SAGA REPORT 2006

EXECUTIVE SUMMARY

SAGA met after a half day of presentations concerning issues relevant to the IDDP and the current status of drilling at Reykjanes, Hellisheidi and Krafla (see Appendix 1).
The committee strongly supports the main objective of the IDDP which is to investigate and explore the economic feasibility in producing energy and chemicals from geothermal systems at supercritical conditions. Since our last SAGA meeting (2004) our priorities have not changed, the difference being that we lost well RN-17 from the list of wells of opportunity and that developments in other drill fields have opened up new opportunities. However, given the long lead times in ordering casings and valves etc. and securing the services of a drill rig it now seems unlikely that drilling by IDDP could begin in 2006.

A number of exciting possibilities for the development of IDDP are now under discussion. The committee considered the prospect of taking over wells at Reykjanes and Hellisheiði and/or drilling new wells there or at Krafla (see Appendix 2 for the advantages and disadvantages of deep drilling in each of these fields). However, the overall consensus of the committee was to recommend continuing at Reykjanes in the immediate future by taking over a new well of opportunity, provided that this well is within the up-flow zone (such as RN-19), for deepening to 4000 m. At that point a decision could be made to deepen and core that well to 5000 m or possibly to deepen a well at Krafla or in the Hellisheidi area. However, the committee wishes to reaffirm the long term objectives to drill and core deep wells in all three fields.

This recommendation was passed on the same day (14:00-16:00, April 27) at a meeting between the PI's (GÓF & WAE) and the DeepVision Committee (AA not present). The DeepVision committee strongly urged the PI's to reconsider the recommendation of the SAGA committee, and to consider other drilling options that would be optimized for success in other geothermal fields. The result of this discussion was: drilling a new deep well at Krafla in 2006/2007 should be a higher priority than deepening or drilling a new well at Reykjanes.

From 16:00-18:00, the PI's and members of the DeepVision Committee (BS, HTul), met with Ulrich Harms of ICDP and Leonard Johnson of the US NSF. After briefing these representatives of the science funding agencies, the conclusion was that, as long as the PI's remained focused on the major scientific goals of the project, moving the site of the first IDDP well to another geothermal field should not impact the science funding.

INTRODUCTION

The loss of the well RN-17 as a candidate for deepening at Reykjanes requires us to revise earlier plans, but also creates an opportune moment to review the current overall status of the IDDP and to recommend plans for the short, intermediate and long-term future. The IDDP is an ambitious undertaking with the overall objective of enhancing the power output of geothermal wells by exploiting the deeper, supercritical part of hydrothermal systems. This will require drilling wells in the depth range of 4 to 5 km to reach temperatures in the 400-600°C range. In December 2003 Hitaveita Sudurnesja offered well RN-17, then being planned on the south side of the Reykjanes geothermal borefield, to the IDDP for deep drilling and coring. This well was subsequently drilled to approximately 3.1 km depth, but became plugged during a flow test in November 2005. Attempts to recondition the well in February 2006 failed due to caving of the formation and it was concluded therefore that this well must be abandoned.

Since December 2003 a number of important developments have occurred that change the environment for planning future developments of the project. Firstly, Hitaveita Sudurnesja hf (the Sudurnes District Heating company Ltd), the Landsvirkjun (the National Power Compnany), Orkuveita Reykjavikur (the Reykjavik Energy company), and the Orkustofnun (the National Energy Authority - a government agency), signed a formal contract that describes the terms under which these entities will collaborate to manage the IDDP and fund the first deep well. Secondly, the pace of development of geothermal resources in Iceland has accelerated enormously with 100 MWe of new production coming on line at Reykjanes, 90 MWe at Hellisheidi to come on line in September 2006, and contracts being negotiated to supply electricity to a 250 kt/yr aluminium smelter near Husavik. These developments have led to the drilling of many new production wells at Reykjanes and Hellisheidi, with more planned in the next few years at these sites and at Krafla.. The third development is that the international scientific community has become deeply involved in the IDDP and significant funding has been secured from the International Continental Scientific Drilling Program (ICDP) and from the US National Science Foundation (NSF) to obtain drill cores from the deep well.

These developments create new opportunities and require reassessment of the priorities of the project in the short, medium and long term. Additional factors since 2003 that impact planning for drilling in Iceland today include (a) the sharply increased cost of drilling services and well completion materials on the worldwide market, (b) the long lead time in obtaining valves and casings (6-9 months), (c) the availability of drill rigs in view of the increased level of drilling, (d) the decline in the exchange rate between the US $ and the Icelandic krona.

