Risk Management and Contingency Planning for the First Icelandic Deep Drilling Project Well in Krafla, Iceland

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Location of first IDDP Well: Krafla
Risk Assessment and Evaluation

Analytical elements of this risk assessment:

- Identification of initiating events
- Qualitative evaluation of possible causes
- Probability analysis in order to determine the probability of certain scenarios
- Consequence analysis and according mitigation and action plans

<table>
<thead>
<tr>
<th>Probability</th>
<th>0-20%</th>
<th>20-50%</th>
<th>51-75%</th>
<th>76-85%</th>
<th>86-100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>very unlikely</td>
<td>unlikely</td>
<td>likely</td>
<td>very likely</td>
<td>almost sure</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact Factor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>negligible</td>
<td>minor</td>
<td>serious but tolerable</td>
<td>major</td>
<td>hazardous to whole project</td>
</tr>
</tbody>
</table>
Overview

Geological Risks

- Volcanic Activity
- Earthquake Activity
- Low Productivity

Drilling Risks

- High Temperature Environment
- Circulation Losses
- Coring Operation
- Casing Failure

Conclusions

Perspectives
Geological Risk: Volcanic Activity

- Eruption history gives estimate of long-term probability of renewed activity: eruptive phases are episodic, in 250-1000 year intervals, (each eruptive phase is apparently lasting 10-20 years)

- Geodetic measurements: indicate relatively uniform strain accumulation along the length of the plate boundary in north Iceland
  - Askja segment is considered as the likely location of renewed activity

- Krafla system is considered comparatively safe for utilization during this century

- Ash-fall from distal volcanoes cannot be excluded, but large plinian eruptions are rare.

- Krafla is out of reach of catastrophic floods due to volcanic melting of glacier ice
Assessment

Probability: less than 20% - Impact factor: 5

- **Prevention**: monitoring natural manifestation and seismic activity
- **Contingency plan**: from securing well and drill rig up to abandon drill site
Geological Risk: Earthquake Activity

- Seismic monitoring system (in operation since 1994): seismic activity within the region has remained low, largest earthquake registered: 2.6 on the Richter scale
- Accumulated stresses in the region have been released
- Significant duration as a function of distance to surface for different earthquake magnitude values ➔ ca. 10 sec

(Björnsson et al., 2007)

Measured earthquakes (M ≥ 3) in the NE-region from 1930 to 2000 (Björnsson et al., 2007)
Assessment

Probability (for Magnitude above 3): less than 20% - Impact factor: 4

- **Preventive measures**: monitoring seismic activity and fault movements
- **Contingency plan**: from securing well and drill rig up to abandon drill site
Geological Risk: Low Productivity

- Permeability in Vitismor field is above average
- Brittle-plastic transition zone constrains the maximum depth of fracturing
- Possible limit of fractured zone in Krafla at 4-5km depths
Probability: 50% - Impact factor: 4

- **Consequence**: impermeable formation ➔ No discharge of supercritical fluids
- **Mitigation measures**: investigation of upper permeable zones
- **Contingency plan**: side tracking, applying reservoir enhancement techniques (hydraulic or thermal stimulation)
Drilling Risk: High Temperature

- **Hazard description**: Damages to drill bit, mud motors, drill string, mud gelation, thermal balance of circulation, logging tools

- **Consequences**: Low rate of penetration, delay in drilling process, increasing costs

<table>
<thead>
<tr>
<th>Tools / Materials</th>
<th>Temperature Limitations [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downhole Motor Sator Rubbers</td>
<td>175-200</td>
</tr>
<tr>
<td>Seal Materials</td>
<td>150-190</td>
</tr>
<tr>
<td>Steering Equipment</td>
<td>175</td>
</tr>
<tr>
<td>Mud Dispersant</td>
<td>250-300</td>
</tr>
</tbody>
</table>

modified after Saito et al. (1998)
Assessment

Probability: 65-75% - Impact factor: 3

- **Counteractive measures**: cooling well with cooled drilling fluid, maintaining a sufficient rate of circulation, high temperature resistance material

- **Contingency plan**: different material selection, additional cooling capacities
Drilling Risk: Circulation Losses

- **Hazard**: partly or total loss of drilling fluid, steam kick hazard, possible at any depth
- **Consequence**: Stucking of the bottom hole assembly, loosing ability to cool drilling equipment/well

Assessment

Probability: 80% - Impact factor: 4

- **Mitigation measures**: analyze historic drill data to predict possible circulation loss zones

- **Contingency plan**: using polymers instead of water; Barite plug, cementing
Drilling Risk: Coring Operation

- **Hazard**: reduced circulation \(\Rightarrow\) getting stuck in hole, damages the coring equipment, kick and blow hazard

- **Consequences**: Low rate of penetration, delay in drilling process, increasing cost, loss of scientific data

(Thorhallsson, 2008)
Assessment

Probability: 60-75% - Impact factor: 1

- **Mitigation measure**: applying the new coring barrel with increased fluid circulation capacity
- **Contingency plan**: stop coring process and continue with conventional drilling
Drilling Risk: Casing Failure

- **Hazard**: Casing breakouts, deformation or collapse

- **Consequences**: Delay of drilling process, increase of costs

- Chosen corrosive resistance alloys and high-strength steel are appropriate
Assessment

Probability: 30% - Impact factor: 4

- *Mitigation measures*: strict inspections on material and welding process, strict vertical drilling
- *Contingency plan*: fishing back casing, cement plug and side tracking, maintaining appropriate bending radius
Conclusions

- The natural geological risks arising from volcanic and seismic activity as well as meeting sufficient permeable zones are considered as comparatively minor important factors to the well completion process due to their low probability.

- The main risks are assessed in the hazard of meeting circulation loss zones and material failures due to the high temperature environment.

- In addition borehole failure, formation fracturing, cement and casing failure as well as problems during coring operations are assessed to be likely, but by applying the appropriate techniques as well as mitigation and counteractive measures most of these risks can be reduced or prevented.
Perspectives

- Lack of reliable data limits the risk assessment (for depths exceeding 2 km)
- Investigate rock properties with the help of core samples are essential
- Stress field, rock permeability, thermal conductivity, geochemical data is of particular interest
- A detailed digital reservoir model helps to understand the behaviour and interactions of the different reservoirs, flow regimes and location of magma chamber and intrusions.
THANK YOU VERY MUCH FOR YOUR ATTENTION!

IDDP-1 drillsite in December 2008