

## Technical Report 15-02

Implementation of the Full-scale Emplacement Experiment at Mont Terri:

> Design, Construction and Preliminary Results

> > May 2019

Nagra

National Cooperative for the Disposal of Radioactive Waste

> Hardstrasse 73 CH-5430 Wettingen Switzerland Tel. +41 56 437 11 11

> > www.nagra.ch

## **Table of Contents**

Summary		I	
Zusammenfassung III			
Résumé		VI	
Acknowledg	gements	IX	
Table of Co	ntents	XI	
List of Tabl	es	XV	
List of Figu	res	XVII	
1	Introduction	1	
1.1	Reference concept		
1.2	Report objectives		
1.3	Overview of FE Experiment		
1.3.1	Experiment location		
1.3.2	Experiment objectives		
1.3.3	Experiment Layout	6	
1.3.4	Experiment Schedule	7	
1.3.5	Monitoring system	8	
1.4	Requirements on the disposal concept	10	
1.5	Organisation of this Report	10	
2	Previous THM Experiments in Mont Terri and scoping of the FE Experiment		
2.1	EB Experiment		
2.2	ESDRED emplacement test		
2.3	HE Experiment Series		
2.3.1	HE-B Experiment		
2.3.2	HE-D Experiment		
2.3.3	HE-E Experiment		
2.4	Scoping of the FE Experiment		
3	Construction of the FE Cavern and FE Tunnel and Response of the Rock Mass	29	
3.1	Requirements on construction		
3.2	Monitoring system (Phase 1 and Phase 2a)	30	
3.2.1	Phase 1: Monitoring of Excavation		
3.2.2	Phase 2a: System for monitoring response to tunnel construction		
3.3	Rock excavation and support installation		
3.3.1	FE cavern		

	FE tunnel	33
3.3.2	Excavation method	33
3.3.2.1	Support design and installation	34
3.3.2.2	Support design and instandion	35
3.3.2.3	Shotcrete mixture	
3.4	Geological mapping and hydro-mechanical behaviour during tunnel construction	37
	Geological mapping and tunnel scanning	37
3.4.1	Mechanical response to construction and support installation	39
3.4.2	Summary of tunnel construction	42
3.5		
4	Ventilation period	43
4.1	Requirements on tunnel ventilation period	43
4.2	Tunnel climate and near-field rock instrumentation (Phase 2b)	43
4.3	Ventilation system	44
4.4	Response to ventilation	46
4.4.1	Tunnel climate	46
4.4.2	Rock and shotcrete response to ventilation	46
4.4.2.1	Monitoring results	46
4.5	Summary of ventilation period	
5	Requirements on, and design of, EBS Materials	49
5.1	Requirements on experiment materials and emplacement technology	49
5.2	ISS materials	52
5.3	Design of the bentonite block pedestal (bentonite blocks)	
5.3.1	Laboratory testing of production parameters	
5.3.2	BLL	
5.3.3	BeLLT	
5.3.4	Grono 1	
5.3.5	Conclusions from design work	
5.4	Design of the heaters	
5.5	Design of the GBM buffer	
5.6	Design of the concrete plug	
6	Design of emplacement technology, and production and emplacement of EBS materials	63
6.1	Requirements on emplacement technology	63
6.2	Preparation for emplacement	
6.3	Production and emplacement of the ISS	64
6.4	Production and emplacement of the bentonite block pedestal	
6.4.1	Block production	
6.4.2	Block storage	
6.4.3	Emplacement in the FE tunnel	
6.5	Production and emplacement of the heaters	

6.6	Design, production and emplacement of the GBM buffer	68
6.6.1	Design and testing of the backfilling machine	68
6.6.1.1	Pre-tests	70
6.6.2	Production and emplacement	74
6.7	Design, production and emplacement of the concrete plug	76
6.8	Summary of production and emplacement of experiment materials	77
7	Heating phase	79
7.1	Modelling of the heating phase	79
7.1.1	Modelling using QPAC	79
7.1.2	Modelling using TOUGH2	86
7.1.3	Requirement on heating power	93
7.2	Heating phase monitoring system (Phase 2c and Phase 3)	94
7.2.1	Instrumentation of the EDZ (Phase 2c)	95
7.2.2	Tunnel wall, bentonite and heater instrumentation (Phase 3)	95
7.2.2.1	Instrumentation for monitoring of THM processes, gas concentration and metal corrosion	95
7.2.2.2	Fibre-optic cables on tunnel wall (Phase 3b)	98
7.2.2.3	Geophysical methods	98
7.2.2.4	Gas monitoring	98
7.2.2.5	Corrosion monitoring	99
7.2.3	Data acquisition systems	99
7.3	Results of the heating phase	99
7.3.1	Temperature evolution	101
7.3.2	Hydraulic evolution: relative humidity in bentonite, tunnel wall and Opalinus Clay	110
7.3.3	Mechanical evolution: deformations	113
7.3.4	Chemical evolution: oxygen consumption and hydrogen generation	114
7.4	Summary of the heating phase	115
8	Lessons learnt	117
8.1	Design and construction of the FE Experiment	117
8.1.1	Tunnel construction	117
8.1.2	Tunnel ventilation	118
8.1.3	Design, production and emplacement of bentonite blocks	118
8.1.4	Design, production and emplacement of GBM	119
8.2	Processes occurring during the heating phases	120
8.2.1	Modelling	120
8.2.2	Monitoring system	121
8.2.3	Experiment evolution	
8.3	Feedback on requirements	125
8.3.1	Evaluation of FE Experiment Performance against Requirements	125
8.3.2	Development of requirements	128

8.4	Feedback to reference design – TRL assessment 129
9	Conclusions and outlook 137
9.1	Conclusions 137
9.2	Next steps 138
10	References 141
Appendix I	: Tunnel lengths and component installation datesI-1
Appendix I	I: Requirements on the FE Experiment II-1
II.1	Requirements on construction II-1
II.2	Requirements on bentonite II-4
Appendix l	II: The FE Experiment data base (FEIS)III-1
Appendix l	V: Sensor listingIV-1
Appendix	V: List of Materials in the FE TunnelV-1
Appendix	VI: List of AcronymsVI-1