Novel concepts to construct cost effective geothermal wells with Electro Pulse Power Technology

Report on HSE standards and protocols

Deliverable D2.1

The project DEEPLIGHT is subsidized through the GEOTHERMICA and JPP Smart Energy Systems Joint Call by Netherland Enterprise Agency, RVO, German Federal Ministry for Economic Affairs and Energy BMWi, Icelandic Research Institute, RANNIS, The Scientific and Technological Research Council of Turkey, TÜBİTAK, United States Department of Energy, DOE.

Review process

Project name	Novel concepts to construct cost effective geothermal wells with Electro Pulse Power Technology – "DEEPLIGHT"	
Funding scheme	Joint Call 2021 – GEOTHERMICA and JPP Smart Energy Systems	
Project no.	445	
Duration	01/11/2022 – 31/10/2025	
Work package	WP2 – Electro Pulse Power Drilling development	
Dissemination level	Public (except for two appendices) / ~~Confidential~~	
Submission date	31/03/2023	
Due date	31/03/2023	
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Version	1.0	

Version history

Version	Publication date	Updates	Approved (coordinator)	Approval date
1.0	31/03/2023	Final version	Approved by coordinator TNO	23/03/2023

Executive summary

One of the main objectives of the DEEPLIGH project is to develop contactless drilling with Electrical Pulsed Power (EPP) technology as to be a game changer being far superior to conventional drilling methods. To achieve this objective the project's main Work Package 2 (WP2) for the development of EPP technology starts with the full-scale testing of an existing TU-Dresden set-up for EPP drilling, whereas in parallel the design and construction of a set-up for EPP drilling by IHC takes place and which is subsequently also subject of full-scale testing. These full-scale testing activities, i.e. experiments, take place by TNO at the Rijswijk Centre for Sustainable Geo-energy (RCSG) in The Netherlands.

This deliverable report is generated for the project's WP2 and specifically for Task 2.1 and which focuses on the HSE requirements for the EPP related full-scale testing of EPP drilling set-ups at the RCSG. This report covers the results obtained for Task 2.1. Additionally, this task entails further definition of the scope and methods that will be applied as part of these full-scale experiments. These are covered by an internal report known as "*Technical proposal EPP experiments RCSG*".

The aim for this current report is to provide a risk management strategy for the full-scale EPP drilling experiments that will take place at the RCSG facilities. This is covered by the development of a risk register, which is based on a high-level experimental scope. The risk register has been reviewed by the relevant partners of the DEEPLIGHT project consortium and as a result the main risks were identified. These main risks were then further discussed in a virtual workshop and a risk owner was assigned for each of the risks. This report summarizes the main risks and mitigations that were identified at this point in time. Additionally, a process to keep the risk inventory up to date, taking into account further detailing, is detailed.

Contents

Tables

Figures

1. Introduction

This first section introduces background, scope and goals of the activities performed for which the outcome is described in this report.

1.1. Background

One of the main objectives of the DEEPLIGH project is to develop contactless drilling with Electrical Pulsed Power (EPP) technology as to be a game changer being superior to conventional drilling methods. To achieve this objective the project's main Work Package 2 (WP2) for the development of EPP technology starts with the full-scale testing of an existing TU-Dresden set-up for EPP drilling, whereas in parallel the design and construction of a set-up for EPP drilling by IHC takes place and which is subsequently also subject of full-scale testing. These full-scale testing activities, i.e. experiments, take place by TNO at the Rijswijk Centre for Sustainable Geo-energy (RCSG) in The Netherlands at a drilling rig, positioned above a 350 m deep well that can be adapted to obtain a relevant testing environment. This drilling rig will need to be prepared for integration with the specific EPP technology to perform the first set of experiments with the existing EPP set-up of TU Dresden. Results of these tests will serve as a reference point to compare with the characteristics and the performance of the EPP set-up of IHC and which will take place via a set of full-scale experiments in the final year of the project. In the experiments, and also in parallel activities of the DEEPLIGHT project, each EPP sub-system will be separately investigated in order to obtain a complete fully functional EPP system. The full-scale experiments that will be performed with the drilling rig at the RCSG have the objective to acquire engineering parameters for next steps, such as prototype development, and to determine the efficiency and feasibility of the EPP drilling technology. This will be done by drilling a dozen meter of cement in the already existing well under the RCSG rig and which is completed with a 20" cemented casing. A working depth of around 60 m is anticipated at the moment to allow simulation of subsurface drilling in a controlled environment.

