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Deliverable D1.5

Data Management Plan

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DISCLAIMER

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1 General philosophy

EMP participates in the Open Research Data Pilot (ORD pilot) of the European Commission, which will enable us to maximize open access and reuse of research data generated within EMP project. This data management plan (DMP) lays out the details of how we generate, store, archive and provide access to (raw) data; restrictions might be imposed to protect intellectual property rights (IPR) of partners involved in EMP. The FAIR principle, which ensures that these data are findable, accessible, interoperable and reusable, is adapted to the specific needs of EMP.

This DMP is intended to be a "*living document*" and will be updated and reviewed on a regular basis, especially when significant changes arise (e.g. new data, change in consortium policies, so far unhandled questions to be addressed). The EMP management team is responsible for maintaining the document.

1.1 Data Summary

1.1.1 Data collection & generation

The partners involved in the European Microkelvin Platform (EMP) will generate data during the project, which can be roughly divided into (i) experimentally-collected, and (ii) computer-generated data.

(i) Experimental data will be collected by all partners in the consortium. This data will involve calibration data as well as data generated as part of an experimental measurement run.

(ii) Computer-generated data will arise through modelling of the experiments or theory that is developed within EMP. Computer-based models will be built either using off-the-shelf software (e.g., finite-element simulation software such as COMSOL Multiphysics) or software developed in-house. The verification and validation of such models will generate large amounts of data, which will be analyzed by the EMP partner(s)

For details regarding data generated by user projects within EMP's transnational access programme, we refer the reader to chapter 3.

1.1.2 Relation to the objectives of the project, and origin of the data

The central objective of the EMP project is to enhance the multidisciplinary impact and innovation potential of the ultralow temperatures (ULT) state-of-the-art research infrastructure (RI) and scientific community. Implemented by 17 leading ultralow temperature physics and technology partners, the project aims at integrating further the leading ULT facilities in Europe for the development of new ideas, knowledge, technology, applications and commercial exploitation of research results. The particular focus both in shorter and longer terms, lies on the fields of materials, nanoscience and quantum technology in all its forms. EMP will create a major European "laboratory without walls" in the field of ultralow temperatures, by widening and building on previous experience of integration during EC infrastructure calls.
During the project, the partners will generate data from measurements performed in a laboratory setting on the devices and samples fabricated during the project. In addition, theoretical data from computer simulations, either predicting the behaviour of new phenomena, or explaining the

experiments will be generated. The data are mainly produced as a part of the joint research activities (JRA), focused on improving the transnational access services.

Data are owned by the organization that has generated them.

1.1.3 Types and formats of data to be collected

The EMP project will produce different types of data: measurement files including the experimental raw data, analyzed experimental data, theoretical reference data and code to generate graphics from the raw data. The sizes of the created data sets can vary largely and can exceed several GBytes. The various data formats are described in more detail in section 2.1.

1.1.4 Utility of data

The data collected will, in the first instance, be invaluable for the consortium to fulfil the objectives of EMP. It will enable the partners of this project to engage in meaningful discussions with one another and to identify optimal systems and methods for achieving these objectives. In the second instance, specific data will be archived in a publicly accessible location and made available to the scientific community at large, greatly facilitating the reproduction of the results obtained by the consortium and their further analysis.

1.2 FAIR data

1.2.1 Making data findable

As far as possible, within the scope of IP Rights protection, the (raw) data in published journal articles and theses outputs originating from the EMP consortium will be made available in an open data repository. Zenodo (or similar services) will be used which can assign a Digital Object Identifier (DOI) to each dataset in question allowing the traceability of data sets. As far as possible, we will define unified metadata standards for the EMP data that is being opened. Clear file naming, version tracking of the various data sets in question and search keywords will furthermore foster the possibilities to track data sets.

1.2.2 Making data openly accessible

The data used to generate plots and visualizations appearing in the consortium's publications are made accessible online by default or on request. Together with the publication, authors will typically provide their set of all relevant (raw) data and metadata – prepared in a meaningful way including necessary supplements, documentation, code, etc. - in an open data repository such es Zenodo (or similar services); if this is not the case, they will be made available upon request; however, the consortium is aware of the need to protect certain kinds of data for the protection of IP rights or for reasons states in the consortium agreement – therefore, authors might restrict the access to their data. The innovation and dissemination committees shall be consulted in ambiguous cases.

