etc)
    - potential collaboration partners ,
    - funding opportunities,
    - licensing questions,
    - IP implications.
- **Beyond August ’18**:
  - draft project proposal
  - contact potential additional partners
  - find solutions to IP and licensing questions
  - contribution to final deliverable



[A. Dael]

Task 4.1 Proposal – Quench Analysis

B. Auchmann (CERN/PSI), S. Bermudez-Izquierdos (CERN), A. Kario (KIT), C. Calzolaio (PSI), F. Grilli (KIT), J. Lucas (Elytt)

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

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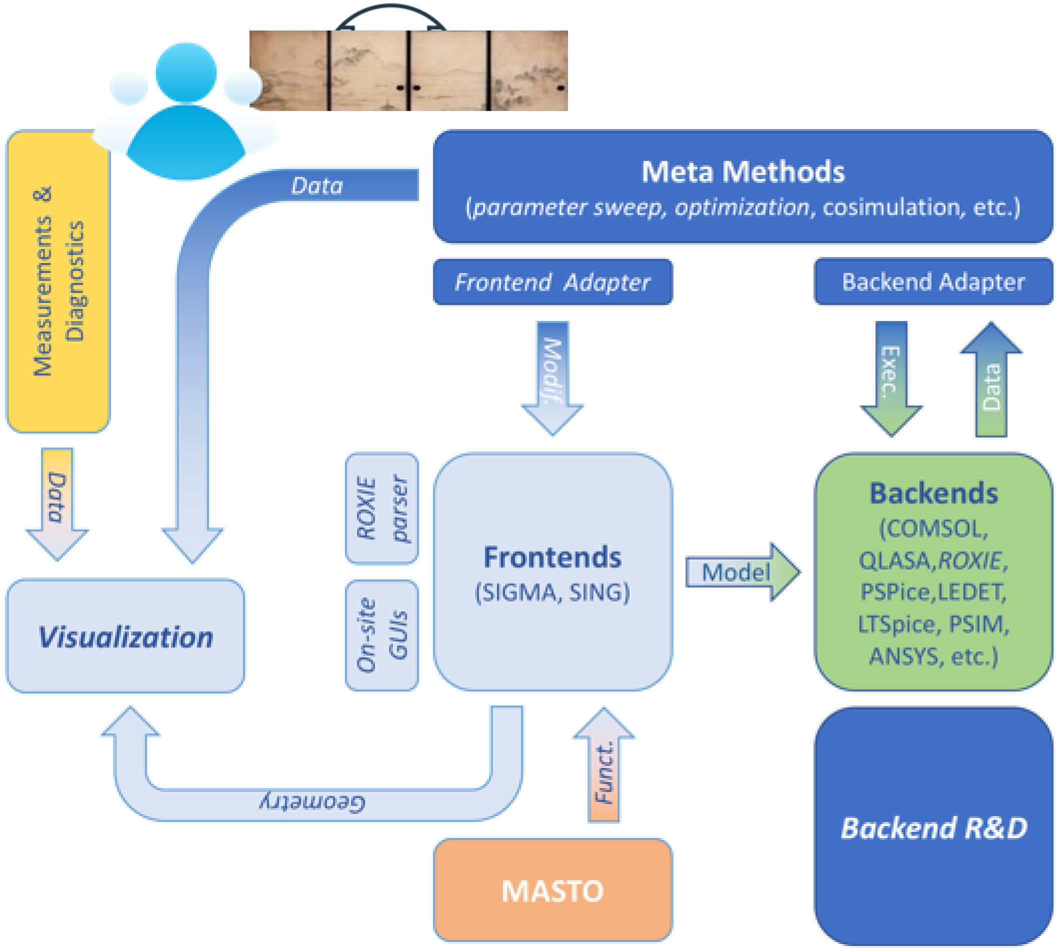
PAUL SCHERRER INSTITUT

Proposed Initiatives

- 6 potential Task 4.1 initiatives:
  - Frontends (Community)
    - Open-source macros for generation of superconducting-magnet representations.
    - Plugins to create models in different tools (backends), e.g., COMSOL, ANSYS, Opera, GetDP (open-source FEM), etc.
    - Materials: Propose properties (wire data?) and simulation interfaces to Task 4.2.
    - App-like UI for application-specific on-site simulation, accessible from your phone.
  - Backend R&D (Univ. institutes for numerical maths.)
    - Fast 3D solvers with HPC support.
  - Meta Methods (Univ. institutes for numerical maths.))
    - Parametric sweeps and optimization.
    - Co-simulation for code-coupling.
    - Physical/spatial/temporal domain decomposition algorithms.
  - Visualization (Community)
    - Frontend preview; viewer for backend-, and meta-method-, and measurement data.
  - HPC infrastructure (CERN IT and KT)
    - Desktop solutions for insular use or hared cluster with license pool.
  - Validation (Community)
    - Definition of benchmark cases.
    - Workshops to discuss measurement data as well as simulation results, etc.

Quench Analysis SW Proposals



Blue non-italic: SW prototypes exist as part of CERN's STEAM initiative with TU Darmstadt.

