

Electricity Production from Hot Rocks

The European Hot Dry Rock Research Project at Soultz-sous-Forêts

T. Hettkamp^{*)}, J. Baumgärtner^{**)}, R. Baria^{*)},
A. Gerard^{*)}, T. Gandy^{***)}, S. Michelet^{*)}, D.
Teza^{***)}

*) EEIG "Heat Mining", Kutzenhausen, France

**) BESTEC GmbH, Kandel, Germany

***) BGR, Hannover, Germany

****) Gandy Inc., Ringling OK, USA

ABSTRACT

The geothermal research program for the extraction of energy from hot fractured rocks started at Soultz-sous-Forêts in 1987. The test site is located in France on the western edge of the Rhine Graben, some 50 km north of Strasbourg near the German border. The basement, granite, at Soultz lies beneath app. 1400 m of sedimentary rock; the fracture network in the granite has been explored down to 5000 m depth, where temperatures exceed 200°C.

A first successful forced circulation test of several months duration has been performed in 1997 between two wells in the depth range of 3000 m to 3500 m. This test demonstrated the validity of the "Hot Dry Rock" concept.

Following this experience, an industrial consortium, an European Economic Interest Grouping called "GEIE Exploitation Minière de la Chaleur" ("Heat Mining"), was created bringing together five partners from the energy world. The aim of this consortium is to develop the Hot Dry Rock Technology to a stage at which the sub-surface heat can be used for commercial electricity production. Under the leadership of the "GEIE Exploitation Minière de la Chaleur", since mid 2001 a scientific pilot plant is being established in Soultz.

This scientific pilot plant will use a total of three boreholes of 5000 meters depth each, one injection well and two production wells. All three wells are drilled from the same platform. The wellheads are separated by not more than 6 m. Two out of the three wells will be drilled directionally. Between 4500 – 5000 m depth, the open hole section of the bore holes will have a horizontal spacing of around 600 m.

It is expected that by end of 2005 this plant will be able to produce around 50 MW of thermal power at temperatures above 180°C. Up to 6 MW of electricity will be produced from this heat. The net output of the power plant is expected to be in the order of 4.5 MWe.

THE LOCATION

The test site is located in France on the western edge of the Rhine Graben, some 50 km north of Strasbourg near the German border. The length of the Rhine Graben is about 300 km NNE/SSW and its average width is 40 km E/W limited by large-scale normal faults. In the Rhine Graben, the post Palaeozoic sediments of the western European platform overlay the Hercynian basement which is made of granite, gneiss and other related basement rocks. This area which is characterised by a thin continental crust, the Moho being located at 25 km depth, shows a Tertiary volcanism that occurred by means of isolated volcanoes of alkaline composition related to a mantellic magmatic activity. Deep seismic events are clearly localised in the southern part of the Rhine Graben in connection with the Alpine front. A number of thermal springs are located on the Rhine Graben borders in connection with the large-scale faults. The granitic basement at Soultz-sous-Fôrets lies beneath app. 1400 m of sedimentary rock. Soultz was located in the heart of an intensive oil exploitation area at the beginning of the last century. The oil wells were drilled down to app. 1000 m depth. In the middle of the 1960's oil exploitation around Soultz was shut down.

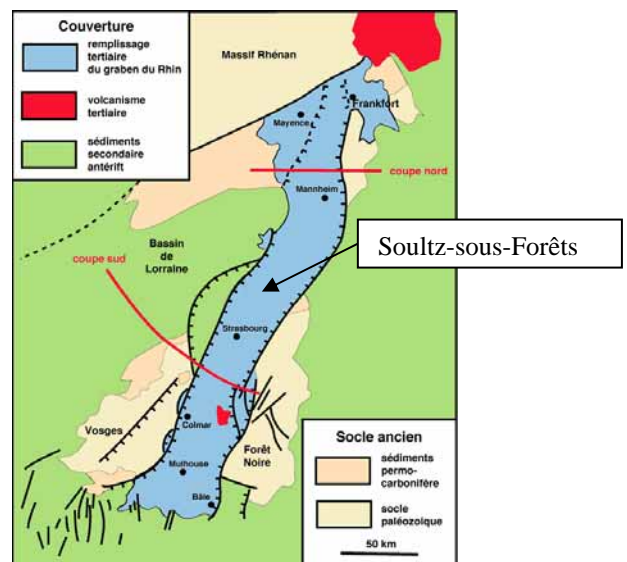


Figure 1: Geological map of the Rhine Graben. (C. Brunet modified after L. Jolivet & H.-C. Nataf, 1998)

THE HISTORY

The geothermal research program for the extraction of energy from hot fractured rocks started at Soultz-sous-Forêts in 1987 by drilling the well GPK-1 down to 2002 m depth under the management of the Bureau de Recherches Géologiques et Minières (BRGM). Following the deepening of four old oil wells into the top of the granite in 1989 and 1990, the project management was taken over by the Company SOCOMINE a subsidiary of BRGM. In 1992 the well GPK-1 was deepened to 3590 m depth and stimulated in 1993. In 1995 the well GPK-2 was drilled down to 3876 m. app. 450 m south from GPK-1 and stimulated in 1995 and 1996. These stimulations of GPK-1 and GPK-2 raised the injectivity of the upper reservoir to app. 0.4 (l/s)/bar – the highest in any HDR/HFR project at that time (Baria, R. 1999). A first successful forced circulation test of 4 months duration was performed in 1997 between GPK-1 and GPK-2. This test demonstrated the validity of the “Hot Dry Rock” concept at soultz (Gerard, A. et al. 1997, Baumgärtner, J. et al. 1998 and Jung, R. et al. 1998). It was possible to circulate continuously about 25 kg/s of brine, at more than 140°C, between two boreholes 450 m apart, without any water losses and requiring only 250 kWe pumping power compared with a thermal output up to 10 Megawatt. It could be shown that such a loop can be managed virtually automatically, reliable and without any noticeable environmental impact. Tracer tests indicated a breakthrough volume of some 6500 m³, a factor of 20 higher than that achieved in Rosemanowes (UK) and a factor of app. 70 higher than in the Hijiori (Japan) project (Baria, R. et al. 1999).