1.2.3 Making data interoperable

The data will be provided in a format that is easily machine-readable. Any instructions, code needed for evaluation, unit conversions, etc., will be provided together with the dataset itself. This will

provide a complete package for third parties to be able to reproduce the figures in the consortium's publications.

1.2.4 Increasing data reuse

Each dataset will be accompanied by a detailed license making it clear how the data can be used. By default, this shall be the CC-BY-NC-SA license[1]. In particular, it will be expected that any data used from such a dataset will be correctly attributed to its original authors and publication, and a link provided to the online repository from where it can be downloaded.

1.3 Allocation of resources

The EMP Executive Board is guiding the implementation of the DMP and the EMP Management Team is in charge of its practical implementation. Once a suitable workflow is established within each partner participating in this consortium, there will be very little overhead involved in making the data FAIR. Furthermore, where possible, data repositories will be used that are either freely available or hosted by the respective institutions. This will allow free access to the data, including its long-term preservation. Data are owned by the organization that has generated them. Data management in the form outlined in this document rests solely with the consortium partner(s) generating or collecting the data in question.
By default, all data are stored for at least 10 years beyond the end of the project.

1.4 Data security

Any repositories chosen for the long-term-storage of data will be required to follow common best practices in ensuring the safe storage of data.

For short term data-storage, EMP participants utilize the storage systems provided by the IT service of their institution. This ensures that the storage systems are reliable, secure and professionally administered. Institutional data storage services all include user and access management, and automatic backups. Measurement data generated in experiments may be initially saved on the devices controlling the experiments, but is transferred to institutional storage systems after the completion of the measurement.

1.5 Best practices

In order to stimulate and help partners with data management, we will communicate and discuss together suggestions for best practices for data management, possibly in a dedicated session at the consortium meetings. The goal will be an improved data management within EMP, allowing an efficient data use and preparing the local infrastructure for future data initiatives.

[1] See https://creativecommons.org/licenses/by-nc-sa/4.0/ for details.

2 Current partner-specific practices

2.1 Generation of data

EMP research infrastructure can be accessed by external researchers. In this paragraph, we provide a list of data types the eight access-giving partners are typically able to handle.

2.1.1 Ruprecht-Karls-Universität Heidelberg (UHEI)

- ASCII data files including metadata from measurements of different experiments.
- Binary data files with ASCII metadata headers from different experiments.
- Analysis and calculation files usable with software such as Origin, Mathematica, Python and GenPlot
- Simulation files in COMSOL and SONNET format.
- Technical Drawings (CAD, gds2, PDF)
- Images (SEM, pictures of set-ups) in JPG, PNG and TIF format.
- Different documentation, reports, final results, design drawing, electrical layouts, etc. will also be created in the PDF format for fast access and review.

2.1.2 Centre National de la Recherche Scientifique (CNRS)

- ASCII data files with metadata and measurements from different experiments.
- Analysis files in Origin and Mathematica format.
- Calculation in Mathematica and Python format.
- Simulation files in COMSOL and SONNET format.
- Images (SEM, pictures of set-ups) in JPG and TIF format.

2.1.3 Aalto-korkeakoulusäätiö (AALTO)

- ASCII data files containing measurement data and metadata from different EMP experiments.
- Lithography software generates a Design CAD file (*.dc2) for sample design and a run file (*.rf6) for the lithography software (both files in text format). Lithography files also include general layout design formats, such as *.gds (Layout Editor) and *.dxf/dwg (AutoCAD).
- Images from the different characterization devices (SEM, AFM, optical microscopes, etc.) are saved in the most common graphic formats (*.tif, *.jpg, *png).
- Simulation files in COMSOL format.
- Designs for different experimental hardware both in CAD and PDF formats.
- Experimental data and analysis scripts in the MatLab format.
- Different documentation, reports, final results, design drawing, electrical layouts, etc. will also be created in the PDF format for fast access and review.

2.1.4 Ustav experimentalnej Fyziki Slovenskej Akademie Vied (UEF SAV)

- ASCII data files including metadata from measurements of different experiments.
- Binary data files with ASCII metadata headers from different experiments.
- Analysis and calculation files usable with software such as Origin, MathLab, Python and Octave including scripts.