Blue italic: no prototypes exist to date.

Light blue: Community with SW competence; Dark blue: Numerical math. (TU Darmstadt, etc.)

Green: Existing SW tools. Yellow: Measured data. Orange: Material library, TU Tampere.

T4.2: Material properties database at Cryogenic temperature

Task leader: Simon Canfer (STFC) – Participants: CERN, Ox. Inst, KIT, PSI

And Antti St on Material database SW

T4.2: Material properties database at Cryogenic temperature

Task leader: STFC – Participants: CERN, Ox. Inst, KIT, PSI

- T4.2.1 - Determine the standard measurement data format with detailed property data points covering the full operating temperature ranges from research activities, applications and industry, by liaison with representatives from academia and industry sectors
- T4.2.2 - Collect existing data, verifying its accuracy and its fit with the standard format
- T4.2.3 - Identify existing and new materials not yet measured.
- T4.2.4 - Develop a network of testing facilities, in which the different material properties can be measured.
- T4.2.5 - Propose a scheme for long time management of this data with succession

Status of T4.2: Preparation of a proposal for the creation of a new database of Material properties at Cryogenic temperature

- **Task leader**: STFC – **Participants**: CERN, Ox. Inst, KIT, PSI

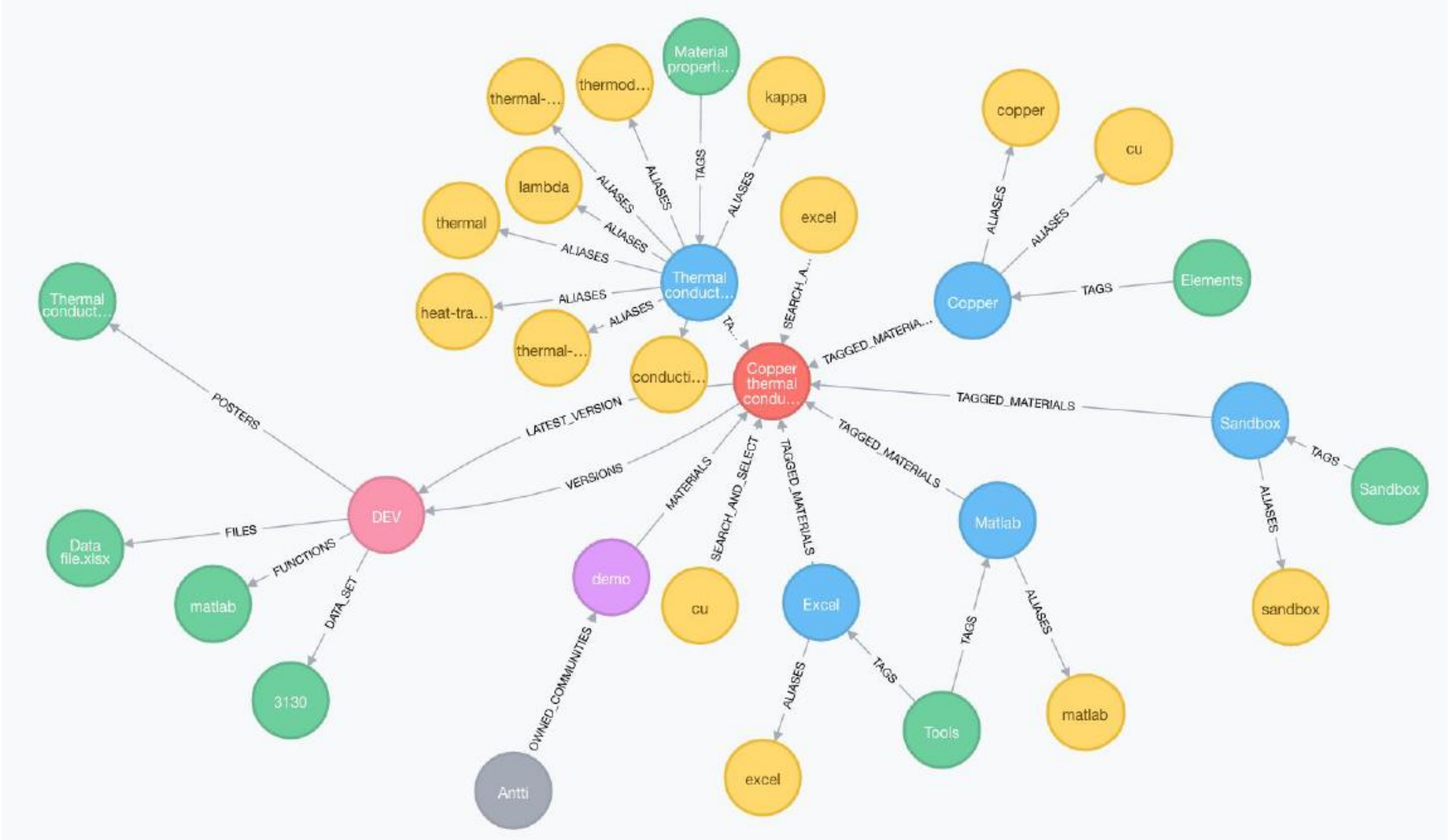
  - **T4 2.4: Facilities survey**
    - Low temperature European testing capabilities
  - **T4 2.2: Data – collect and verify existing**
    - Low temperature existing databases