1.2. Scope

This deliverable report is part of DEEPLIGHT's WP2 and which focuses on the development and testing of EPP drilling technology. Task 2.1 of WP2 is related to HSE requirements for the aforementioned full-scale experiments on this technology. Additionally, this task entails further definition of the scope and methods that will be applied as part of these experiments. These are covered by the report "*Technical proposal EPP experiments RCSG*" and which is only available within the DEEPLIGHT project consortium. This report serving as project deliverable D2.1 solely focuses on the risk assessment methodology (Section 2), the experimental scope and boundary conditions (Sections 3), the risk register format (Section 4), the main risks and mitigations that were identified (Section 5) and the follow-up steps related to HSE aspects until the execution of the experiments (Section 6).

1.3. Objective

To let us have a risk management strategy for the full-scale experiments at RCSG on EPP drilling technology, this report will provide the main risks and mitigations that were identified at this point in time. It is realistic to assume that with maturing EPP Bottom Hole Assembly (BHA) design during the project also the experimental programs will require further detailing. The process to manage this further detailing appropriately is also covered in this report.

2. Methodology

The methodology that was adopted to provide a comprehensive initial risk assessment, including mitigations and follow-up actions is as follows:

1. *Prepare a high-level scope for the full-scale experiments, including boundary conditions*
   In order to do a risk assessment, it is important to determine a high-level scope and the boundary conditions for the experiments as much as possible. This also allows to group the risks according to the identified experimental activities. This is covered by a separate document "*Technical proposal EPP experiments RCSG*" and which is only available within the DEEPLIGHT project consortium. A summary of this high-level scope is provided in Section 3.
2. *Develop initial risk register framework and provide initial risks*
   TNO developed a risk register format to register all risks that could be identified and weigh them. It also allows to assign mitigative actions and score the residual risks. The format is explained in Section 4.
3. *Have a dedicated risk assessment workshop in the consortium to identify main risks and mitigations*
   TNO organized a virtual risk assessment workshop for the DEEPLIGHT project consortium on 15 February 2023, fully dedicated to the risks related to the full-scale experiments on EPP drilling set-ups, and which was attended by 11 persons from of 6 partners. The participants received in advance the scope and risk register and were requested to provide feedback via online tooling (Mentimeter) in preparation of the workshop. This feedback was used to focus the workshop on the critical elements. During the workshop a risk owner has been agreed and who is responsible for substantiating the risk rating, defining mitigations and owning the resulting actions. The main risks discussed and the risk owner are found in Section 5.
4. *Define action list*
   An action list has been defined to track the progress of the actions related to the risks. This progress and actions will be subject of the regular meetings that take place for WP2.
5. *Document agreements in this D2.1 deliverable*
   The agreed process(es) and actions are described in this D2.1 deliverable report and therefore it describes the relevant HSE standards and protocols that will be followed for the full-scale experiments at RCSG. It should be noted that these processes might be updated when new insights give reason for this, and in such a case this will be discussed and evaluated by the parties involved.

3. High level experimental scope and boundary conditions

The details for the high-level experimental scope can be found in the report "*Technical proposal EPP experiments RCSG*", only available within the DEEPLIGHT project consortium. This section provides the main elements that are relevant for the risk assessment process.

3.1. Summary of proposed activities

Two periods of full-scale experiments for EPP technology at RCSG are foreseen. In the first year of the project the existing EPP technology from TU Dresden will be subject of experiments, whereas in the final (3rd) year of the project this will hold for the EPP technology as newly developed in the project. The results of the experiments in the first year serve the project developments of, and also assist in the evaluation of the performance of, the new EPP technology. It is therefore that the following three phase should be recognized:

1. Phase 1: Experimental testing of EPP technology of TU Dresden
2. Phase 2: Evaluation of the results obtained
3. Phase 3: Experimental testing of EPP technology as developed in the project, mainly by IHC.