- Technical drawings of different experimental setups including 3D models and electronic hardware using CAD programs (AutoCAD, FreeCAD, LibreCAD, KiCad).
- Images (SEM, pictures of set-ups) in JPG, PNG and TIF format.
- Various documentations, reports, final results, design drawing, electrical layouts, etc. will also be created in the PDF format for fast access and review.

2.1.5 Universitat Basel (UBAS)

- ASCII data files and binary data files in IgorPro or hdf5 formats, containing measurement data and metadata from different experiments.
- Lithography software generates a Design CAD file (*.dc2) or a GDS file (*.gds) for sample design and a run file (*.rf6) for the lithography software (dc2 and rf6 in text format).
- Images from the different characterization devices (SEM, AFM, optical microscopes, etc.) are saved in the most common graphic formats (*.tif, *.jpg, *png).
- Simulation files in IgorPro, Python, MatLab and COMSOL format.
- Designs for different experimental hardware both in CAD and PDF formats.
- Experimental data and analysis scripts in the IgorPro, PythonNotebooks and MatLab format.

Different documentation, reports, final results, design drawing, electrical layouts, etc. will also be created in the PDF format for fast access and review.

2.1.6 Royal Holloway and Bedford New College (RHUL)

- ASCII data files including metadata from measurements of different experiments.
- Binary data files with ASCII metadata headers from different experiments.
- Analysis and calculation files usable with software such as
  Origin, SigmaPlot, Mathematica, Python and MatLab.
- Simulation files in COMSOL format.
- Technical Drawings (CAD, STEP, PDF)
- Images (SEM, pictures of set-ups) in JPG, PNG and TIF format.
- Different documentation, reports, final results, design drawing, electrical layouts, etc. will also be created in the PDF format for fast access and review.

2.1.7 Technische Universität Wien (TU WIEN)

- Transport and thermodynamic measurement data are saved in text (ASCII) and/or binary (hdf5) formats.
- Microwave measurements are saved in SnP (Touchstone) data files.
- MatLab and Python scripts are used for experimental data analysis.
- Simulation files are in COMSOL format.
- Images generated by optical microscopies are saved as .jpeg, .png, .tiff.

2.1.8 Lancaster University (ULANC)

Exchanging information and data within the consortium can be done via Box or OneDrive for small files, or via sharing ftp-links for downloading and viewing files.

2.2 Storage of data

2.2.1 Ruprecht-Karls-Universität Heidelberg (UHEI)

Measurement data is at first stored on the hard disks of the measurement PCs or external hard drives. After the end of each measurement cycle, those data are copied to the group directories of the data servers of the Kirchhoff Institute for Physics. All data including measurement data, analyzed data, material for publication, experimental plots, etc. will also be stored at these data servers. The IT department creates a backup of the relevant folders every day and a backup of the archive directory every week.
Commercial Software for the measurement devices and analysis of data is stored either as a hard copy on DVD/CD disks or on hard drives and flash drives. Newer versions can often be downloaded directly from the manufacturer's web pages.

2.2.2 Centre National de la Recherche Scientifique (CNRS)

Measurement data is primarily stored on the hard disks of the measurement PCs. This is also copied on the PCs of the researchers, and on external hard drives. Software for data taking and analysis is also stored this way. The final analysis of the data is on the researcher's PCs. Part of the data can be stored on the local Institut Néel Cloud for exchange and backup.

2.2.3 Aalto-korkeakoulusäätiö (AALTO)

Measurement data will be stored both locally on the hard disks of the measurement computers, the personal computers of the researchers and in the group/personal directories at the AALTO servers. Analyzed data, material for publication, experimental plots, etc. will be stored in the archival directory of the responsible research group. AALTO servers create a backup of the measured data every day and a backup of the archive directory every week. Some devices with connection ports use external HDD for local backup and the data are periodically transferred to AALTO servers (to group directories and archival drives). Original software for the measurement devices is stored on separate distribution drives and as a hard copy on DVD/CD disks whereas newer version can be downloaded from the manufacturers' web pages.