Prototype Database

- T4 2.3
  - Antti's database ??
  - Build on existing databases ??
  - Define scope

Not started: Data collection/verification

- T4.2.2
- Collect existing data, verifying its accuracy and its fit with the standard format



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WP4.2 Materials Proposal

- Cost reduction enabled by high quality cryogenic materials data in a user-friendly database
  - High quality, verified data
    - Fully characterised materials (chemical analysis, thermal history)
    - Composites and polymers exhibit different properties depending on the direction of stress (anisotropy), thermal history, and the chemistry of the matrix. Without full characterisation of these aspects, data will not be trusted by engineers or excessive safety factors will be applied- leading to inefficient material use
    - Sufficiently large datasets to allow statistically significant results
  - Including modern materials such as high performance thermoplastics, 3D/AM materials and historical data
- Needs of the future cryo-materials database user:
  - Web/mobile not textbook/proceedings
  - Integration with FE packages
- Missing materials… connect with suppliers – short, reliable supply chain
  - Supply chains can be complex and trust in specifications can easily be lost

- Missing test facilities
    - Results of a survey to identify where investment is required
- Materials testing cost reduction and quality improvement through:
    - cryogen-free cooling (cryocoolers) are used in thermal conductivity testing but work is required to extend this to mechanical testing
    - Higher testing rate- can automation be used? Robotic sample changing is common in ambient temperature testing and in thermal analysis. What stops it's application in cryogenic materials testing?
        - More results-> higher confidence in data
- Drive testing standardisation in cryo materials testing
    - Contact with national standards bodies
    - Round-robin testing desirable

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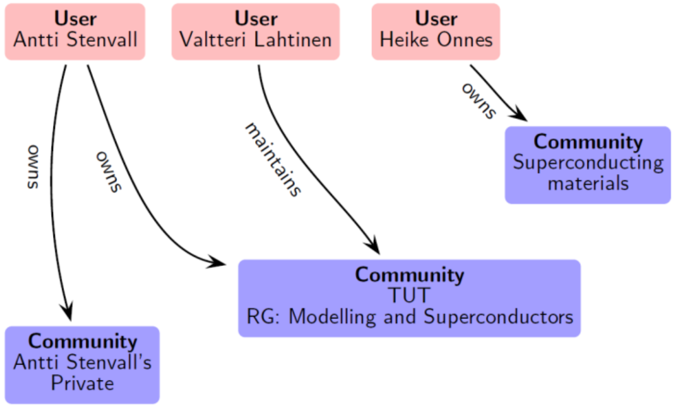
Proposal on Material Property Database

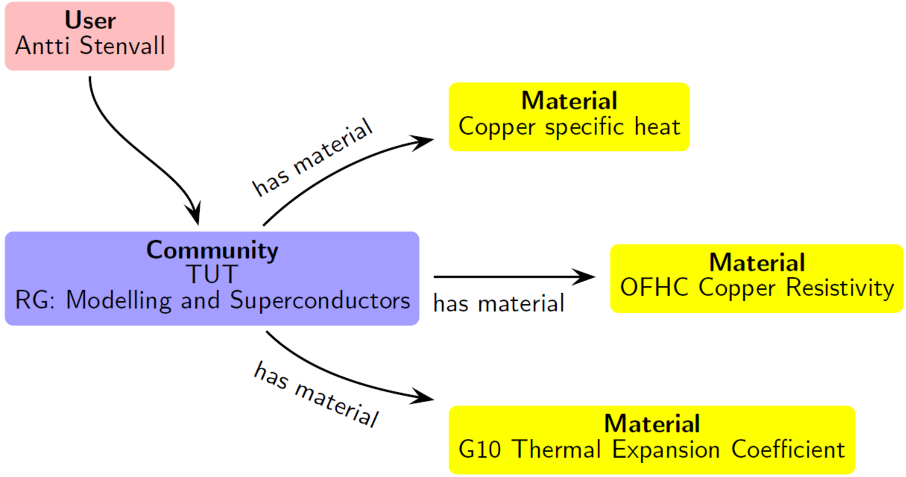
Antti Stenvall
Tampere University of Technology, Tampere, Finland
antti.stenvall@tut.fi