For now it is assumed that the experiments will roughly follow the same procedure, and therefore the same high-level steps take place for phase 1 and phase 3. These consist of:

1. Site and test preparations
    a. Create sections with artificial formations to be hardened and ready at start
    b. Perform a rig function test
    c. Prepare site with required materials and tools
    d. Rig-up surface equipment
2. Prepare and install test set-up, including
    a. Install artificial formation and casing string
    b. Connect circulation pumps and lines
    c. Create access/feedthrough for power cable
    d. Deploy the BHA
3. Drill artificial formation with EPP drilling tool
4. Retrieve test set-up for analysis
    a. Retrieve drilling BHA
    b. Retrieve casings with artificial formation
5. Repeat steps 2-4 for multiple tests
    a. Possibly adjust set-up for next test
6. Clean-up site

The full technical proposal for the experiments includes more detailed sub-steps. These sub-steps have been taken to organize the risk register, as will be explained in Section 4.

A maximum of 10 weeks of experimental testing is foreseen for both phase 1 and phase 3. It is assumed that a single test takes about 1 week to be successful, and which means that a maximum of 10 experimental tests could be foreseen. The final number of tests and duration of the testing period will depend on the final scope of the full-scale experiments. The first test is assumed to be a functional test at 60 m depth. In the consecutive experiments certain conditions could be varied, such as depth, artificial formation type/strength, and Rate of Penetration (ROP). This will be defined in a later phase of the project.

3.2. Conceptual test set-up

Confidential Appendix B shows what a conceptual (first) test in the test well at the RCSG could look like and provides data requirements for the specific elements. The design of the set-up as shown will be further detailed in the coming months.

4. Risk register format

This section describes the risk register's set-up and how it is used to collect, rank and evaluate risks and mitigations.

The risks are captured in an Excel based risk register. In this register a separate sheet/tab is available for each of the individual high-level operational steps as provided in Section 3.1. The detailed description of the individual risks per sub-step is provided in these sheets. The sheets are organized as follows, also see Figure 1:

- **Risk ID**: assigns a unique ID to each risk to enable referring to risks.
- **Op. step**: refers to the operational step from "*Technical proposal EPP experiments RCSG*". Each operational step can have multiple associated risks.
- **Description of the operation**: describes in words the activities of the operational step.
- **Stakeholders**: the parties that could be affected by the risk.
- **Risks**: description of the risk.
- **Potential consequences**: describes the consequence in case the risks turn into reality.
- **Initial risk (probability, severity and risk rating)**: the initial risk ranking is related to the risk without taking mitigations into account. It scores on probability of risk occurring and severity of the consequence if the risk occurs. The resulting risk rating is simply a multiplication of the probability and severity, the related color coding will be described below.
- **Action to mitigate or create contingency plan**: describes the mitigation actions that have to be taken into account. Normally mitigations either reduce the probability or the severity of the risk. The mitigations are labelled: P = covered by existing procedure, D = should be covered in detailed experimental program and A = requires specific action and has action party assigned. A contingency measure, relevant if the mitigation of the risk cannot be adequately applied, is included in the description where suitable.
- **Residual risk**: ranks the risk after mitigations are in place. For further description see above "Initial risk".
- **Remarks**: provides an option to put in additional considerations or information.

Example of Risk Matrix						initial Risk				Residual Risk			
Task ID	Op. Step	Description of Operation	Stakeholder(s)	Risks	Potential Consequences	Probability	Severity	Risk rating	Action to mitigate or create contingency plan	Probability	Severity	Risk rating	Remarks
Generic risks													
2-I Prepare and install test set-up													
I1	2.10					2	4	8		1	3	3	
I2						2	2	4		1	2	2	
I3						2	4	8		1	4	4	
I4						2	3	6		1	2	2	

Figure 1 Impression of an empty sheet in the risk register

The first tab of the register serves as version control purposes. Here version numbers and dates are logged and any changes resulting in an updated version can be found, including reviewers. In this way it should be prevented that changes are not logged or that wrong version numbers ultimately end up on site during the experiments. The register also includes a signature sheet than can be used to sign the risk register in or after a so-called "Drilling Well in Paper" (DWOP) session. Lastly, the register also contains a risk matrix that is used to rank the risks, explaining the colors associated to the risk ranking, see Figure 2.

Appendix A provides more details on the likelihood of consequence levels, likelihood of occurrence levels and the risk classes for safety and operational impact.

