Hazard Number	Hazard Description	Scenario		Safeguards / Mitigation	RECOMMENDATIONS Action	Who	By
0	**UDG SPECIFIC HAZARDS**		**NOTE: THIS RISK REGISTER IS MEANT FOR GENERIC USE ONLY.**	**NOTE: THIS RISK REGISTER IS TO BE CRITICALLY EVALUATED FOR EACH INDIVIDUAL PROJECT.**	**NOTE: THIS RISK REGISTER IS MEANT FOR GENERIC USE ONLY.**		
0.0	***GENERIC GEOTHERMAL WELL***		***Please assess carefully and follow closely all (other) drilling related Hazards scenarios that are generally applicable to drilling a geothermal well.***	***Reference is made to, e.g., the 'DAGO' (generic) HAZID-template for geothermal projects, or any other useable reference.***	***Please assess carefully and follow closely all (other) drilling related Hazards and scenarios that are generally applicable to drilling a geothermal well. ANTICIPATE ON EFFECTS THAT, e.g., HIGH(-ER) PRESSURE AND HIGH(-ER) TEMPERATURES MIGHT HAVE ON SHALLOWER FORMATIONS, THE USE AND FUNCTIONING OF TOOLS, USE AND QUALIFICATION OF MATERIALS (e.g. CASINGS),***		
0.1	**TEMPERATURE (UDG-specific)**						
	High(er) temperatures due to nature of UDG ('Ultra Deep').	0.1.1	Encounter high temperatures (as per objectives), temperature gradient can be higher/lower than expected. ***Note: final Temperature range/ Temperature gradient can be much higher (a number of Dinantien reference wells show significantly higher gradient), leading to misc. negative effects (than in drilling a 'normal' well, see below).***	International industry standards on High Temperature (and High Pressure, ref. below) wells (e.g. NORSOK, HPHT standards & guidelines, New Zealand GT standard, ISO, API, NOGEPA).	Assess and incorporate applicable industry standards in planning and execution phases. Define worst case scenarios and mitigations.		
	Temperature effects on materials (casing, drilling equipment, fluids).	0.1.2	Deterioration of materials and equipment such as casing, liners, liner hangers, drilling tools (bits, mudmotors, M/LWD tools, etc), well control equipment, seals, drilling fluids and additives, cement. ***Note: also temperature effects on higher/ un-deeper trajectories!***	Suitability of all components in well construction process anticipating worst case temperature effects. Consider using mudcoolers, extra mudcirculation, etc. Use field proven technology, concider simple/mechanical tools vs hydraulic and electronic components. For liner hangers consider mechanical setting mechanisms versus hydraulic tools, multi trip versus single trip systems.	Asses and incorporate proper material and equipment selection during engineering and execution phases. Develop and implement an efficiënt QA/QC system. Consider pre-testing critical parts and components under downhole conditions. Note: check compatibility of materials, drillpipe conections (including make up torque and suitable pipe dope), (ring) gaskets, seals, bearings, etc. Include (longer) order times ('long lead items') in		
		0.1.3	Effect on material behaviour, in particular metals: higher temperatures will lead to elongation ('uitzetten') and/or increase of	See above. In particular be aware of 'well growth'.	See above.		
		0.1.4	Effect on (selection of) measurement and logging tools (sensitive equipment).	Suitability of all components in well construction process due to worst case temperature effects. Consider using mudcoolers, extra mudcirculation, etc. to reduce temperature. Use field proven technology, concider simple/mechanical tools vs hydraulic and electronic components. Only wireline logging and LWD/MWD contractors with High Temperature capabilities should be invited and selected.	See above. Only wireline logging and LWD/MWD contractors with High Temperature capabilities should be invited and selected		
		0.1.5	Temperature impact battery performance and batterylife of MDW-equipment and other electrical devices.	Compatibility of batteries vs. temperature and use only fit-for-purpose equipment. Only wireline logging and LWD/MWD contractors with High Temperature capabilities should be invited and selected	See above.		
		0.1.6	Temperature impact on magnet performance and strength. Magnets are sometimes used in fishing equipment.	Compatibility of magnets vs. temperature and use only fit-for-purpose equipment.	See above.		
	Temperature effects on humans and environment.	0.1.7	Various effects due to hot surfaces on surface equipment (Note: higher than conventional wells), steam generation (mist, vapours), visual effects outside wellsite, breathing of vapours.	Proper personal protection equipment ('PPE') for personnel, wellsite preparation, anticipate effects to environment and neighbouring surroundings of wellsite. Dedicated temperature measurment devices on critical locations. Develop correct procedures.	Assess and incorporate correct procedures to safeguard personal protection, supply PPE means to all involved.		