The production temperature of the upper reservoir reached a value of more than 140°C. Economical calculation showed that under 1997 / 98 legal boundary conditions a production temperature of #180°C would have been required to operate a power plant on a commercial basis. Therefore, in 1999 GPK-2 was deepened to 5084 m, where a rock temperature of 202°C was measured. In 2000 the open hole section of GPK-2 (4431 – 5084 m depth) was stimulated. A large deeper reservoir/heat exchanger was created, surprisingly, fully separated from the upper reservoir (Weidler, R. et al. 2002). The injectivity of GPK-2 could be improved from 0.02 – 0.03 (l/s)/bar before stimulation (Klee, G. et al. 2000) to app. 0.4 - 0.6 (l/s)/bar, varying with the injection rate and duration (Weidler, R. 2000).

In 2001 an industrial consortium, a European Economic Interest Grouping called “GEIE

Exploitation Minière de la Chaleur” (“EEIG Heat Mining”) bringing together five partners from the energy world, Electricité de France, Electricité de Strasbourg S.A. (both French), ENEL S.p.A. (Italian), Pfalzwerke AG and BESTEC GmbH (both German) acquired the site facilities and took over the management of the Soultz project. BESTEC since then acts as the on site manager and operator of the EEIG “Heat Mining”. Shell Int. Exploration and Production B.V. and SHELL Geothermal B.V. are associated and contributing to the project as special industrial partners.

Year	Milestones
1987	Drilling of GPK-1 (2002 m)
1989	Deepening of three old oil wells to monitor micro seismicity
1990	Deepening the old oil well EPS-1 by coring (2227 m)
1991	Stimulation of GPK-1 (1420 – 2002 m)
1992	Deepening of GPK-1 down to 3590 m
1993	Stimulation of GPK-1 (2850 – 3590 m)
1994	Production from GPK-1
1995	Drilling of GPK-2 (3876 m)
	Stimulation of GPK-2 (3211 – 3876 m)
	Circulation (GPK-1(+)) and GPK-2 (-)) 2 weeks
1996	Re-Stimulation of GPK-2 (3211 – 3876 m)
1997	Circulation (GPK-1(-) and GPK-2 (+)) 4 months
1999	Deepening of GPK-2 down to 5084 m
2000	Drilling the seismic observation well OPS-4 (1537 m)
	Stimulation of GPK-2 (4431 – 5084 m)

Table 1: Milestones of the Soultz Project managed by BRGM or SOCOMINE

The aim of the EEIG Heat Mining is to develop the Hot Dry Rock Technology to a stage at which the sub-surface heat can be used for commercial electricity production. Under the leadership of the “EEIG Heat Mining”, since mid 2001, a scientific pilot plant is being established in Soultz.

THE PROJECT PHASE 2001 – 2004

In the current project phase 2001 - 2004 the underground work required to establish the power plant will be performed. On site operations were divided into five work packages, WP1 – re-stimulation of the existing well GPK-2 (1st Production well), WP2 - drill the deviated well GPK-3 (central injection well), WP3 - stimulation of GPK-3, WP4 – drill the deviated well GPK-4 (2nd production well) and WP5 – stimulation of GPK-4.

The three-well module (triplet) is considered to be the optimum base for a commercially viable energy generation from HDR/HFR systems. This configuration has not been field tested, but it is expected that - compared to the traditional 2-well system - the triplet potentially could help to multiply production by a factor of 3 or even more.

At the end of the previous project phase, in 2000, a downhole probe was stuck in GPK-2. The wireline broke at app. 3880 m depth during subsequent operations trying to work the tool free. For commercial reasons the fishing operation was postponed until the work permission for the current phase (2001 – 2004) was obtained. As the legal formalities needed more time than expected, the work packages WP1 (restimulation of GPK-2) & WP2 (drilling of GPK-3) were swapped to gain some time and to first drill the GPK-3 injection well (WP2) and then combine the stimulation experiments in GPK-2 and GPK-3 (WP1 & WP3). As soon as the work permission was approved in **June 2002** on site activities started.

During the fishing operations in GPK-2 it was observed that the floating 7" casing had been blocked in the wellhead while growing after stimulation in 2000 and as a consequence was partially collapsed at 3904 m with a minimal opening of app. 3" in diameter. During a first short term injection test in June 2002 (app. 120 m³ of fluid were injected at various rates) the functionality of the well bore in its present condition could be considered as being enough for the near future tests. As continued remedial work could possibly place the future use of the well bore in jeopardy, the decision was taken to stop work on the GPK-2 well bore to ensure the capability of future use of this well bore.

WP2 - Drilling GPK-3 (Center injection well)

The target volume for GPK-3 was defined on the base of the locations of the micro seismic events of the stimulation test in GPK-2 in 2000. Considering also the stress regime and the fracture network as far as known, the target for GPK-3 was defined as an inclined cylinder with a radius of 75 m (see figure 2 & 3) located app. 600 m south of the open hole section of GPK-2, i.e. some 450 m south from the wellhead of GPK-3 along an azimuth of N178°. The target was slightly inclined to limit torque and drag during directional drilling in granite.