Risk Matrix *(as used for the Huisman RA process)*				Likelihood of occurrence					
				Probability	> 1:100 wells	1:20 - 1:100 wells	1:10 - 1:20 wells	1:5 - 1:10 wells	1:5 - 1:1 wells
				Description					
				Characterization	**Very unlikely**	**Remote**	**Occasional**	**Probable**	**Frequent**
Severity of consequence	**Category**								
	Safety	**Operational impact**	**Characterization**	**Level**	**1**	**2**	**3**	**4**	**5**
	No injury / First Aid Case (FAC)	< 1 hour	**Negligible**	**1**	1	2	3	4	5
	Medical Treatment Case (MTC)	1 hour - 4 hours	**Minor**	**2**	2	4	6	8	10
	Restricted Work Case (RWC)	5 hours - 24 hours	**Major**	**3**	3	6	9	12	15
	Large Permanent Injury (LPI)	1 - 7 days	**Critical**	**4**	4	8	12	16	20
	Multiple LPI / Casualty	7+ days	**Catastrophic**	**5**	5*	10	15	20	25

* Special type of risk. Failure very unlikely to happen, can however have serious consequences. To be checked regularly (i.e., watch list) to ensure it does not change to an unacceptable level over time.

Severity category	Description
Safety	The potential personal injury caused by the hazard
Operational impact	The potential operational impact, indicated by means of downtime / unavailability, caused by the hazard

Figure 2 Risk matrix used for ranking the risks

5. Main identified risks and mitigations

5.1. Risk register

The complete risk register that was used for the risk assessment workshop, and which is subject of further project considerations and activities, is available as confidential data sheets within the DEEPLIGHT project consortium. In this section an outline is given of the main aspects of this risk register.

5.2. Identified main risks and owners

Following the proposed experimental steps the main risks could be identified. These are the risks that sparked discussion in the workshop and that are not covered in "standard procedures". Furthermore, to each of the main risks a risk owner has been assigned.

The main risks are provided in confidential Appendix C. and are listed per the following main steps of the experimental program, i.e.

0. General RCSG and rig related risks
1. Site and test preparation
2. Prepare and install test set-up
3. EPP drilling
4. Retrieve set-up.

5.3. Monitoring risk owner progress

The risks that require further actions by the risk owner are covered in a progress sheet to monitor status of the actions required to manage the risk. This sheet is only available within the DEEPLIGHT project consortium and will be reviewed (and subsequently updates) in regular meetings with the relevant parties. This progress sheet covers among others the following items:

- **Project phase**: Such as preparation of site and test, preparation and installation of test set-up, and execution of EPP drilling experiments.
- **Risk**: Short risk description
- **Risk owner**: Explained in the previous paragraph
- **Progress**: This is being used to track the status of the required actions via a traffic light in order to indicate the status to be "Behind", "Started", "In progress", "Nearly finished" and "Finished.
- **Deadline**: When the actions need to be sufficiently completed.

5.4. Main mitigation actions identified

Six overarching mitigations were identified by TNO in the preparatory phase and which were provided to the DEEPLIGHT consortium partners to be ranked for effectiveness and/or importance. The mitigations and how these are ranked can be found below in Figure 3