		0.1.8	High temperatures may lead to changing of the density-profile over the well. Mudweight at surface may not be representative of mudweight downhole. ***NOTE: Density deviations may lead to well control incidents.***	Accurate knowledge and selection of drilling fluids type and properties under actual/expected conditions. Extensively test drilling fluids under actual downhole conditions. Develop correct procedures, e.g. assess circulation time to condition mud (may take several hours (>5 hrs, depending on bottoms-up time). Reduce Rate of Penetration (ROP), temperature profiling, density profiling.	Design and execute extensive mudtesting in close cooperation with mud service company. Incorporate and adhere to correct procedures.		
		0.1.9	High temperatures may lead to changing viscosity/yield point, sagging of weighting material, degradation of mud additives, other effects.	Accurate knowledge and selection of drilling fluids type and properties under actual/expected conditions. Extensively test drilling fluids under actual downhole conditions. Develop correct procedures, e.g. assess circulation time to condition mud (may take several hours (>5 hrs, depending on bottoms-up time). Reduce Rate of Penetration (ROP), temperature profiling, density profiling.	See above.		
	Temperature effect on cement.	0.1.10	High temperature may effect cement quality. Cement placement is critical for longevity of well: e.g. expansion of gas or fluids in pockets (inclusions) may lead to casing collapse; uncemented casing may expand and buckle.	Accurate knowledge and selection of cementing requirements and criteria, cement type properties and cementing procedures under actual/expected conditions. Extensively test cements, including washers/ spacers under actual downhole condition.	Extensively test cement composition under actual downhole conditions in close cooperation with cementing service company. Develop correct procedures (including top of cement, hole cleaning, spacers, centralisation,		
0.2	**PRESSURE (UDG-specific)**						
	High(er) pressures due to nature of UDG ('Ultra Deep').	0.2.1	Encounter high pressures in formations (or higher than expected) due to depth and/or abnormalities in formations or due to fractures/ faults. ***NOTE: (unexpected) pressure behaviour may lead to well control incidents.***	International industry standards (e.g. NORSOK, HPHT standards & guidelines, New Zealand GT standard, ISO, API, NOGEPA).	Incorporate applicable industry standards in planning and execution phases. Define worst case scenarios and mitigations. Assess potential overpressures due to pressure inclusions.		

		0.2.2		Fit-for-purpose' well control philosophy and select associated well control measures/equipment. Critically assess requirements for BOP's, downhole pressure management, APWD (Annular Pressure Measurements While Drilling) for realtime pressure control, ECD (Equivalent Circulating Density), MPD (Managed Pressure Drilling), UBD (Underbalanced Drilling), other.	Study pressure regimes, pressure and fracture gradients offset wells. Incorporate selected well control philosophy and well control measures/equipment. Include (longer) order times ('long lead items') in planning. Execute Driiling-Well-On-Paper ('DWOP') exercises. Perform 'test-drills' to be able to react swiftly with whole drilling team on abnormal situation(s).		
		0.2.3	Uncertainties of pressure ranges leading to incorrect pore pressure prediction in HPHT wells.	Assume large variations in actual pressures (both higher and lower) during drilling, develop contingency scenarios & mitigations and define equipment requirements for fast response.	Study pressure regimes, pressure and fracture gradients offset wells. Incorporate selected well control philosophy and well control measures/equipment.		
		0.2.4	Influx may occur due to higher than expected formation pressures, or loss of balance.	Availabilty of systems and equipment such as: Gas detection sytems, Early kick detection (HPHT procedure), including software to model fingerprint, accurate pitlevel monitoring. Mudlogging program, Early warning sysytem (Note: the 'D-exponent' does not work in carbonates, need shale layers (above carbonates)), well	Develop and apply suitable procedures for influx and well control scenarios. Execute HAZOP of all well control system and mudsystem/components. Perform 'test-drills' to be able to react swiftly with whole drilling team on abnormal situation(s).		