2.2.4 Ustav experimentalnej Fyziki Slovenskej Akademie Vied (UEF SAV)

Measurement data are, at first, collected and stored on the hard disks of the measurement PCs, each of them having mirror HDDs for the data-backup, and simultaneously copied on the external HDDs connected to these computers. Moreover, all data are on a regular base – every day - stored on the Data Storage Discs (DSD) of the Center of Low Temperature Physics (CLTP). In addition, CLTP uses the services for the data storage and data protection provided by the authorized and certified company – the Centre for Scientific and Technical Information (CSTI) of the Slovak republic (see https://iss.cvtisr.sk), where data back-up is made on a regular time base.
All data including measurement data, analyzed data, software for measurements and analysis, material for publication, experimental plots, etc. will also be stored on the data servers of the CSTI. CSTI provides also access to software packages such as MatLab, Comsol and SAS.

2.2.5 Universitat Basel (UBAS)

All data including measurement data, analyzed data, material for publication, experimental plots, etc. will be stored both locally on the hard disks of the measurement computers, the personal computers of the researchers and in the group/personal directories at the departmental servers. Departmental servers create a backup of the measured data every day and a backup of the archive directory every week. Some devices with connection ports use external HDD for local backup and the data are periodically transferred to departmental servers (to group directories and archival drives). Original software for the measurement devices is stored as a hard copy on DVD/CD disks whereas newer version can be downloaded from the manufacturers' web pages.

2.2.6 Royal Holloway University of London (RHUL)

Experimental data, log files, analysis scripts are primarily stored on the hard disks of the measurement PCs. This is also copied on the PCs of the researchers. The data generated via user projects is stored on the Institutional Dropbox account for backup and exchange.

2.2.7 Technische Universität Wien (TU WIEN)

Experimental data, log files, and measurement scripts are stored locally on the hard disks of the measurement devices (e.g. the Vector Network Analyser) and/or measurement computers. Results of analysis, Python and Matlab data analysis scripts, plots, tables, etc. are stored and archived in the personal computers of the research group. All these data are backed up every day to the Institute servers.

2.2.8 Lancaster University (ULANC)

Measurement data will be stored both locally on the hard disks of the measurement computers, the personal computers of the researchers and in the group directories of the research storage at ULANC. Analyzed data, material for publication, experimental plots, etc. will be stored in the group directory of the research storage at ULANC. ULANC servers create a backup of the research storage data daily. Original software for the measurement devices is stored on separate distribution drives, whereas newer version can be downloaded from the manufacturers' web pages.

2.3 Archiving of data

2.3.1 Ruprecht-Karls-Universität Heidelberg (UHEI)

The long-term data storage on the file servers of the Kirchhoff Institute for Physics provides periodically backups to external service providers. Archiving is ensured in this way in an automated manner.

2.3.2 Centre National de la Recherche Scientifique (CNRS)

The long-term storage of data is the responsibility of each group at Néel. As such, group leaders have their own backup systems like burned DVDs or external hard-drives. Duplicates of these are usually also present on the Néel Cloud server for exchange.

2.3.3 Aalto-korkeakoulusäätiö (AALTO)

All of the data and the files related to the project on the personal and measurement computers will be stored permanently in the archival directory of the project at the AALTO server.

2.3.4 Ustav experimentalnej Fyziki Slovenskej Akademie Vied (UEF SAV)

All experimental data and documents related to the project will be stored permanently in the archival directory of the project at the Data Storage Discs of the Center of Low Temperature Physics (CLTP) and at the servers provided by the CSTI.

2.3.5 Universitat Basel (UBAS)

All of the data and the files related to the project on the personal and measurement computers will be stored permanently in the archival directory of the project at the departmental server.

2.3.6 Royal Holloway and Bedford New College (RHUL)

All of the data and the files related to the project on the personal and measurement computers will be stored permanently in the archival directory of the project at the institutional server.

2.3.7 Technische Universität Wien (TU WIEN)

All of the data and the files related to the project on the personal and measurement computers and devices are stored permanently in the archival directory of the project at the Institute server and backed-up periodically.

2.3.8 Lancaster University (ULANC)

All of the data and the files related to the project on the personal and measurement computers will be stored permanently in the archival directory of the project at the ULANC research storage.