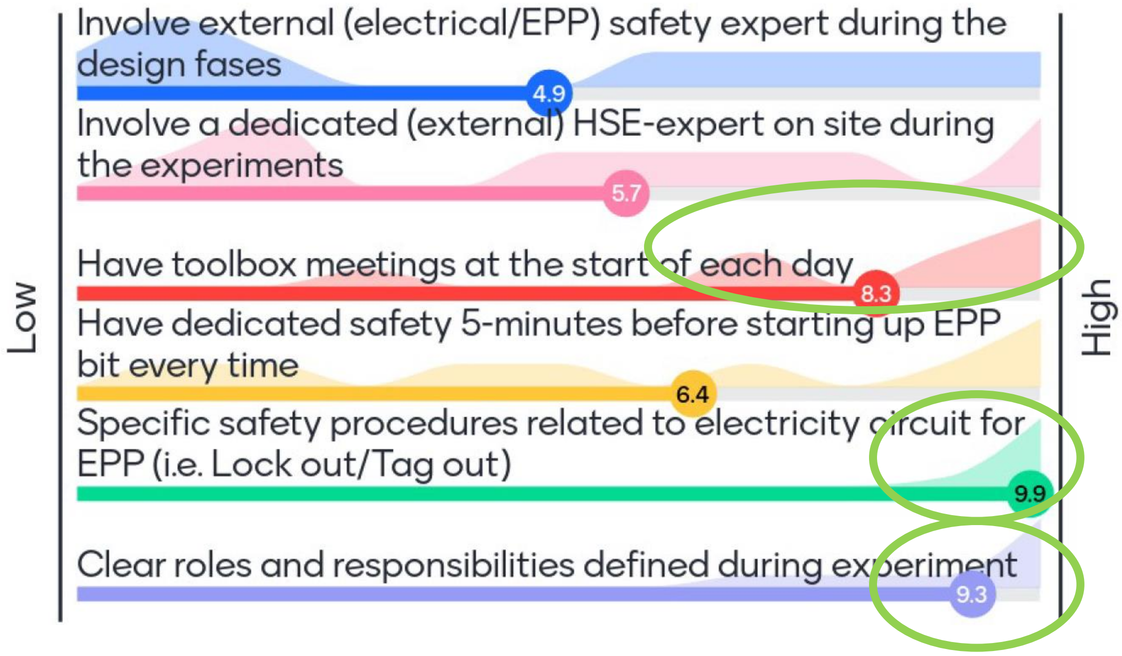

Figure 3 Ranking of proposed overarching mitigations for importance and effectiveness. A number was selected on a scale of 1 (low priority) to 10 (high priority). The number indicated in the picture indicates the average of the provided input numbers.

The three highest ranked mitigations are widely considered to be important and will be taken into account in follow-up steps. :

1. Specific procedures regarding electricity and EPP start-up
2. Clear Roles and Responsibilities during the experiments
3. Daily toolbox meetings at the start of the experimental activities on the rig with all involved parties to discuss the planned operations, risks and mitigations

The need for the other three mitigations indicated in figure 4 is not commonly shared and will be further evaluated in the course of the project.

Additionally, some more overarching mitigations were identified via a Mentimeter and/or in the workshop:

1. Do not take shortcuts; the experiments can only be executed if all involved parties are happy, shown by a signature on the relevant documents.
2. Organization of visitors (who, when, how many, supervision) and clearly marked no-go areas to ensure the experiments can continue and people do not enter hazardous areas.
3. Internal earthing in the tool – this is seen as one of the most important (if not the most important) mitigation that is relevant for electricity and short circuit related risks.
4. Application of the five safety rules as provided in the DIN VDE 0105 standard about operation of electrical installations.

5. Clear experimental program with objectives, escalation/decision levels and clear procedures and responsibilities.

These mitigations will be taken on board and considered for application during the design phases.

6. HSE and protocol procedures

The above-described methods that were applied provide a solid basis and understanding of risks. However, this overview has to be updated regularly based on new information on experimental design and EPP tool developments. Therefore, procedures have to be aligned to ensure this is sufficiently covered. This section describes the procedures related to HSE aspects of the experiments with EPP tools at RCSG that will be applied as a minimum in the remainder of this project.

6.1. High level process

The complete high-level methodology, including the steps leading up to this point, to provide a comprehensive risk assessment, including mitigations and follow-up actions, is described below. It details the process for the experiments with the existing TU Dresden tool (phase 1) and how the learnings will be transferred to the experiments with the new, to be developed, EPP tool (phase 3):

1. *Prepare a high-level scope for the full-scale experiments, including boundary conditions*
   In order to do a risk assessment it is important to determine a high-level scope and the boundary conditions for the experiments as much as possible. This also allows to group the risks according to the identified experimental activities.
2. *Develop initial risk register framework and provide initial risks*
   TNO RCSG has developed a risk register format to register all risks that could be identified and weigh them. It also allows to assign mitigative actions and score the residual risks.
3. *Have a dedicated risk assessment workshop in the consortium to identify main risks and mitigations*
   Such a workshop serves to identify relevant risks. To make it as complete as possible, this workshop should include people with different expertise profiles and from different parties. TNO has organized such workshop virtually on 15 February 2023, fully dedicated to the risks related to the EPP drilling experiments.
4. *(Re-)evaluate risks continuously and update where required*
   As there might be new, changed or obsolete risks because of developments during the design and construction of the EPP tool and detailed design of the experiments it is important to re-evaluate the risks continuously. The risk register will therefore at least be updated before the DWOP session. Additionally, the main risks will be discussed in the regular WP2 meetings, and the actions are logged in an action list.
5. *DWOP(s)*
   Before execution of the experiments a final meeting with all involved stakeholders will be organized, a so-called *Drill Well on Paper* (DWOP) session. In such a session the detailed operations and the associated risks will be discussed and agreed once more to confirm all is set for the execution of the experiments. Ultimately the experimental program and risk assessment should be signed by the relevant parties to confirm that:
   a. The program reflects the goals as described in the GEOTHERMICA proposal
   b. The program reflects the mitigations as were prescribed in the risk assessment
   c. The contents of risk assessment are correct and known to the relevant persons/parties