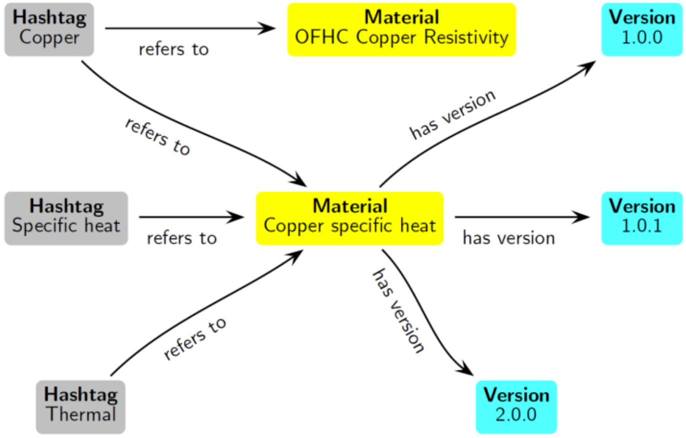
- Vision on completely new way to think about material property database
- Technology readiness levels (TRL)
- Initial insight: a TRL 3 experimental proof of concept called MASTO
- Phase 1: A TRL 6 Demonstrator – requirements
- Phase 2: A TRL 8 System ready to be taken in use – requirements

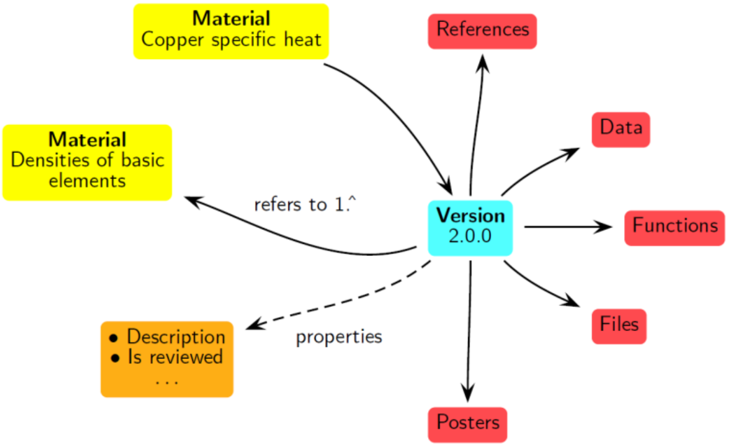
MASTO – Brief description

- Data is stored into **versions** of **materials** that belong to **communities** which are maintained by **users**









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Technology readiness levels (TRL)

- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially
- relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment

(industrially relevant environment in the case of key enabling technologies)

- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environment

(competitive manufacturing in the case of key enabling technologies; or in space)

TRL3 demonstrator use MASTO – Brief description

- MASTO: Open Material Property Library With Native Simulation Tool Integrations
  - http://masto.eu.com
- MASTO is a TRL 3 demonstrator showing that a web based software for integrating material property database to simulation tools can be constructed.
- Data is stored into versions of materials that belong to communities which are maintained by users
- Data can be browsed with a web browser and directly downloaded from there.

Phase 1: TRL 6 – technology demonstrated in relevant environment

(industrially relevant environment in the case of key enabling technologies)

- This level requires that the technology behind the vision is demonstrated in a multiuser environment.

Key points:

- The flow of data import from material characterization in at least two different environments (institutions) with at least two different clients. This should replicate real user cases.
- Data utilization in modelling in at least two modelling software and two programming frameworks via dedicated MSCs (i.e. at least four MSCs). This also includes automatic function creation for these programs from the raw data. In this phase, the type of raw data can be limited.
- Data searching via meta data layer and its (automatic/assisted) population from raw data.

Phase 2: TRL 8 – System complete and qualified

Key issues in this level are

- Professionality behind the applications (especially testing, development environment, database backups, security),
- Population of the database to a reasonable extent,
- Extending MSCs to cover all the selected modelling software (this requires major work also for the backend to generalize the raw data to function generation)
- implementing meta-data descriptions for selected materials etc,
- implementation of the review flow,
- focus user experience in client applications.

T4.3: Smart diagnostics
Task leader: CERN
Participants: CEA

D. Calcoen, CERN TE-MPE-EP

T4.3: Smart diagnostics – from M1 to M18

Task leader: CERN – Participants: CEA

- T4.3.1 Define R&D and pilot programme for industrial and scientific members and how the programme will be achieved
- T4.3.2 Define required budget and intellectual property rules.

T4.3: Smart diagnostics

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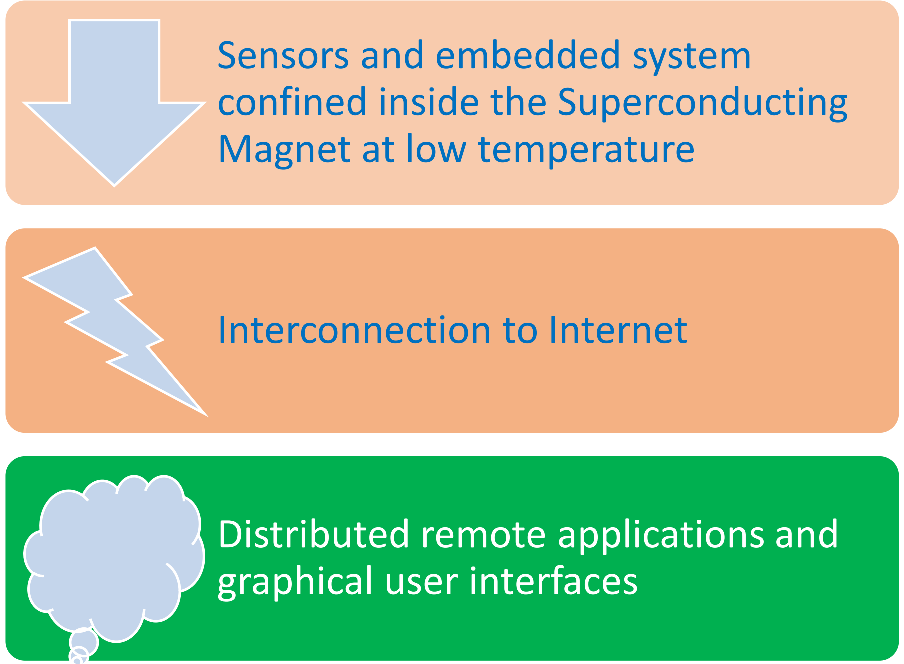
What we understand by Smart Diagnostics:

- Considering the superconducting magnet as an IoT (Internet of Things) device,
- the Smart Diagnostics is the set of all the systems and functionalities which makes the enhanced remote monitoring and diagnostic of the superconducting magnets via the Internet technologies possible.
- Allowing the data to be collected and analysed by remote devices, connected to internet running graphical user interfaces (like smart phones, tablets or intelligent screens).

- This can be structured in 3 layers:
  - Sensors + embedded system
  - Interconnection to internet
  - Remote applications
- For the Superconducting Magnets Community the research effort should be dedicated to:
  - Sensors + embedded system
  - Local interconnection to the embedded system
  - The interconnection from the local point to the internet and the applications layer can be covered by more generic research.



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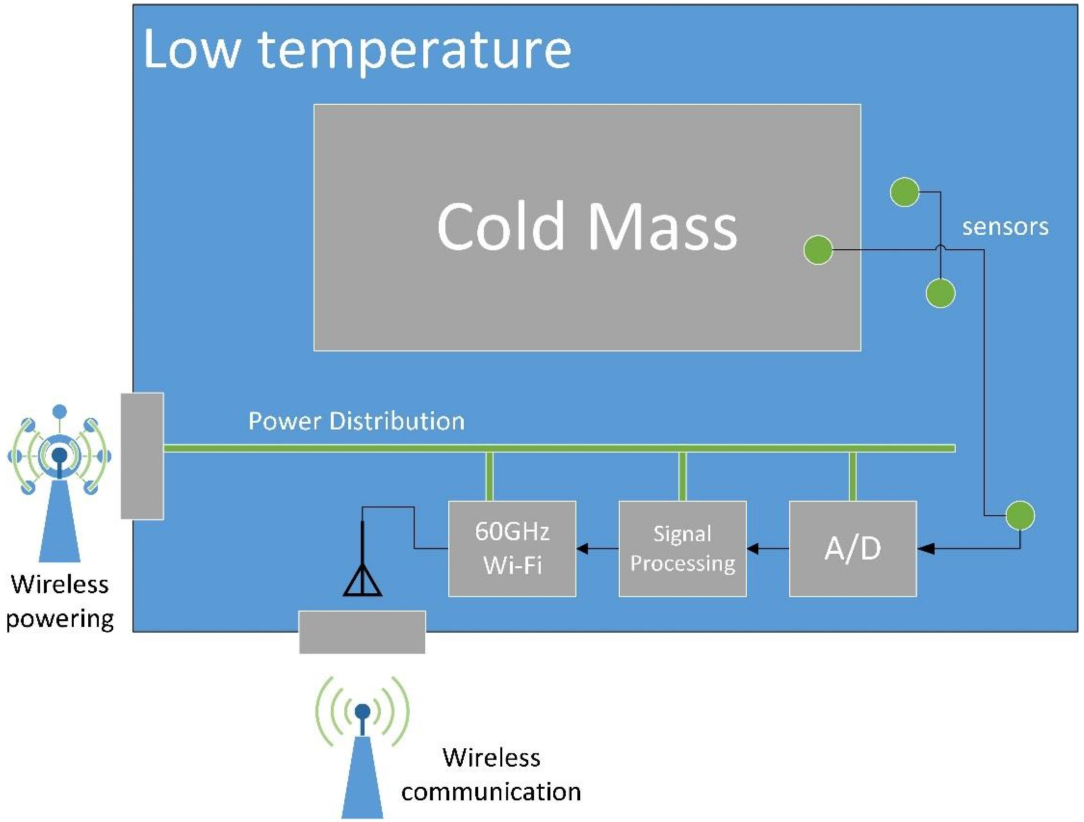
The T4.3 R&D&I program proposal is focused

- On the embedded electronics confined inside the superconducting magnet.
- working at low temperatures (thermal shield levels, 50 K to 70 K) and without wires towards the exterior (even for the powering).