The committee used the following criteria in its deliberations:

> Optimize the chances of reaching supercritical conditions with reasonable permeability by appropriate selection of a drillsite. Achieving that goal will meet the economic and the scientific objectives of the IDDP.

Maintain the momentum of the project at Reykjanes, while simultaneously probing the options made available at Hellisheidi and Krafla. We anticipate deep drilling in all three geothermal areas once more funding becomes available**.**

THE OPTIONS CURRENTLY CONSIDERED

KRAFLA

The Krafla East field is well established and 34 boreholes have been drilled so far to a maximum depth of 2.2 km. The wells produce steam for the existing 60 MW power plant and there are plans to enlarge the plant to 100 MW and to develop another production field within the area Krafla West.

S-wave shadows, microearthquakes and MT surveys confirm that a magma chamber is present at about 3.5 to 7 km depth within the caldera under the Krafla field. This magma chamber was last recharged during the Krafla eruptions (1975 to 1984), with repeated injections of dikes into the fissure swarms north and south of the caldera. The highest temperatures and the best permeability have been found in wells intersecting the volcanic Hveragil Fissure. The fluid temperature in the deep geothermal reservoir drilled so far follows the boiling point to depth curve. Highest recorded temperatures are about 340°C. If the system is two phase to deeper levels, supercritical temperatures should be expected to be found at less than 4 km.

The National Power Company which operates the Krafla Field has suggested that a deep well could be drilled at Leirbotnar just north of the power house. Another site that might be considered is just north of the explosive crater Víti where the exploratory well number 2 was originally to be drilled. This site would be expected to intersect brecciated rocks and encounter favorable permeability on top of the magma chamber. Both these sites were recommended in the Feasibility Report.

Available evidence suggests that the reservoir fluid will be dilute and limited scaling and corrosion problems are expected, unless the well encounters a high flux of magmatic gases.

SAGA recommends:
That a deep well targeted to 4-5 km depth should ideally be designed with a wider casing program than existing wells at Krafla, as recommended in the Feasibility Report for the IDDP wells. To better understand the structure of this geothermal field, we recommend that an attempt be made to map active faults using microearthquakes and to improve the knowledge of the resistivity structure by a combination of additional MT and TEM soundings. A compilation of all available data on wells close to the proposed sites for IDDP drilling is recommended.

HELLISHEIDI

At Hellisheidi, on the other site of the Hengill volcano from Nesjavellir, there are at present some 20 new wells drilled in the last few years for steam production to produce 90 MWe. Many of these wells are directional wells and the earlier of the wells were finished by 8 ½" production hole and 7" liner. Since HE-10 was drilled, many of the wells have a wider casing program, finished by 12 ¼" hole and 9 5/8" slotted liner, and some of them are directional wells.

IDDP was offered well HE-10 to consider as a potential well of opportunity, which could be made available within the next few months – if the need arises. The well is 2,200 m deep, the production casing reaches to 700 m depth and the quality of the cement appears acceptable. A slotted hanging liner, 9 5/8" wide was inserted. The last down hole temperature log was done in December 2004, and at that time it was clear that the well had not recovered thermally since drilling. The bottom hole temperature was about 210°C at 2,200 m. During attempts to flow test the well in 2005, a piston and 300 m long cable were lost in the hole. This has prevented new temperature logs from being made, so uncertainty about the true bottom hole temperature exists. The piston and the cable need to be removed from the well so that the temperature can be logged. If this drillhole qualifies as a well of opportunity for deepening, the slotted liner would first need to be removed, and then the well should be deepened to 2,500 m, before cementing a 9 7/8" IDDP casing.

He-10 located within an area with volcanic fissures 10,300 and 2,000 years old. A feature of the Hellisheidi temperature distribution with depth is a prominent temperature reversal below 1 km depth in many of the wells, including well HE-10. The depths to temperatures approaching the boiling point curve at say – 3.5 km depth is not known yet. If the bottom hole temperature does not approach 300°C at 2,500 m depth, there would be some doubt that the well is suitable for deepening by IDDP. However, there are new wells several km away both SE and SW of well HE-10, which have temperatures well above 300°C at 2 km depth, and a new model of the temperature distribution at Hellisheidi needs to be looked at closer before IDDP can comment much further. A new conceptual model of the Hellisheidi reservoir system was presented at the SAGA meeting, but it did not clarify in detail the most likely scenario for the temperature distribution at deeper levels below the current depth of HE-10.