2.4 Access to data

2.4.1 Ruprecht-Karls-Universität Heidelberg (UHEI)

If data have not (yet) been made available via an open data repository, they can be provided to internal and external researchers either via the OwnCloud server hosted by the Kirchhoff Institute for Physics or via the institutes' file sharing web interface (http://www.kip.uni-heidelberg.de/upload) upon request.

2.4.2 Centre National de la Recherche Scientifique (CNRS)

Data can be made available through the Néel OwnCloud server, which is hosted by the Institute. Files are then accessed through shared folders with passwords, upon request.

2.4.3 Aalto-korkeakoulusäätiö (AALTO)

Exchanging information and data within the consortium can be done via Dropbox for small files, or via sharing ftp-links for downloading and viewing files (e.g., https://filesender.funet.fi/). If needed,

we can also create user accounts for external users in order to share larger sets of data and to perform work in parallel. The same can be done for outside researchers upon request. AALTO recommended repository for long-term data storage and sharing is Zenodo. Small datasets of up to 1024 MB can be stored and made available via Aalto Current Research Information System (ACRIS).

2.4.4 Ustav experimentalnej Fyziki Slovenskej Akademie Vied (UEF SAV)

Exchanging information and data within the consortium can be done via Dropbox for small files, or via sharing ftp-links for downloading and viewing files. Access to the information can also be provided to internal and external researchers via the DSDs server upon request.

2.4.5 Universitat Basel (UBAS)

Exchanging information and data within the consortium can be done via Dropbox for small files, or via sharing ftp-links for downloading and viewing files.

2.4.6 Royal Holloway and Bedford New College (RHUL)

Exchanging information and data within the consortium can be done via the institutional Dropbox (up to 500TB), or via sharing ftp-links for downloading and viewing files. RHUL recommends repositories for long-term data storage and sharing such as Zenodo and figshare (www.figshare.com).

2.4.7 Technische Universität Wien (TU WIEN)

The experimental data can be copied to and accessed via the TU Wien OwnCloud (owncloud.tuwien.ac.at) after creating user accounts for external users upon requests.

2.4.8 Lancaster University (ULANC)

Exchanging information and data within the consortium can be done via Box or OneDrive for small files, or via sharing ftp-links for downloading and viewing files.

2.5 Summary table

The following table summarizes the processing of data at each access-giving site.

		Generation						*Storage*			*Archiving*		*Access*		
	Node	**Measurement data**	**Images and photos**	**Fabrication data**	**Simulation data**	**Analysis files**	**Proprietary formats**	**Zenodo**	**Group storage**	**Institution storage**	**Own**	**Third party**	**DOI, etc.**	**Sharing links, etc.**	**Ad hoc**
Access-giving site	**UHEI**	✓	✓	✓	✓	✓	✓	✓		✓	(✓)	✓	✓	✓	✓
	CNRS	✓	✓		✓	✓			✓	✓	✓			✓	✓
	AALTO	✓	✓	✓	✓	✓		✓		✓	✓	(✓)	✓	✓	✓
	UEF SAV	✓	✓	✓	✓	✓			✓	✓	✓	✓		✓	✓
	UBAS	✓	✓	?	✓	✓		✓	✓	✓	✓		✓	✓	✓
	RHUL	✓	✓	✓	✓	✓		✓		✓	✓	(✓)	✓	✓	✓
	TUW	✓	✓	✓	✓	✓			✓	✓	✓	(✓)	(✓)	✓	✓
	ULANC	✓	✓	✓	✓	✓			✓	✓	✓			✓	✓

3 Data generated within the Transnational Access Programme

Within the Transnational Access Programme of EMP, external user groups (“Research Team”) will generate data. The research team is responsible for the data handling regarding the generation and storage of the generated data. The hosting facility will provide support and hosting capabilities[2] for the long-term archiving of the data in agreement with this DMP and inform the user group on their operational practices. The knowledge and all data resulting from the use of the installations under this programme is the property of the Research Team, with the following limitations on their property rights:

- all collected data (prepared in a meaningful way including adequate metadata and with the exception of erroneous data sets or data sets that are clearly not worthwhile to archive from a scientific point of view), publications and reports must be provided by the research team to the facility manager of the Infrastructure immediately after completion; The facility manager is responsible for archiving the data in accordance with this DMP.
- all collected data, prepared as and with the exceptions mentioned above, should be made available to any European researcher on their request, but not before two years after the last experiment; In accordance with the Open Data Research Pilot, data shall be made available to the public following the FAIR principle if no restrictions (such as IPR-related limitations) apply.
- Users are strongly encouraged to publish the results of their research as many times as possible in the open literature. Within the scope of IP Rights protection, the (raw)

[2] Hosting capabilities can be provided by the hosting facility itself or via a third-party (such as Zenodo)

data used to generate published journal articles and theses outputs originating from the EMP TNA programme will typically be made available in an open data repository such as Zenodo or upon request. The FAIR principles laid out in this document shall be applied.