- The Work Package 4.3 will develop 6 subtasks, each one dedicated to a **produce a Research Program Proposal** with the aim to have the basic constitutive elements of the Smart Diagnostics

- T4.3.1- Sensors
- T4.3.2 - Electronic System for sensor reading and processing
- T4.3.3 - Wireless Data Transmission
- T4.3.4 - Wireless power source
- T4.3.5 - Radio Frequency transparent materials
- T4.3.6 - Smart Diagnostics - Integration of sub tasks 1..5 in the test case



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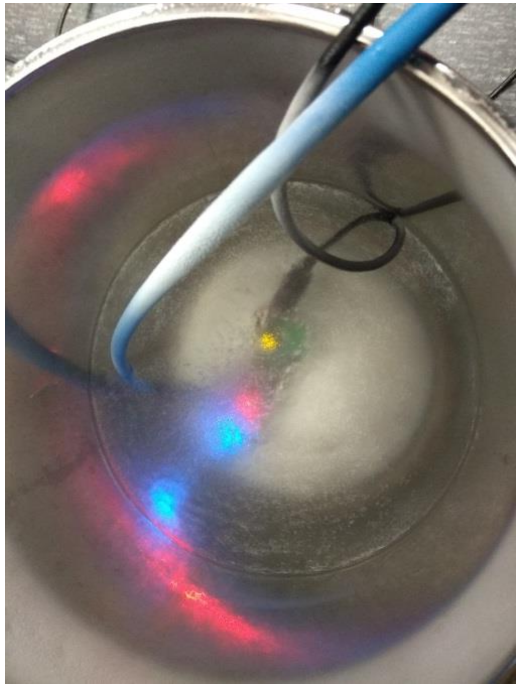
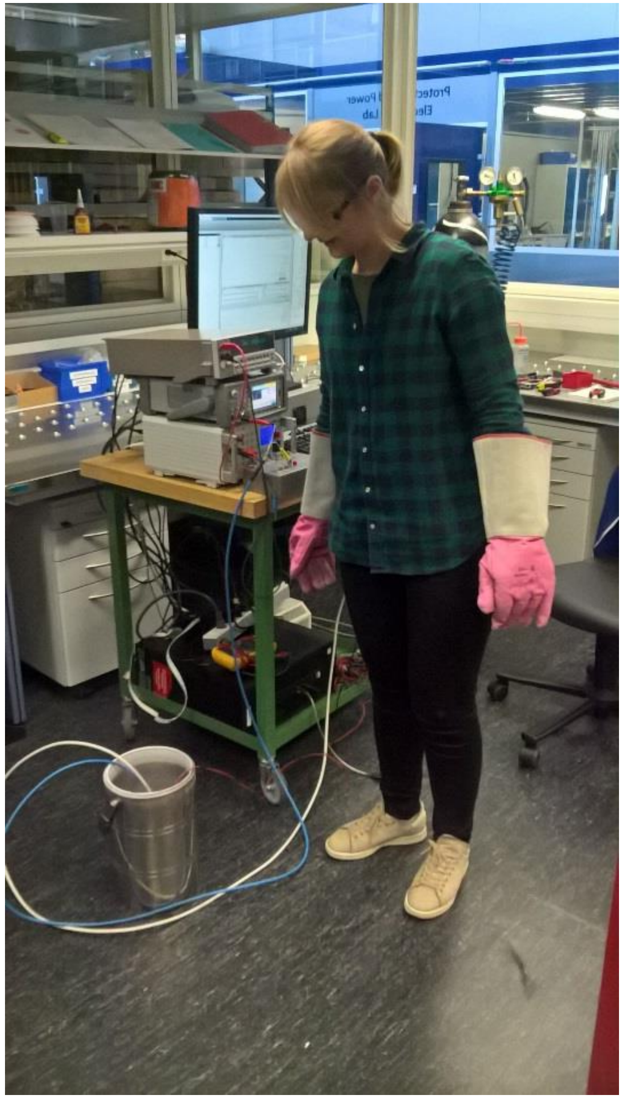
We have some confidence because

- we are already doing research on this with good results.

the minimal objective is highly achievable





Task 4.4

Heat extraction and helium free cryogenics

Bertrand Baudouy

bertrand.baudouy@cea.fr

T4.4: Heat extraction and helium free cryogenics

Task leader: CEA – Participants: Babcock Noell, ELYTT

- T 4.4.1 – Review of existing cryo-generator performances and of major cryogen free systems
- T 4.4.2 – Review of Multiphysics software available for cryogenic design of cryogen free systems associated with database of properties.
- T4.4.3 – Identification of efficient European companies and research institutes in cryogenic issues
- T4.4.4 – Identification of needs in industrial HTS and LTS applications and in particular for the WP5 technology pilots
- T 4.4.4 – Identification of necessary improvements over the present state of the art and of the potential innovations
- T4.4.5 – Establishment of a work plan for the FuSuMaTech Phase 2