New wells will be drilled at Hellisheidi this year and next, and some of these may possibly be considered as wells of opportunity for IDDP to deepen. Available evidence suggests that the reservoir fluid will be dilute and limited scaling and corrosion problems are expected.

SAGA recommends:

That IDDP keep the possibility open for deepening a well at Hellisheidi in the near future, while HE-10 is reconditioned. The overall temperature distribution should be studied closer and the resulting model communicated to the IDDP. A deep well targeted to 5 km depth should ideally be designed with a wider casing program than existing wells at Hellisheidi, as recommended in the Feasibility Report for the IDDP wells.

REYKJANES
The consensus of the SAGA committee is to make continuation of deep drilling in the Reykjanes field the highest priority for the immediate future. The loss of RN-17 as a well of opportunity does not change the scientific rationale for deep drilling at Reykjanes, although it will likely change the drilling schedule. Our recommendation is to proceed with deepening and casing a well within the up-flow zone, as near as possible to well RN-12 to 3 km, followed by drilling and spot coring of the well to 4 km. This well would be a candidate for drilling with continuous core to 5 km during phase 3 of IDDP. RN-16 is sufficiently far from the upflow zone to be ruled out as a candidate for deepening. Hitaveita Sudurnesja cannot release wells in the up-flow zone such as RN-19 for at least 6 months, while the steam supply for the power plant is being evaluated (see table in Appendix 3 and the report ISOR-2006/008, by G.O.Fridleifsson and W.A.Elders "Criteria for selection of a well at Reykjanes for deepening by the IDDP, 21 p.").

The following factors were considered as advantages in continuing the next phase of drilling at Reykjanes. This is a well established and productive geothermal field with significant geological and geophysical data to support interpretation of deep drilling results. There are several wells within the up-flow zone that could potentially be available for deepening, including RN-19, RN-13, and RN-15. Drilling at Reykjanes could likely occur as soon as well casing, hardware and drillrig are available and will therefore continue the momentum of the IDDP. Funding for coring and scientific studies at Reykjanes has already been secured from ICDP and NSF. Scientific investigations of cuttings and core from the Reykjanes field have already been started by an international team of scientists. Reykjanes is the only high-temperature, seawater-recharged geothermal system on a mid-ocean ridge that is available for deep drilling anywhere in the world. International interest and support for this drilling is high among scientists working on seafloor hydrothermal systems and ore deposit genesis.

The Reykjanes field also presents several disadvantages and challenges that were considered in making our recommendation. The high salinity, dissolved metal and sulfide load in the Reykjanes system increase the potential for corrosion and scaling problems compared with fields recharged by fresh water. The critical point for seawater salinity fluids will be reached at approximately 37°C higher temperature than for pure water, and the critical pressure is elevated by some 80 bar. Therefore drilling at Reykjanes may require deeper drilling compared with low salinity systems. The design of the wells that could be available for deepening is not the optimum design recommended in the Feasibility Report.

SAGA recommends :
That we proceed with deepening and casing a well within the up-flow zone at Reykjanes, as near as possible to well RN-12, to 3 km, followed by drilling and spot coring of the well to 4 km. This well would be a candidate for drilling with continuous core to 5 km during phase 3 of IDDP.

CONCLUSIONS

The short term (~1 year) recommendation of SAGA is to request that Hitaveita Sudurnesja release to the IDDP a well close to the center of the up-flow zone of the Reykjanes geothermal system, and that this well be deepened to 4000 m with spot coring. In the intermediate term (~ 1 - 3 years), if the results of this deepening are favorable and suggest that supercritical conditions are reachable, this well should be deepened by slim hole, continuous coring as was intended for RN-17. If not, further drilling by IDDP should move to one of the other geothermal fields. In the longer term (~ 3 - 6 years) preparations should be made, and funds sought, for a second and third deep well in the search for supercritical conditions in each of the other two geothermal systems discussed above.

MINUTES OF THE DEEP VISION MEETING, 27 APRIL, 2006

The meeting was held at Orkugardur, from 14.00 until 16.00, with all of the members of Deep Vision present, except for AA, together with GOF, WAE and STh.

The PI's presented the recommendations of the SAGA Report that was prepared as a result of the meetings held on 26th and 27th April. The first recommendation from SAGA was that the IDDP in the short term should request that Hitaveita Sudurnesja make available an existing well in the up-flow zone at Reykjanes as a replacement for RN-17, for the IDDP to deepen to 4 km with spot coring. In the intermediate term, if the results of this drilling are favorable, the IDDP would then deepen this well to 5 km with continuous coring, as was planned for RN-17. In the longer term the IDDP should plan and seek funding for deep drilling in the other two geothermal fields under consideration.