The hosting facility will provide support and storage capacities to archive the data either at the EMP site or on an open data repository. Prior to the end of the user group project, the Transnational Access Responsible of the hosting site has to confirm (via the EMP TNA web portal) that all data are archived correctly in accordance with this DMP.

Further details on the user's rights and obligations are provided in the "General Rules and Conditions" made available at EMP's website.

4 Best practice examples

4.1 SAS Košice

During the first year of implementation of the EMP project by SAS Košice, we introduced and developed a data storage and repository system to implement the data management plan. Our data storage and repository system consists of three mutually interconnected levels. The first level is composed from the measurement computers performing data acquisition from a particular experimental facility. Each of these measurement computers has a mirror hard disk (HDD or SSD) for the backup of the experimental raw data.

The experimental data include all pre-analyzed data, scientific projects, analytical programs used, experimental plots, figures, photo documentation, etc. and are stored on the Data Repository Discs (DRDs) of the Centre of Low Temperature Physics, which represents the second level of the data management. The meta data stored on the DRDs are structured according to the particular activities implemented by the EMP project, that is, TNAs, JRAs and NAs. In case of the TNA user groups, each of these user projects has its own folder with sub-folders for the experimental meta data (mentioned above), administrative documentation (copy of the accepted project, travel tickets, reports, consumption of the cryogenic liquids, consumption of the electricity, personal data of the visitor, time sheets, etc.). The DRD (any folder part) of the CLTP is remotely accessible upon request (a login account can be provided by our administrator).

The Centre for Scientific and Technical Information (CSTI) of the Slovak republic (see iss.cvtisr.sk) represents the third level of the data storage and repository system. A data backup from the DRD of the CLTP is made on a regular time base (once a week). The CSTI is a governmental organization providing a long-term storage and repository for the data produced within the EMP research project. This long-term data repository is subject to an agreement between the Institute of Experimental Physics SAS and CSTI of the Slovak republic. The CSTI adapts the EOSC strategy in Slovakia. The access to these data is available only upon request (a login account can be provided by CSTI administrators after our approval).

4.2 Lancaster

Lancaster data storage and repository system consists of several mutually interconnected levels. The first level is composed from the measurement computers performing data acquisition from a particular experimental facility. Most of these measurement computers have a mirror hard disk (HDD or SSD) for the backup of the experimental raw data. These machines also include all data analyzed on the fly during the experiments including scientific projects, experimental plots, figures, photo documentation, etc.

The second level of the data management is Research Data Storage (RDS), where all the experimental data and analysis is replicated. Lancaster University servers create a backup of the RDS daily. The data stored on the RDSs are structured according to the particular activities implemented by the EMP project, that is, TNAs, JRAs and NAs. In case of the TNA user groups, each of these user projects has its own folder with sub-folders for the experimental meta data and log journal, administrative documentation (copy of the accepted project, travel tickets, reports, consumption of the cryogenic liquids, time sheets, material used, etc.). The RDS is accessible to any member of the group and is used for analysis of the data. The raw data sharing with visitors is organized via OneDrive access by individual TNA user groups collaborations.

The data acquisition programs and analysis scripts are a separate layer and implemented via LabVIEW, Python and Matlab. Python and Matlab analysis scripts typically access the raw experimental data from RDS and are managed via Git repositories (Bitbucket, GitHub, etc.) for being clear, transparent and traceable. Any member of TNA user groups can execute and reproduce the analysis results on their PC or a laptop. The publication data and figures are managed in the same manner. Commercial software for the measurement devices is managed by the university centrally and are stored on separate distribution drives, whereas newer version can be downloaded from the manufacturers' web pages.