Status of subtask 4.4

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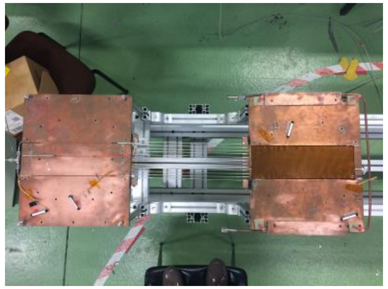
- Questionnaire sent to all the partners in March
- Questionnaire includes
  - Questions about the cryogenic design practice
  - Needs in HTS and LTS applications (with a focus on cryogen-free cryogenics)
- Questionnaire's return
  - 12 partners contacted
  - Answers by CEA, SigmaPhi, LNCMI, CERN, Bilfinger, Elytt, SFTC
  - 4/7 do not currently design cryogen free magnet
- The answers of the partners are "homogeneous" as they are
  - Using the same tools (software) and methods for the design
  - Interested by using a common materials data base
  - Asking for the development of thermal link between the cold source and magnet
  - Asking for the improvement of the knowledge on thermal contact resistance
  - Asking for the development of cheap and reliable thermal measurements
  - Asking for specific materials dada

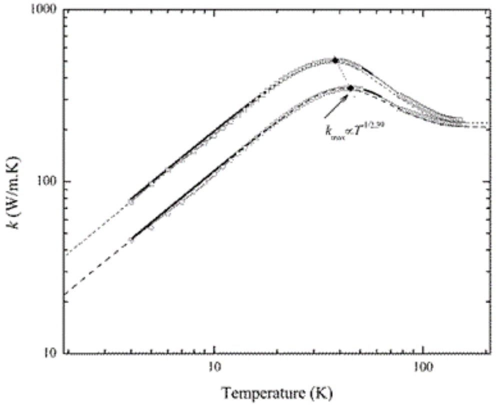
Status of subtask 4.4

- Questionnaire's return to be closed by the end of April-May
  - Return will be asked to Oxford Instrument, PSI, KIT, Tesla and ASG
- Refined analysis with the task members by the end of May-June
  - Round trip interactions for specific answers between the task leaders and the partners
  - Refinement of the initiative ideas
- Proposition of initiatives' list by the end of June-July
  - Final initiative ideas



Thermal link

Thermal contact



Thermal data

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Proposals (under discussion)

- Innovative thermal link
  - Building test rigs for testing the thermal link
  - Test program of PHP in real configuration and scenarios (geometry effect, cold down and quench scenarios test, …)
  - Implementation of a PHP into a SM prototype (linked with the task 5)
- Thermal contact resistance
  - Building test rigs for testing of thermal contact resistance and should be linked with the task 4.2
  - Experimental test program of generic thermal contact resistance
  - Experimental test program of thermal contact resistance typically encountered in cryogen free magnet
- Materials
  - Developed in tight connection with task 4.2
  - Propose a list of material and associated properties to be included in the task 4
- Instrumentation (in collaboration with task 4.3)
  - Development of a plug-and-play acquisition system or method
  - Development of cheap reliable, easy-to-use distributed sensing in the magnet coils

T4.5: New high stress materials at cryogenic temperature

Task leader: KIT – Participants: Ox Inst, CERN

Online survey send to project participants to compile information regarding:

- T4.5.1 Define key parameter to survey the state of the art and R&D on high strength materials
- T4.5.2 List materials regarding their classes, characteristics and properties as defined
- T4.5.3 Survey EU and worldwide efforts (projects/technologies) of high strength material fabrication and development

Under assessment:

- T4.5.4 Identify actions on new materials to qualify them for application at cryogenic temperatures

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T4.5: New high stress materials at cryogenic temperature

Task leader: KIT – Participants: Ox Inst, CERN

- T4.5.1 Define key parameter to survey the state of the art and R&D on high strength materials

Which components have to be considered to allow high strength?
What temperatures are important?
What kind of system/application driven boundary conditions have to be considered?

- T4.5.2 List materials regarding their classes, characteristics and properties as defined

Which materials are commonly in use for cryogenic magnet application?
What material properties are in focus?
What information has to be given to qualify a material?
What further productions requirements are necessary?

- T4.5.3 Survey EU and worldwide efforts (projects/technologies) of high strength material fabrication and development

Several projects are already launched to survey existing publications and data available in regard of cryogenic high strength together with experimental work to perform R&D.
Compiled list mainly focuses on fusion magnet applications and need to be supplemented by other partners.

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T4.5: New high stress materials at cryogenic temperature 4a/4

Task leader: KIT – Participants: Ox Inst, CERN

- T4.5.4 Identify actions on new materials to qualify them for application at cryogenic temperatures

A detailed survey to define candidate materials for further R&D work.

- classical 316LN or JJ1,
- high Cr-Ni or Mn stainless steel [1],
- MP35N (see Table 1 for mechanical properties [2])
- or XM19/Nitronic-50 steel used in space application,

composite materials e.g. Zylon fibe/Epoxy [3].