   <u>The experiments can only take place if both the experimental program and the risk assessment are signed by all relevant parties.</u>
6. *Execute experiments*

The experiments will be executed as per signed experimental program and risk assessment.

7. *After Action Review (AAR)*
   The execution of the experiments will be evaluated in an AAR. A strong focus will be on HSE during the experiments and potential learnings for the next set of EPP experiments in RCSG (phase 3).
8. Repeat process for phase 3:
   All the above steps will be repeated for the experiments in phase 3, taking the potential changes and updates into account. If this process can be improved to increase efficiency or safety, these changes will be adopted.

The complete process, including the workshop is illustrated by Figure 4:

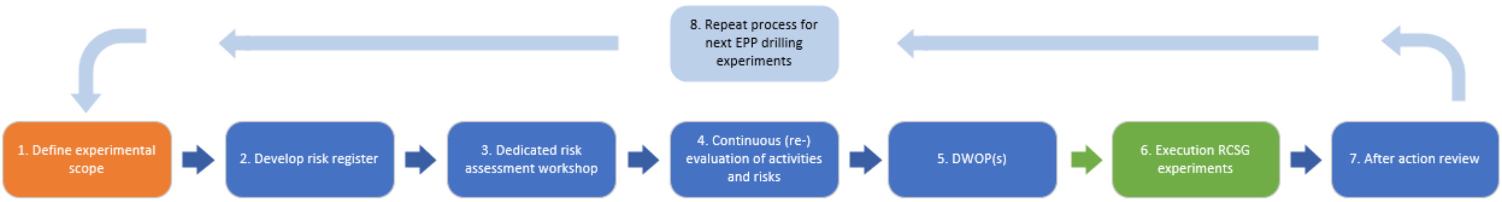

Figure 4 High level process for HSE and protocols

6.2. Milestones related to experiment planning and HSE

Below a list of internal project milestones is defined to prepare for the first set of EPP drilling experiments. The indicated dates are set to meet a start date of the experiments on the rig in Q3 but may shift if this start date cannot be met for any reason.

Table 1 Internal project milestones until phase 1 experiments with TU Dresden EPP tool

Milestone	Due date (month)	Owner	Involved	Informed
Agree on experimental scope	March 2023	TNO	TUD, WEP, IHC, TU/e	All
Prepare and submit deliverable report D2.1	March 2023	TNO		All
Continuous tracking of actions related to HSE	Continuously	TNO	Action owners	All
Update and finalize risk register	May 2023	TNO	TUD, WEP, IHC, TU/e	All
Preparing detailed experimental program	May 2023	TNO	TUD, WEP, IHC, TU/e	All
DWOP 1	June 2023	TNO	TUD, WEP, IHC, TU/e	All
DWOP 2 (back-up)	August 2023	TNO	TUD, WEP, IHC, TU/e	All
Start EPP experiments phase 1	September 2023	TNO	TUD	All
After Action Review (AAR) phase 1	December 2023	TNO	TUD	All
Continue developing and planning IHC tool experiments	Continuous	TNO	IHC, TU/e, WEP, TUD	All

6.3. Documents

The documents that will be prepared as part of the HSE process:

- Proposal EPP experiments RCSG (Scope) – to be agreed and fixed in March 2023
- Risk register – continuous updates and signed and fixed in DWOP
- D2.1 Report on HSE standards and protocols – this report, made final by end of March 2023.
- Detailed experimental program – To be signed and fixed in DWOP
    - Incl. Management of Change (MoC) procedure, Roles & Responsibilities (R&R) + organigram, planning
    - Background documents supplementing the experimental program and risk register are (non-exhaustive): procedures, manuals, Risk Inventory and Evaluation (RIE), TNO Company emergency plan, TU Dresden risk assessment, TU/e protocols