		0.2.5	Losses may occur due to lower than expected formation pressures, fractured or karstified zones.	Close monitoring and accurate monitoring equipment, lossed circulation scenario planning (including mitigation scenarios), LCM strategy (LCM, cement squeezes, GUNK	Develop and apply suitable procedures for lost circulation. Perform 'test-drills' to be able to react swiftly with whole drilling team on abnormal		
0.3	**DRILLING & GEOLOGY (UDG-specific)**						
	Formation strength uncertainty.	0.3.1	Uncertainties of formation strengths can lead to inadequate well design (e.g. shoe placement, gas filled well).	Design standards for exploration drilling/ characteristics (i.e: 'unknown teritory'). Plan for (setting) additional casing string(s) (for e.g. well control). Develop formation strength testing requirements and strategy.	Study pressure regimes, pressure and fracture gradients offset wells. Incorporate selected well control philosophy and well control measures/equipment. Plan for formation strength Inflow Test/FIT, Leak-off Test/LOT.		
	Integrity testing, pressure testing of well.	0.3.2	FIT/LOT/LIT difficult to obtain desired values. Procedures for FIT/LOT's at large depths: difficult to execute, difficult to interpret.	Procedures and HPHT expertise.	Design, incorporate and adhere to best suited testing procedures.		
	Integrity testing of barriers.	0.3.3	Integrity testing of barriers (pressure testing for barrier verification) difficult or impractical (may exceed limits).	Barrier verification philosohy (e.g. inflow testing (Horner test) instead of pressure testing).	See above.		
	Presence and release of H2S.	0.3.4	Release of H2S can lead to asphyxiation and death ***NOTE: Dinantian carbonate have known H2S potential. Note: QRA-contours are expected to extend (well beyond) the***	H2S assesment, H2S detection (Gastrain (gas garret)), training to personnel (incl. PPE such as escape masks, pressurized air), drilling fluidproperties to buffer H2S in the mud (scavenger) PH-control.	Execute QRA for potential release of H2S. Incorporate and adhere to correct procedures. Perform 'test-drills' to be able to react swiftly with whole drilling team on abnormal situation(s).		
		0.3.5	H2S is highly corrosive to steel.	H2S resistant materials in well design and contruction (casing and liners, seals, BOP's), surface equipment.	Addres potential presence of H2S in welldesign; if H2S present all materials need to be suitable for sour service (apply NACE (National Association of Corrosion Engineers) classification for steel.		
	Depth control inaccuracy (leading to encountering horizons at other levels than expected).	0.3.6	Formations can come in shallower or deeper and can lead to wrong mudweight. This has direct implication on wellcontrol and well design.	Continuous monitoring of formations, through mudlogging and M/LWD. Plan for contingency casings for wel control. Deploy VSP survey(s) to validate or update depthmodel. Close interaction between well operations and G&G staff. Plan for swift action on mudweight, pressure prediction, ECD control, MPD systems.	Include (variations in depth) into final well design (and scenarios) and associated drilling and evaluation procedures.		
		0.3.7	Formations can come in shallower or deeper and can lead to wrong placement of casing (shoe). This has direct implication on wellcontrol and well design.	Continuous monitoring of formations, through mudlogging and MWD/LWD. Plan for contingency casings for wel control. Use VSP survey(s) to validate or update depthmodel. Close interaction between well operations and G&G staff.	See above.		
		0.3.8	Target formation Dinantian shallower than expected.	Continuous monitoring of formations, through mudlogging and MWD/LWD. Use VSP survey(s) to validate or update depthmodel. Close interaction between well operations and Geofysical and Geological staff.	See above.		
		0.3.9	Target formation Dinantian deeper than expected.	See above. Be prepared to drill deeper. Have sufficient materials in stock.	See above.		
		0.3.10	Cuttings description hampered due to too fine cuttings: cuttings are milled and ground to very fine fraction and can get mixed up due to long well trajectory.	Alternative measurements and intermedient logging to keep track of gelogical situation in well in close interaction between well operations and G&G staff.	Implement strict geological tracking methodology in close interaction with geological support services/ on-site geologists.		
		0.3.11	Thickness of Dinantien (reservoir) more than expected.	Be prepared for deeper drilling, or stop sooner if economics of project allow. Have sufficient materials in stock in case of deeper drilling).	Prepare decision-tree on how to decide when well targets have, or have not, been achieved, and include scenarios.		
		0.3.12	Thickness of Dinantien (reservoir) less than expected (less productive zone).	Review options to encounter more target formation (e.g. increase angle ('horizontal'), well stimulation techniques,….). Might need sidtrack of original well, extra materials, langer duration, (significant) extra costs	See above.		