The members of Deep Vision challenged the first two of these recommendations, stressing the following points:-

(1) If funding, now, and in the future, only allowed IDDP to drill ONE deep well, would the recommendation be the same?

(2) The decision to deepen RN-17 was made in 2003 because it was the only option available to proceed at that time. Today we have the contract between the energy companies and the Government that opens up the possibility of drilling a well entirely for IDDP rather than taking over an existing well. Thus there is no financial benefit in taking over an existing production well. Drilling a new well has the advantage of allowing the choice of better locations and using well designs and casing programs better suited for deepening a well.

(3) The Feasibility Study ranked Nesjavellir first, Krafla second and Reykjanes third in order of priority. Now that Nesjavellir must be removed from consideration for environmental reasons, Krafla should be drilled before Reykjanes.

(4) We know enough about Krafla to proceed to site a deep well there and Krafla has a more favorable fluid chemistry for reaching supercritical conditions at lower P-T.

(5) An industrial company may be interested in participating in deep drilling at Krafla.
(6) Given the at least 6 months delay before decision can be made on RN-19 (or another well) at Reykjanes, the long lead time in delivering casings and valves, and the other commitments of drilling rigs in Iceland, preparation and drilling of a new well at Krafla could begin just as soon as could deepening an existing well at Reykjanes.

The issue was raised about how proposing to move the IDDP drilling to Krafla might affect the scientific objectives and funding from the science agencies ICDP and the US-NSF. The science program has already commenced study of samples from the shallower part of the Reykjanes system, and because of its location, structure and fluid chemistry, the Reykjanes Peninsula is a better analogue of mid-ocean ridge spreading centers.

The conclusion of this meeting was that drilling a new deep well at Krafla should take precedence over deepening or drilling a new well at Reykjanes. As mentioned in the Feasibility Report, a location at the drill pipe storage site at Krafla would be an excellent choice. Similarly options at Hellisheidi should remain on the table, although selection of a site for deep drilling there would need further study.

REPORT OF SUBSEQUENT MEETING BETWEEN THE PI's, REPRESENTATIVES OF DEEP VISION, THE ICDP AND THE US-NSF, APRIL 27th 2006

The issue of science funding was addressed in a subsequent meeting held from 16.00 to 18.00 that followed immediately after the Deep Vision meeting. Attending this meeting were the PI's, BS, HTul, Ulrich Harms of the ICDP, Potsdam, Germany, and Leonard Johnson of the National Science Foundation, Washington DC, USA.

The representatives of the funding agencies concurred that the vital point was that the project should maintain its focus on direct exploration of high-temperature geothermal systems in Iceland in search of supercritical conditions. If this were done, moving the deep drilling site to Krafla, or elsewhere, would still be regarded as being within the terms of the existing financial awards, and should not require resubmission of proposals through the review process. However both representatives indicated that it would be unlikely that their agencies would be able to award incremental funds.

In response to questions from the agency representatives, the PI's expressed the opinion that the science that could be done on a deep well at Krafla would be of great interest to the worldwide scientific community. It would also be relevant to understanding oceanic hydrothermal systems, however not so directly as would be the case at Reykjanes. They would therefore explore the possibility of drilling at Krafla in 2006/2007 as an alternative to drilling at Reykjanes or Hellisheidi.

APPENDIX 1 : MEETING AGENDA

Open Meeting at Víðgelmir
Wednesday 26 April 2006

8:00	G. Ómar Fridleifsson	IDDP Status Report and options for drilling 2006-2007
8:30	Wilfred A. Elders	What do we need from this SAGA meeting
8:50	Arnar Hjartarson	Temperature and reservoir model of Reykjanes
9:10	Grímur Björnsson	Temperature and reservoir model of Hellisheidi – Hengill area
9:30	Árni Gunnarsson	Current development plans for Krafla
	9:50 --	Coffee break -- 10:10
10:10	Knútur Árnason	Magneto-telluric - surveys – potential significance for IDDP
10:30	Kristín Vogfjörð	Seismic interpretation of fracture planes - significance for IDDP
10:50	Andri Stefánsson	Supercritical saline fluids – significance for IDDP at Reykjanes
11:10	Robert Zirenberg	Drilling black smokers – view from central science team
11:25	Sverrir Þórhallsson	Integrity of Reykjanes drillholes with respect to IDDP
11:45	Sveinbjörn Björnsson	- Review and Open discussion –