The trajectory of GPK-3 was planned based on the experience from drilling of GPK-2. GPK-3 was kicked off at a depth of 2700 m with a down hole motor and it was planned to lock it in at around 17° inclination and to rotary drill towards the target. Motor drilling was performed in 8 1/2" and the well was then opened up to 12 1/4". Re-opening took more time than originally anticipated.

While drilling through the stimulated rock volume of the upper reservoir the packed hole assembly used started to build angle. A caliper log showed later that the hole size in this section was on average app. 1" larger than the nominal bit size. A pendulum assembly was used to drop the well as soon as the upper reservoir had been crossed. As the realized trajectory of GPK-3 hit the top of the target app. 60 m south of well plan, it was possible to maintain a nearly vertical trajectory in the open hole section thus facilitating all open hole operations. Drilling of GPK-3 was finished after 144 days, 12 days ahead of schedule (see figure 4). Experience from GPK-3 with directional drilling in granite clearly showed that not the drill bits but the reamers become the limiting factor for on-bottom time.

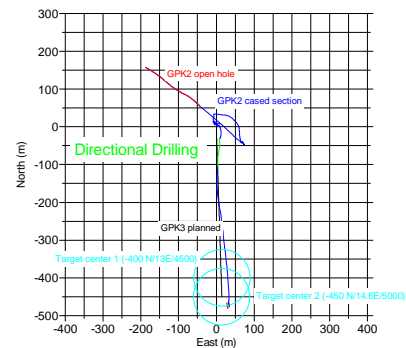


Figure 2: Plan view of the well trajectories of GPK-2 and GPK-3.

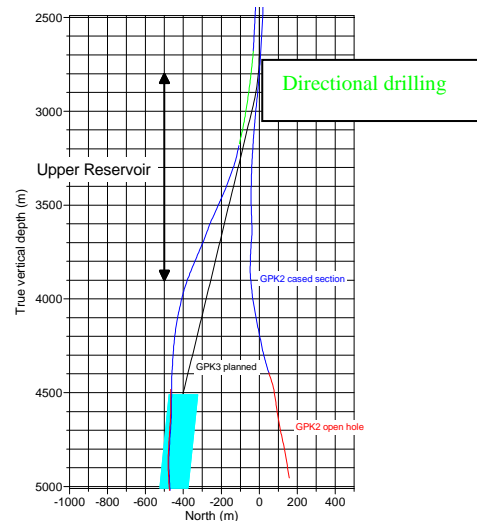


Figure 3: Side view of the well trajectories of GPK-2 and GPK-3.

The well completion of GPK-3 is done with a floating 9 5/8" casing down to 4565 m depth. This floating casing is anchored in the granite with two high temperature CuNi packers and cemented from 4556 m up to app. 4200 m with high magnesium resistance (HMR) cement (see figure 5). On surface the floating 9 5/8" casing is

sealed with a new-developed dynamic high temperature and high-pressure pack off.

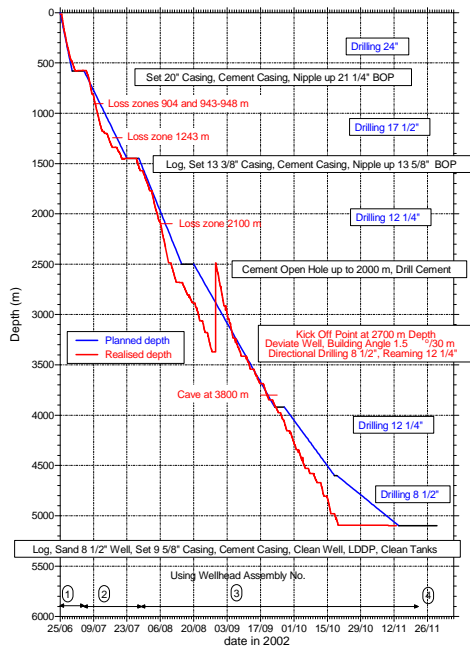


Figure 4: Planned and realized Drilling Plan of GPK-3.

During the drilling of GPK-3 total losses were observed at app. 4757 m and close to the bottom hole at # 5091 m. A UBI log performed showed a large fracture zone between 4757 to 4761 m (see figure 6) with (apparent) fracture apertures in the order of **0.5 m!!**

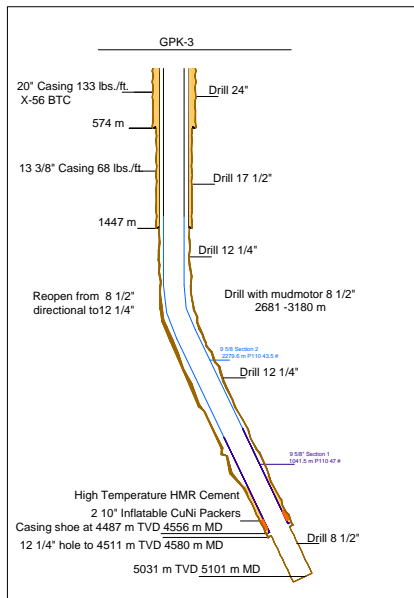


Figure 5: Well Completion of GPK-3 (depth from R.K.B.)

As some losses occurred while drilling into this fracture zone a temperature kick can be observed in the same depth range in the temperature log of GPK-3 (see figure 7). The loss zone at 2100 m depth in GPK-2 was kept under control while drilling GPK-3 and is therefore not appearing again. The temperature minimum observed in GPK-2 between 3200 and 3700 m depth is the result of the stimulation experiments in the upper reservoir in 1995 & 1996.