	Drilling problems to, near or in Dinantien.	0.3.13	Devonian formation below Dinantien could be charged, leading to influx and/or kick.	Pore pressure prediction and depth control. Be prepared for higher than expected pressures, wellcontrol measures.	See part 0.1 in this Risk Register on 'Pressure'		
		0.3.14	Drilling into fault zone may lead to higher than expected pressures; fault may be connected to other formation/pressure regime.	Good seismic mapping of faults, welltrajectory planning, be prepared for losses and/or influx. Wellcontrol measures. Pore pressure prediction and depth control. Be prepared for higher than expected pressures.	See part 0.1 in this Risk Register on 'Pressure'		
		0.3.15	Drilling into fault zone, may lead to losses.	As above.	See part 0.1 in this Risk Register on 'Pressure'		
		0.3.17	Drilling into fault zone may lead to borehole (in)stability issues (collapse, caving, stuck pipe).	Good drilling practices, drilling fluid engineering and maintaining of drilling fluid properties. Monitoring of parameters. Stuck pipe prevention training. Borehole stability studies (Geomechanics), stress caging techniques.	Design for and adhere to best drilling practices. Define worst case scenarios and mitigations.		
		0.3.18	Long well trajectories may lead to high torque and drag, which can harm driling equipment or prevent well to be finished.	In engineering phase well trajectory optimisation for torque and drag through simulation. Design welltrajectory and drilling equipment (rig, drillstring, stabilisers, torque reducers, etc.) to minimise torque and drag. In drilling phase monitor torque and drag, follow trends and compare to simulation results. Take additional measures if needed (e.g. mud additives).	See above. In well design phase: execute torque&drag simulation and welltrajectory optimisation. In drilling phase: closly monitor torque&drag bahaviour.		

	Coring in deep wells needs special expertise.	0.3.19	Trapped pressure in core barrel.	Follow best coring practices. : Pressure release at shallow levels, the last couple of 100 m and shallower is important. (This is typically implemented at stopping at 200 m, 100 m, 50 m and 25 m for 30 min-1 hr to release the trapped pressure in the core. Do not have deeper stations than approximately 200 m, as these do not really add to the risk reduction.)	Design, incorporate and adhere to coring equipment and procedures in close corporation with coring service company.		
		0.3.20	Gas expansion in cores.	Follow best coring practices, control pulling-out speed.	Same.		
	Logging in deep wells needs special expertise.	0.3.21	Trapped pressure in logging equipment (applies to fluid sampling tools and sidewall coring tools).	Follow best logging practices.	Design, incorporate and adhere to logging equipment and procedures in close corporation with logging service company.		
0.4	**WELLTESTING (UDG-specific)**						
	Well testing at high temperature.	0.4.1	Temperature impact on well testing equipment and other devices (e.g. perforating guns).	Compatibility of well testing equipment, use only fit-for-purpose equipment.	Design, incorporate and adhere to well stimulation equipment and procedures in close corporation with well stimulation service company.		
	Blockages of piping, valves, equipment due to scaling.	0.4.2	Handling of salt saturated fluids on surface, cooling may lead precipitation of salts/other solids (scaling in coolers).	Anticipate effects of salt precipitation in surface equipment, continuous cleanup, availibility of backup or auxiliary equipment.	Design and select equipment and procedures, including NORM.		
	Hot surfaces, liquids (brine) and gasses (steam) may pose risk to personnel.	0.4.3	Generation of steam/ vapours from welltest outlet and production storage basins may lead to personal injury, burns.	All areas with hot fluids, steam barriered off (no-go areas); personnel to keep clear of risk areas.	Assess and incorporate correct procedures to safeguard personal protection, supply PPE means to all involved.		
	Hot surfaces, liquids (brine) and gasses (steam) may pose risk to outside perimeter.	0.4.4	Generation of steam/ vapours from welltest outlet and production storage basins may lead to visibility restraints (mist) and possibly	Plan welltest in conjunction with weather conditions, warn surrounding neighbours. Plan to limit disturbances. Further mitigations depending on more precise wellsite	Investigate mitigation actions, engage stakeholders.		
	Transport and temporary storage of (hot) well test fluids.	0.4.5	Well test fluids need safe temorary storage facilities when flowing from well test equipment, requiring seperate surface area and/or trucking of fluids to other storage area. Due to high temperature of fluids, this is more complex than conventional geothermal well testing.	Availability of sufficient well testing fluids storage space, either on drilling location or in vicinity (e.g. trucking or piping).	Anticipate on well testing when designing well location (and lay-out thereof), or have alternative at hand (e.g. trucking or temporary pipeline). Ensure proper environmental protection and procedure(s) is in place (e.g. to prevent leakage, clean-up). Also here, effects to reduce steam generation is of importance (vapours, 'visibility').		