Appendix A. Additional information risk register

Severity of consequence levels			
Discrete level (1 out of a possible 5) specifying the severity of the consequence caused by the hazard.			
Level	**Characterization**	**Consequence category**	**Consequence description**
1	Negligible	Safety	First Aid Case (FAC): minor work-related injury or illness that calls for only simple treatment and does not call for follow-up treatment by a health-care professional (e.g., bandage, painkiller). FAC does not result in time lost from work or work restrictions, as the person can continue working after treatment.
		Operational impact	<1 hour downtime
2	Minor	Safety	Medical Treatment Case (MTC): work-related injury or illness that calls for medication, treatment, or medical check that is normally administered by a health-care professional and that goes beyond a First Aid Case. MTC does not result in lost time from work of a couple of days (e.g., recovering from fever, twitching of ankle).
		Operational impact	1 - 4 hours downtime
3	Major	Safety	Restricted Work Case (RWC): work-related injury or illness that results in limitations on work activity that prevents an individual from doing any task of his / her normal job for a prolonged time (e.g., broken leg, dislocated shoulder).
		Operational impact	4 hours - 24 hours downtime
4	Critical	Safety	Large Permanent Injury (LPI): work-related permanent / irreversible injury or illness that results in an individual not being able to work (e.g., loss of limbs, blindness).
		Operational impact	1 - 7 days downtime
5	Catastrophic	Safety	Casualty or multiple persons with permanent / irreversible injuries.
		Operational impact	7+ days downtime

Figure 5 Severity of consequence levels

Likelihood of occurrence levels		
Discrete level (1 out of a possible 5) specifying the likelihood of occurrence (probability) of the incident (i.e., harm).		
Level	**Characterization**	**Probability description**
1	Very unlikely	> 1:100 wells
2	Remote	1:20 - 1:100 wells
3	Occasional	1:10 - 1:20 wells
4	Probable	1:5 - 1:10 wells
5	Frequent	1:1 - 1:5 wells

Figure 6 Likelihood of occurrence levels

Risk class - Safety	
Discrete level (1 out of a possible 3) specifying the risk class, where class 3 has the highest level of unsafety and class 1 the lowest.	
Class	**Required response and approach**
High (red)	
H	Safety risks regarded as unacceptable. Extensive high reliable risk reducing measures shall be taken to reduce the risk class to at least a manageable level (by decreasing the likelihood and / or severity level).
Moderate (orange)	
M	Safety risks that are tolerated only if further risk reduction is impracticable or requires action that is grossly disproportionate in time, trouble and effort to the reduction in risk achieved (i.e., ALARP principle as described in HSE OTR 2001/063 Standard).
Low (green)	
L	Safety risks regarded as acceptable, further effort to reduce risk not normally required as resources to reduce risks likely to be grossly disproportionate to the risk reduction achieved.

Risk class - Operational impact	
Discrete level (1 out of a possible 3) specifying the risk class, where class 3 has the highest operational impact and class 1 the lowest.	
Class	**Required response and approach**
High (red)	
H	Operational impact risks regarded as unacceptable, measures shall be taken to prevent the function from stopping. For instance redundant actuators and, as far as practicable, complete backup systems.
Moderate (orange)	
M	Operational impact risks that are tolerated as long as the function can be restored easily during a single point of failure (i.e., alternative means of operation). Performance might be reduced with regard to speed and / or load handling capacity.
Low (green)	
L	Operational impact risks regarded as acceptable, no further risk reduction required. As a best design practice, always consider good access for repair and maintenance.

NOTE: The benefits of the risk assessment come from the discipline of the process rather than in the absolute precision of the results, as long as all the elements of risk are fully considered. Moreover, resources are better directed at risk reduction efforts rather than attempting to achieve absolute precision in risk estimation. [NPR-ISO/TR 14121-2:2012, pag 9]

Figure 7 Risk classes for Safety and Operational impact classes

Appendix B. Confidential: Conceptual test set-up

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Appendix C. Confidential: Main risks identified and risk owner

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