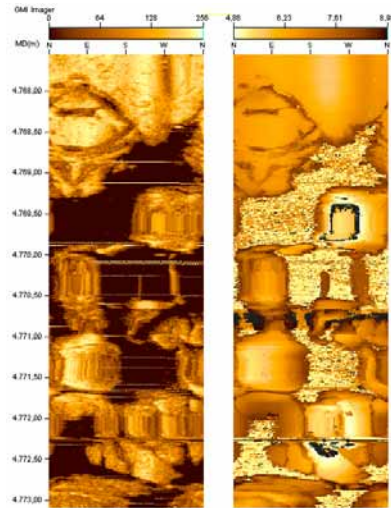


Figure 6: UBI between 4756 m and 4761 m (Driller's depth = Logging depth – 12 m).

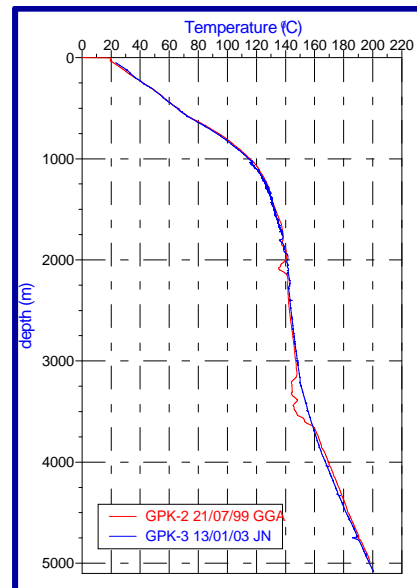


Figure 7: Temperatures measured in GPK-2 (red) in 1999 and in GPK-3 (blue) in 2003.

WPI & WP3 – Stimulation of GPK-2 & GPK-3

The main objectives of the test series in 2003 were:

- Evaluate the hydraulic behavior of the future production well GPK-2.

- Improve the injectivity /productivity of GPK-2 if required through a re-stimulation of GPK-2.
- Stimulate the new well GPK-3.
- Target the second production well GPK-4.
- Test the flow communication in the first wing of the future down hole heat exchanger (GPK2 > GPK3).

During the hydraulic test 03JAN23, over a period of one week, 9214 m³ of fresh water were injected into GPK-2 at a constant flow rate of 15 l/s (see figure 8). Several pump failures occurred on the second and third day of injection due to a faulty electronic card in the frequency variator of the centrifugal pump. During injection into GPK-2 the well GPK-3 remained shut in. From this test it was concluded that GPK-2 was hydraulically open, the fish and the restriction in the 7" casing showed no major influence on the injection pressures. The injectivity observed was practically unchanged since the stimulation test in 2000 - before the fish got lost in the well. However, GPK-3 reacted immediately to the injection into GPK-2! By the end of the experiment, the wellhead pressure of GPK-3 had increased to 24 bars. For comparison, the overpressure during injection in GPK-2 peaked only at approx. 50 bars at 15 l/s. The excellent pressure communication between the two wells was seen as a clear indication, that the targeting of GPK-3 had been successful.

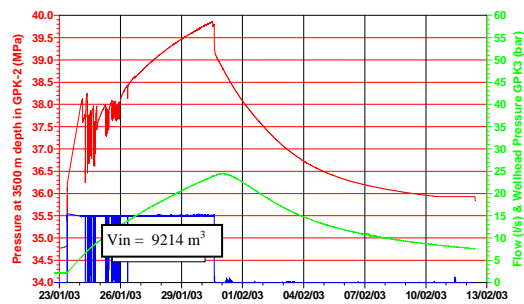


Figure 8: Pressures and flow during the Injection test 03JAN23.

During the second injection test of 03FEB12 the impact of soft acidizing on the calcite deposits in the granite fractures as well as the pressure communication between GPK-2 and GPK-3 at different flow rates were investigated. 5814 m³ of fresh water were injected into GPK-2, the base injection rate being again 15 l/s. Four flow rate pulses at 30 l/s, each 6 hours long, were performed (see figure 9). During the second pulse as well as before and within the third 30 l/s flow pulse, 2 respectively 3 m³ of HCl (285 kg/m³) diluted in 300 (2nd pulse) and 700 m³ (3rd pulse) of brine were injected in GPK-2. As soon

as the acid hit the formation in app. 4700 m depth (during the 2nd 30 l/s pulse), the injection pressure dropped by 7 bars. The impact of the second acid injection pulse was less obvious. Comparison of the down hole pressure increase during the 1st 30 l/s flow pulse before acidizing and during the 4th 30 l/s flow pulse after acidizing shows quite clearly that the acid improved the near well bore impedance in GPK-2. At the same time in GPK-3 a flow rate dependent pressure response could be observed at the wellhead.

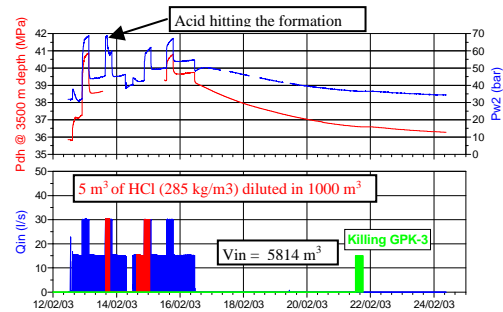


Figure 9: Pressures and flow during the soft Acidizing test 03FEB12. During the 2nd and before and during the 3rd 30 l/s pulse acid was diluted in the injected fluid.

Because of the strong pressure communication towards the un-stimulated well GPK-3 the flow communication between the two wells was tested during the injection and production test of 03MAR11. The main objective of the test of 03MAR11 was to analyze the impact of different injection flow rates into GPK-2 to the production flow rate from GPK-3. Therefore, the wellhead of GPK-3 was connected to a steam separator. During the test of 03MAR11 another default appeared in the frequency variator of the injection pump which could be identified but not repaired immediately. Consequently, this pump was not available during the second part of the experiment. However, some important results could be derived from the test of 03MAR11. 8950 m³ of water were injected into GPK-2 mainly at an injection rate of 30 l/s and 1890 m³ of water were produced from GPK-3 at a production rate of 4 -5 l/s (see figure 10).