12:45 – Lunch break – 14:00

Closed Meeting at Skúti

14:00-17:00 SAGA discussion, recommendation, report writing

Thursday 27 April 2006

9:00-12:00 **SAGA r**eport and meeting completed
- Adjourn –

14:00-15:30 **SAGA report presented to DeepVision**

16:00-18:00 **PI & DeepVision meeting with ICDP and NSF**

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SAGA members present:	DN, GOF, JOB, KI (for RM), SA, SvB, VKJ, VS (partly), WAE;
Also at the SAGA closed meeting:	STh and RZ
SAGA members absent	AS & RF (sent written comments), GC
Deep Vision present:	BS, EG, HTul
Deep Vision excused:	AA

40~50 people from the energy consortium and other institutes attended the open part of the SAGA meeting Wednesday morning and participated in the presentations and the discussions.

APPENDIX 2 :

Comparison of four geothermal fields

Reykjanes

Advantages:

1 Well established geothermal field
2 RN-16 available, and possibly others
3 Scientific studies are already underway
4 ICDP and NSF have already committed funds
5 Analog situation with black smokers
6 Pressure maintenance of the system due to seawater recharge

Disadvantages:

1 Potential scaling and corrosion
2 Supercritical P-T conditions are higher than in the dilute systems and may not be within drillable depths
3 The design of the wells is not optimal for deepening as a production well
4 RN-16 is not suitable in terms of temperatures and location

Krafla

Advantages:

1 Well established geothermal field
2 Interest to develop the field further by more drilling
3 Dilute fluid
4 Limited scaling and corrosion expected
5 Higher thermal gradient
6 Possibility of additional funding from an industrial company
7 Chance of drilling optimal design by a new well from the beginning
8 Injection wells available

Disadvantages:

1 No well available for deepening
2 Possibly of less interest to the international scientific community
3 Weather conditions harsher (summer operation preferable)
4 More likelihood of granophyric rocks at depths (ductile at lower temperatures)
5 Possibility of encountering acid magmatic gases

Hellisheidi

Advantages:

1 Large geothermal system
2 Well HE-10 available – wide diameter well
3 Injection wells available
4 Dilute fluid
5 Limited scaling and corrosion expected

Disadvantages:

1 Drilled through 250-260°C zone and reversal to 220-230°C bottom hole
2 Less interest to the international scientific community
3 More likelihood of granophyric rocks (more ductile) at depths
4 Response to production load not known

Nesjavellir

Advantages:

1 Well established geothermal field
2 Supercritical conditions encountered in NJ-11 at Nesjavellir

Disadvantages:

1 Field not available to IDDP
2 Environmentally sensitive
3 Injection wells not available

APPENDIX 3:

Comparison of wells at Reykjanes

Well	Depth	Temp.	Injectivity II	Productivity PI	Potential availability to IDDP	Priority for deepening by IDDP
name	(m)	(°C)	(kg/s/bar)	(kg/s/bar)	Comments	Ranking
RN-10	2054	310	6.6	2.3	Attractive due to high temperature. May become available due to difficult chemistry. Broken liner.	High
RN-11	2248	293	>10	10	Dedicated for production.	n.a.
RN-12	2506	290	8-9	20-40	Dedicated for production.	n.a.
RN-13	2457	285	4-5	1-2	May become available due to low wellhead pressure.	Medium
RN-14	2306	290	6-7		Dedicated for production.	n.a.
RN-15	2507	280	4	1	May become available due to low wellhead pressure.	High
RN-16	2627	200-306	2		Has been offered to IDDP. Located on reservoir margin.	Low
RN-17	3082	250-260	<1		Collapsed in open hole and has a fish. No longer suitable for IDDP.	n.a.
RN-18	1815	>285	5.4	1.5	Dedicated for production.	n.a.
RN-19	2245	260-275	5		May become available due to low wellhead pressure.	High
RN-20	2126	250-280	2.5		Collapsed well casing. Not suitable for IDDP.	Low
RN-21	1713	>274	13	6	Dedicated for production.	n.a.
RN-22	1680	304	10	13	Dedicated for production.	n.a.
RN-23	1924		38-49		Dedicated for production. Directionally drilled.	n.a.
RN-24	2114	>275	10-20	38	Dedicated for production.	n.a.

n.a. Not available