0.5	**WELL STIMULATION (UDG-specific)**						
	High pressure stimulation (if 'standard' well testing does not give expected results). ***NOTE: High pressure stimulation may require significant efforts (incl.***	0.5.1	Very low or no positive results from (conventional) well testing process.	Application of well stimulation techniques. Have sufficient equipment and materials on call-off.	Be prepared to apply well stimulation techniques. Prepare decision-tree on how to decide when well stimulation is required, and with which technology (incl. duration, intensity, lenghts, etc.).		
		0.5.2	Activating fault(s) leading to local seismic activities leading to potential (local) damages and/or public disturbances.	Proper engineering of well stimulation plan. Installation of seismometers, Seismic Risk Action plan.	Design, incorporate and adhere to well stimulation equipment and procedures in close corporation with well stimulation service company.		
0.6	**PERMITTING (UDG-specific)**						
	No or late permit(s) issued by official authorities.	0.6.1	Delay due to waiting on permit(s), or no permit(s). E.g. longer than expected Environmental Impact Assessment(EIA/'MER') procedure. ***Note: multiple official authorities ('Bevoegde Gezagen') are invoved in submitting permits based on legal obligations (i.e. Ministries, Province, Local Government ('Gemeente),***	Follow correct permitting applications and associated preparations (such as an EIA/MER), once location is known. Due to specific nature of the UDG-project ('new'), anticipate on more (rigid) preparations, multiple information sessions, but also court-procedures up to Council of State/ 'Raad van State'. ***Note: Ministry of Economic Affairs (as official authority under the Dutch Mining Act) to consider following special procedure to***	Study required permitting applications and associated preparations (such as an EIA/'MER'), once location is known and follow-up as soon as possible. Involve Ministry of Economic Affairs, and other official authorities, at earliest moment. Initiate communication strategy.		
		0.6.2	Delay due to additional queries by authorities or, e.g. State Supervision of Mines (SSM). Focus by SSM is onto geothermal sector as a whole, for UDG in particular. **Note: SSM is executing its own Risk Assessment related to UDG (2018/2019).**	Very thorough well engineering process anticipating worst case temperature and pressure effects. Traceable QA/QC process. Regular contact and updares to relevant authorities. Assess findings of SSM Risk Assessment into UDG (expected Q3 2019).	Follow best engineering practices and detailed preparations and internal cross-checks. Develop and implement international based QA/QC system(s) (e.g. ISO 9000, 14000, 45000). Inform all stakeholders on regular basis. Avoid miscommunication. Incorporate findings of SSM UDG Risk Assessment into well design and drilling		
		0.6.3	H2S and QRA contours could be much larger in diameter than an 'standard' well.	Alternative location. Execute 'quick-scan' on external effects (so outside drilling location), once location is known. This might lead to a change in location selection.	Execute 'quick-scan' on external effects (so outside drilling location), once location is known, prior to starting up formal permitting process. Have alternative location(s) available.		
0.7	**OTHER UDG-SPECIFIC**						
	UDG-specific Seismic phase (if needed).	*0.7*	*NOT ASSESSED.*	*NOT ASSESSED.*	*NOT ASSESSED.*		
	UDG-specific Production phase (in close conjunction with Injection	*0.7*	*NOT ASSESSED.*	*NOT ASSESSED.*	*NOT ASSESSED.*		
	UDG-specific Injection phase (in close conjunction with Production	*0.7*	*NOT ASSESSED.*	*NOT ASSESSED.*	*NOT ASSESSED.*		
	UDG-specific Monitoring phase (during life-time of wells).	*0.7*	*NOT ASSESSED.*	*NOT ASSESSED.*	*NOT ASSESSED.*		
	UDG-specific Welll Maintenenance/ Intervention phase (e.g. after 5-10-20-30 years, or in case of unforseen situations).	*0.7*	*NOT ASSESSED.*	*NOT ASSESSED.*	*NOT ASSESSED.*		
	UDG-specific Abandonment phase.	*0.7*	*NOT ASSESSED.*	*NOT ASSESSED.*	*NOT ASSESSED.*		
	UDG-specific (external) Communication.	*0.7*	*NOT ASSESSED.*	*NOT ASSESSED.*	*NOT ASSESSED.*		
	UDG-specific Financial/ Economical considerations.	*0.7*	*NOT ASSESSED.*	*NOT ASSESSED.*	*NOT ASSESSED.*		