The analysis of fluid samples taken from GPK-3 showed that 95 % were natural brine and the rest of the produced fluid was fresh water (4% from the 2000 stimulation in GPK-2 and 1% from the 2003 injection tests in GPK-2 !!) (Sanjuan, B. et al. 2004). The productivity of the un-stimulated well GPK-3 was estimated to app. 0.3 (l/s)/ bar in the test of 03MAR11, i.e. ten times higher

than the injectivity of the un-stimulated well GPK-2 in 2000.

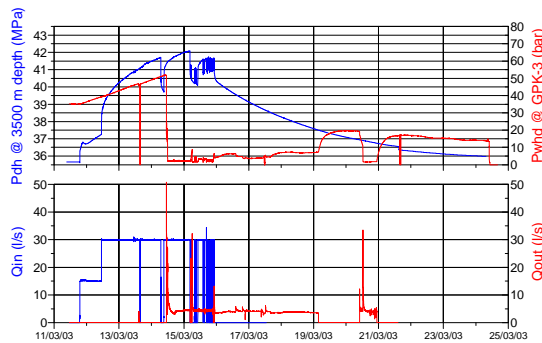


Figure 10: Pressure and flow during the injection and production test 03MAR11.

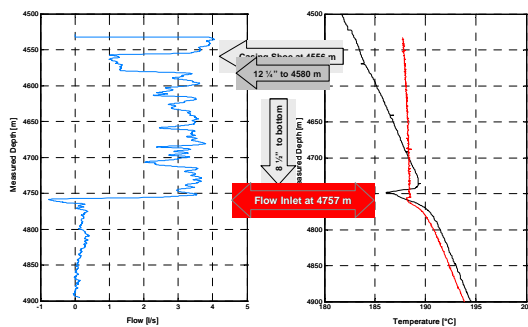


Figure 11: Results of the temperature and flow log in GPK-3 during the production test 03MAR11 (black equilibrium temperature and red temperature while producing).

On 21st of March a temperature and flow log was performed in the open hole section of GPK-3 (see figure 10). App. 80 % of the fluid was produced from the large fracture zone at 4757 m depth.

During the three hydraulic tests in 2003 only minor micro-seismic activity was observed. Location of the observed seismic activity was only possible for the last test 03MAR11 as not all geophones had been activated before. Some events were located within the upper reservoir (Hettkamp, T. et al. 2003). This corresponds to a slight increase of app. 0.15 bar observed at the wellhead of GPK-1 (3590 m deep) which is connected to the shallow reservoir. It has to be noted that during the 1st stimulation test of 2000 in GPK-2 no such pressure response was observed. Both observations thus seem to indicate a small leakage to the shallow reservoir, which was not observed during the stimulation test in 2000.

After the production test from GPK-3 the wellhead of GPK-3 was fully revised for the upcoming stimulation test. During this operation it was found that the annulus between the floating 9 5/8” casing and the riser was filled with cuttings. This might be seen as an indication that with production tests, even at low flow rates, are cleaning the fracture network. However, this is a technically not simple operation because these cuttings do block the moving casing, an effect which has to be prevented during future experiments.

The stimulation of GPK-3 started on the 27th of May. A total of 34.000 m³ was injected into GPK-3 at flow rates up to 95 l/s (see figure 12). At the beginning of the stimulation app. 450 m³ of heavy brine with a density of 1.15 g/cm³ were injected to raise the pressure gradient in the well and to thus favor the opening of deep near wellbore fractures. Because of the hot weather the generators of the triplex pumps over-heated and the aim to inject over a longer period of time at 100 l/s could not be achieved. During a dual injection phase (injection into GPK-3 and GPK-2 simultaneously) the (repaired) centrifugal pump was used to inject 3400 m³ of fresh water into GPK-2. During this phase of the stimulation micro-seismic locations filled the space in between the two wells (Baria, R. et al 2004).

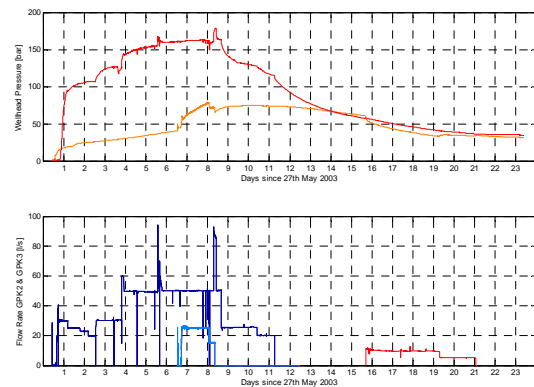


Figure 12: Pressures and flow during the stimulation test 03MAY27.

During the shut in phase of the stimulation two major micro-seismic events with a magnitude of 2.8 respectively 2.7 (M_L) were recorded. In order to relax the reservoir, 4000 m³ of water & brine were vented from GPK-2. The event rate declined faster after the venting. Four pressure, temperature and flow logs (PTF) were run in the open hole section of GPK-3 during the stimulation test of 03MAY26. The fracture at 4756 m depth was still dominating the flow distribution, but more than 10 % of the flow left the well below 5000 m depth (see figure 13)!

The total number of micro seismic events recorded exceeded 90,000 (!), of which some 9,000 were located. According to micro seismicity the down hole heat exchanger was extended over a horizontal distance of more than 2.5 km. The total seismically activated rock volume was in the order of 2.5 km³ (see figure 14).