MECHANICAL TEST RESULTS OF MP35N ROD**

Specimen	Test Temp. (K)		Yield Strength (M Pa)	Tensile Strength (M Pa)	% Elong.
As Deformed	295	Average	1436	1707	12.8
		Stdev	91	8	0.1
	77	Average	1783	2161	12.7
		Stdev	22	6	0.1
Heat treated	295	Average	2023	2052	11.3
		Stdev	1	3	0.1
	77	Average	2387	2483	11.6
		Stdev	49	26	-

**Heat treated = Aged at 843 K for 4 hrs in argon atmosphere; elongation is from strain measurement over 12.7 mm gage length, stdev = standard deviation

Fiber Volume %	Temp K	Young's Modulus GPa	Tensile Strength GPa
85	295	240	4.22
90	295	255	4.47
95	295	269	4.71
85	77	n/a	4.85
90	77	n/a	5.07
95	77	n/a	5.29

Tensile Properties of Zylon/Epoxy [3]

[1] Nishimura 2014 Need for development of higher strength cryogenic structural materials for fusion magnet
[2] Han 2002 Mechanical Properties of MP35N as Reinforcement
[3] Walsh 2006 Mechanical properties of Zylon/Epoxy Composite

continued ...

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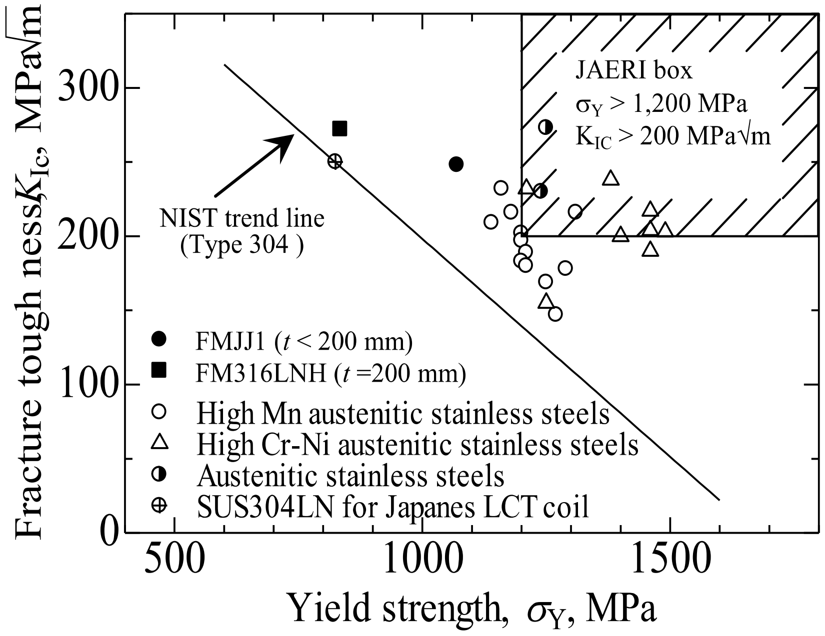
T4.5: New high stress materials at cryogenic temperature 4b/4

Task leader: KIT – Participants: Ox Inst, CERN

- T4.5.4 Identify actions on new materials to qualify them for application at cryogenic temperatures

To have a better idea of a possible target high strength materials are classified by fracture toughness versus Yield strength [1].

Beside of these properties ductility, machining, weldability, cost, etc. have to be considered.
→ see above T4.5.1 & T4.5.2



[1] Nishimura 2014 Need for development of higher strength cryogenic structural materials for fusion m
[2] Han 2002 Mechanical Properties of MP35N as Reinforcement
[3] Walsh 2006 Mechanical properties of Zylon/Epoxy Composite

continued ...

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T4.5: New high stress materials at cryogenic temperature 4c/4

Task leader: KIT – Participants: Ox Inst, CERN

- T4.5.4 Identify actions on new materials to qualify them for application at cryogenic temperatures
- Connect on an official base to other projects (e.g. NIMS/NIFS, other…???)
- Identify material suppliers (experimental quantities, scalability to industrial production, deformation processes like forging/rolling)
- Assess the possibility for detailed chemical analysis of composition (by supplier)
- Availability of structural analysis (SEM/EDX/EBSD/TEM, optical) (by supplier or laboratory)
- Existing cryogenic test facilities for desired temperature ranges (access / availability / costs)
  → T4.2.4 Facility Survey
- Provision of results in Database
  → T4.2 What will be a possible platform?

continued …

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T4.5: New high stress materials at cryogenic temperature 4d/4

Task leader: KIT – Participants: Ox Inst, CERN

- T4.5.4 Identify actions on new materials to qualify them for application at cryogenic temperatures

Possible contribution to fill the gaps for material requirements:

- CEA/Tesla to cover the NMR/MRI
- CERN to cover the Accelerator requirements
- KIT/ITER to cover the Fusion

Together with T4.2 list of suppliers and test facilities will be compiled.

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Summary

- ✓ All task are progressing
- ✓ Good progress with material data base
- ✓ One day Task leaders meeting at Oxford 4th April 18
- Plans going forward
  - ✓ To have an Outline proposal for April Meeting at CERN
  - Draft Proposal for End of Sep 18
  - Refine Proposal Dec 18
  - Final Proposal mar 19
- Need to link with WP5
  - Agree R&D requirements for the prototypes (End of May)
  - Meeting at Sub-Task leaders level for WP4 and WP5 to incorporate requirements into proposals