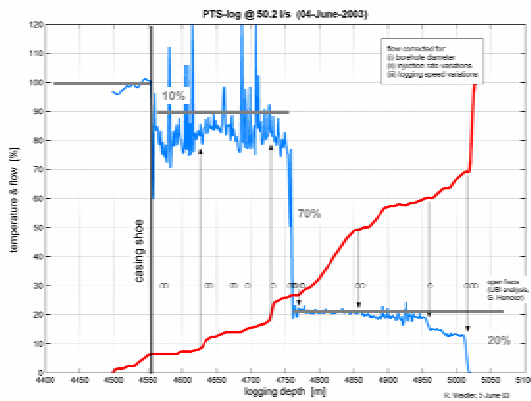


Figure 13: Normalized temperature (red) and flow (blue) from the flow log of the 4th of June during the stimulation test 03MAY27 while injecting at 50.2 l/s. Circles are indicating open fractures derived from the UBI log.

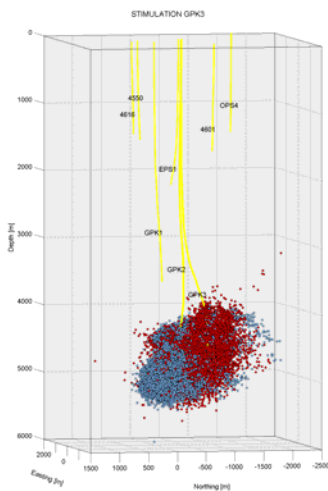


Figure 14: The underground at the Hot Dry Rock test site in Soultz sous Forêts. Well trajectories are shown in yellow. Blue dots mark micro seismic events located in 2000 during the stimulation of the well GPK-2. Red dots mark micro-seismic events located in 2003 during the stimulation of the well GPK-3.

Following this stimulation experiment, a successful 16 days circulation test (03JUN24) was performed between the wells GPK-2 and

GPK-3 at a flow rate of app. 15 l/s, just using the buoyancy effect to drive production from GPK-2 (figure 15). At the wellhead of GPK-2 a temperature of 153°C was achieved after 12 days. Wellhead temperature appeared to be extremely flow rate depended. The expected final production temperature of more than 180 °C will only be achieved at flow rates of 40 - 50 l/s using a submersible pump.

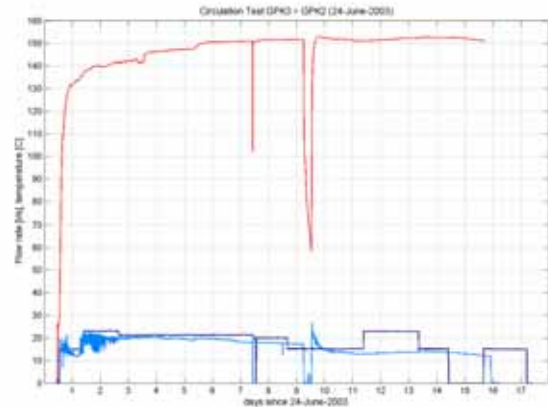


Figure 15: Production temperature and flow during the circulation test 03JUN24.

Production from GPK-2 showed a clear flow response to the injection into GPK-3. An increase in the injection flow rate of 8 l/s in GPK-3 resulted in an increase of app. 1 l/s in the production flow from GPK-2.

During circulation 11.3 m³ of HCl (285 kg /m³) diluted in 942 m³ of fluid (mean concentration # 4500 ppm) were injected into GPK-3. Due to the large fracture at 4757 m depth, this experiment appeared to be difficult to analyze. Only a minor immediate reaction on the injectivity of GPK-3 was observed. Overall, the injectivity of GPK-3 as observed during circulation (unchanged at less than 0.3 (l/s)/bar) is still considered to be too low for future operations and will have to be improved.

On the positive side, during circulation, GPK-2 showed a productivity in the order of app. 1 (l/s)/bar, which is close from the target productivity for the future power plant assuming productivity will be stable at higher flows. It is assumed that cleaning of the fractures during 16 days of production as well as the acidizing clearly improved the hydraulic injectivity of GPK-2. Nevertheless, it might be that during the circulation test of 04JUN24 parts of the reservoir may have been still slightly over-pressured. Therefore, injectivity values may be slightly underestimated while productivity values might be over-estimated.

A tracer test using NaNO_3 was performed during the circulation test 03JUN24. Seven days after the tracer was injected into GPK-3 it was detected in the produced fluid in GPK-2 (Sanjuan, B. et al. 2004).

WP4 – Drilling GPK-4 (2nd Production well)

During the stimulation of 03MAY26 the located seismicity was extended sufficiently southward to be able to target GPK-4. The target of GPK-4 was slightly rotated from an azimuth of $N178^\circ$ to $N172^\circ$ after stimulation of GPK-4. Again the target of GPK-4 is an inclined cylinder, located app. 1100 m south/southeast of the wellhead of GPK-3 with a radius of 75 m (see figure 16 and 17).

Drilling of the second production well GPK-4 started in September 2003. On 5th of September, while running the 20" casing the casing string parted on its own weight (!) and a piece weighing some 39 tons fell to the bottom. While laying down the casing remaining caught in the slips on surface, this string also parted and another piece (50 tons) dropped in the well, landing on top of the first fish. During subsequent fishing operations the top fish parted again, leaving 3 fishes in the well. After 28 days of complex fishing operations the damaged casing finally could be recovered and a new surface casing was installed and cemented.

GPK-4 was drilled vertical to app. 2100 m depth. At that point a gyro survey of the well trajectory showed that GPK-4 could be on a collision course with GPK-3. Therefore the well plan was slightly modified (see figure 16 and 17) guiding GPK-4 around GPK-3. GPK-4 will be app. 5250 m long and will be the longest directional well drilled in the crystalline basement in Soultz so far.

The well GPK-4 was kicked-off using a 12 ¼" motor and an inclination of app. 29° was obtained. During the subsequent rotary drilling phase the well trajectory of GPK-4 was measured online down hole using an MWD system. By end of 2003 the well GPK-4 had reached a depth of 3733 m. The planned and the realized well trajectory correlate very good up to now. Because of some technical difficulties with the down hole electronics of the MWD caused by vibrations while drilling in granite, the progress during the last 200 m drilled was slower than expected (see figure 18). It is expected that GPK-4 will be finished by end of February 2004.

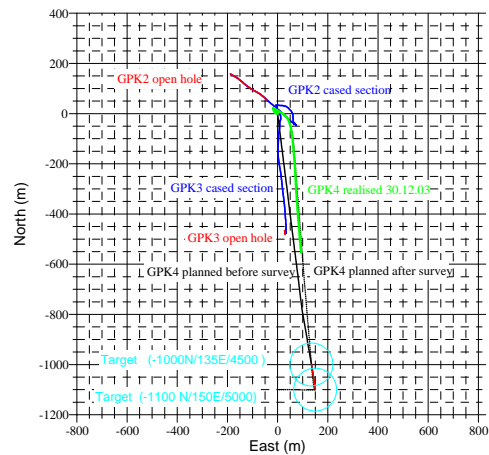


Figure 16: Plan view of the well trajectories of GPK-2, GPK-3 (blue cased section, red open hole) and GPK-4 (black plan before survey, black and dashed plan after survey, green realized at 30.12.2003).

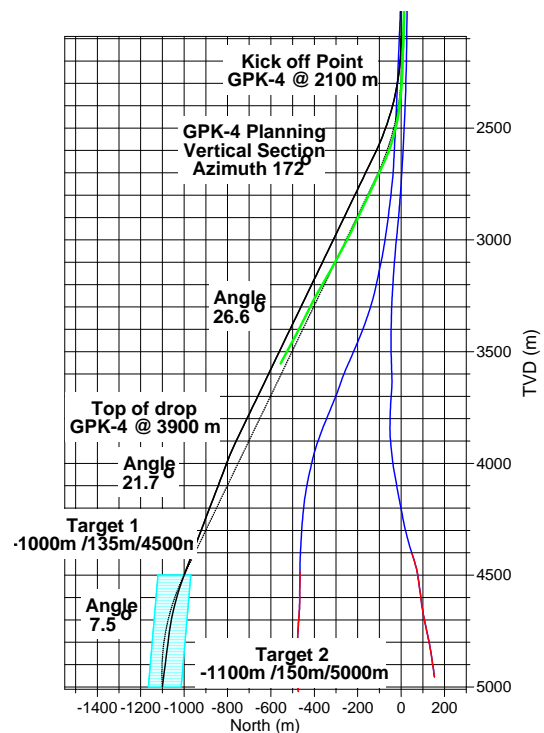


Figure 17: Side view of the well trajectories of GPK-2, GPK-3 (blue cased section, red open hole) and GPK-4 (black plan before survey, black and dashed plan after survey, green realized at 30.12.2003).

The well completion of GPK-4 will be similar to the well completion of GPK-3. The intermediate 13 3/8" casing is cemented only up to 500 m depth to maintain the option to cut the 9 5/8" at a later stage at this depth and install a pump chamber in 13 3/8" (see figure 19).

Similar to GPK-3 the planned well completion of GPK-4 calls for light HMR cements and Cu Ni-Packers as well as the new developed high pressure pack-off on surface to seal-off the floating 9 5/8" casing.

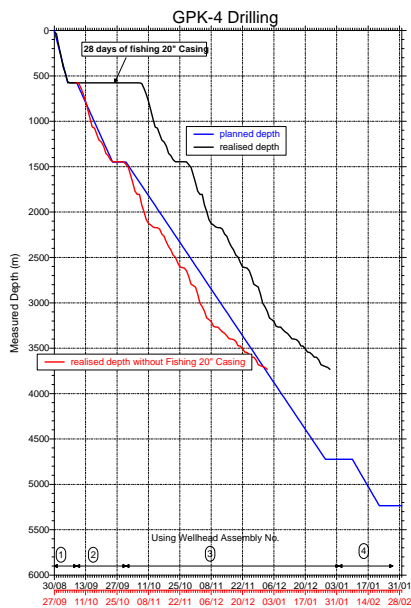


Figure 18: Drilling Plan (blue) and realized depth (black) of GPK-4 (31.12.2003). The 28 days of fishing the 20" casing are subtracted (red).

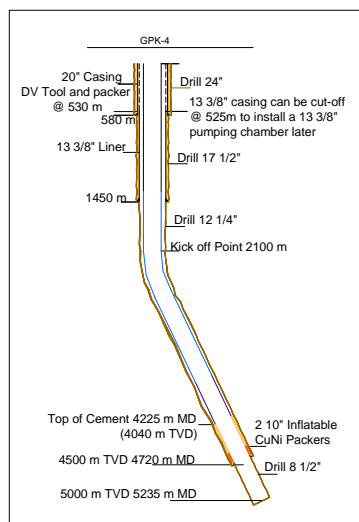


Figure 19: Planned Well Completion of GPK-4.

WP5 – Stimulation GPK-4

After the drilling of GPK-4 surface installations will have to be modified again for the stimulation of GPK-4 and the re-stimulation of GPK-3. Soft acidizing, longer production periods as well as simultaneous injection and injection &

production experiments in several wells are presently evaluated as possible elements of the future stimulation strategy. These strategies become easier because the wellheads of GPK-2, GPK-3 and GPK-4 are only separated by 6 m each. In September 2004 the construction of the underground part of the scientific pilot plant will be finalized.

THE FUTURE PROJECT PHASE 2004 - 2007

The installation of the power plant is planned in two steps. During a first step the mid to long term behavior of the down hole heat exchanger will be tested intensively and only a small power plant with a capacity of app. 1.5 MWe will be installed and operated. If the underground heat exchanger meets the required performance (wellhead temperature > 180 °C, total flow rate 80 – 100 l/s), the power plant will be expanded to app. 6 MWe. At this point it is expected that the plant will consume itself # 1.5 MWe and that the net output will be thus in the order of 4.5 MWe.

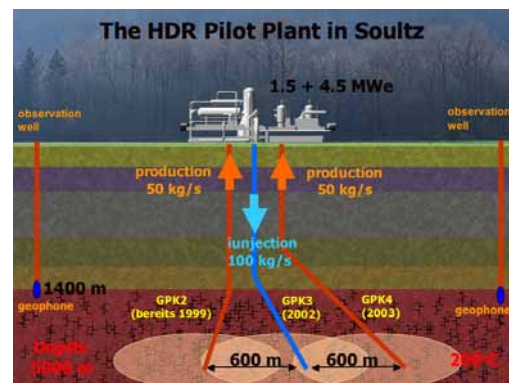


Figure 20: Schematic of the scientific "Hot Dry Rock" pilot plant at Soultz (the well trajectories shown reflect the real situation).

FUNDING

Work at Soultz is funded and supported by the European Commission Directorate-General Research, the French Ministère délégué à la Recherche et aux Nouvelles Technologies, the French Agence de l'Environnement et de la Maîtrise de l'Energie, the German Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit within the frame of the "Zukunftsinvestitionsprogramm", the Projektträger of the Forschungszentrum Jülich in Germany and by the Members of the EEIG "Exploitation Minière de la Chaleur".

ACKNOWLEDGEMENT

The authors would like to thank our former drilling manager Mr. Perry Moore for his continuous engagement, his advice and his lessons in drilling technology. Without his support the progress in HDR-Technology in Soultz would not have been possible. Mr. Moore died in March 2003 during a drilling operation in Kazakhstan. We miss him.

The 24 / 7 operations of drilling and stimulation would not be possible without the support of our on site Soultz team: C. Lanoix and K. Mattel, J.L. Riff, J. P. Fath, V. Kahn, P. Vix and M. Degouy.

We thank our drilling supervisors S. Davideit, P. Harney and J. Gray for their contribution to realize our project.

We thank G. Homeier (cutting and logging analyse), R. Weidler (both hydraulics), B. Dyer (seismics), J. Nicholls (logging), Ph. Agostini (logging), Soma, N. and Kumano (both seismic back up), P. Matifas (electronic pump control) for their participation and contribution to the hydraulic tests in 2003.

LITERATURE

- Baria, R., Baumgärtner, J., Rummel, F., Pine, R. J., Sato, Y. 1999. HDR/HWR reservoirs: concepts, understanding and creation. *Geothermics* 28, no. 4/5, pp. 533-552, ISSN 0-375-6505.
- Baria, R., Michelet, S., Baumgärtner, J., Dyer, B., Gerard, A., Nicholls, J., Hettkamp, T., Teza, D., Soma, N. and Asanuma, H., 2004. Microseismic monitoring of the world largest potential HDR reservoir. *Proceedings of the 29th Workshop on Geothermal Reservoir Engineering*, Stanford University, California.
- Baumgärtner, J., Gérard, A., Baria, R., Jung, R., Tran-Viet, T., Gandy, T., Aquilina, L., Garnish, J., 1998. Circulating the HDR reservoir at Soultz: maintaining production and injection flow in complete balance. *Proceedings of the 23rd Workshop on Geothermal Reservoir Engineering*, Stanford University, California.
- Brunet C. 1998.
<http://www.cnrs.fr/cw/dossiers/dosegeol/decouy/extension/zterrain/le-graben.html>
- Gerard, A., Baumgärtner, J. and Baria, R. 1997. An attempt towards a conceptual model derived from 1993-1996 hydraulic operations at Soultz. *Proceedings International; symposium Vol.2*, pp 329-341.
- Hettkamp, T., Teza, D., Michelet, S. and Baumgärtner J. 2003. Technical report on the Soultz 2003 hydraulic testing and stimulation program. Internal EEIG Report.
- Jung R., Baumgärtner J., Rummel F., Tenzer H. und Tran-Viet T., 1998. Erfolgreicher Langzeit-Zirkulationstest im Europäischen HDR Versuchesfeld Soultz-sous-Forêts. In: *Geothermische Energie*, Nr.22-23, 6. Jahrg., Heft 2/3, S. 1-8.
- Klee, G., Weber, U. and Weidler R., 2000. Low-Rate Injection test in borehole GPK-2. BGR-Report.
- Sanjuan, B., Rose P., Foucher, J.-C., Brach, M. and Braibant, G. 2004. Tracer Testing at Soultz-sous-Forêts (France) using Na-Benzate, 1.5 and 2.7 Naphtalene Disulfonate, *Proceedings of the 29th Workshop on Geothermal Reservoir Engineering*, Stanford University, California.
- Weidler, R., 2000. Hydraulic Stimulation of the 5 km deep well GPK-2. BGR-Report.
- Weidler, R., Gerard, A., Baria, R., Baumgärtner, J. and Jung, R., 2002. Hydraulic and Micro-Seismic Results of a Massive Stimulation Test at 5 km Depth at the European Hot-Dry-Rock Test Site Soultz, France. *Proceedings of the 27th Workshop on Geothermal Reservoir Engineering*, Stanford University, California.