Presented at Short Course II on Surface Exploration for Geothermal Resources,
organized by UNU-GTP and KenGen, at Lake Naivasha, Kenya, 2-17 November, 2007.

UNITED NATIONS UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

KenGen
Kenya Electricity Generating Co., Ltd.

PLANNING OF GEOTHERMAL PROJECTS: A CASE STUDY ON KENYA

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ABSTRACT

The planning aspects of geothermal projects in Kenya consist of: a) Review of existing information on a prospect; b) Detailed surface exploration; c) Exploration drilling and well testing; d) Appraisal drilling and well testing; e) Feasibility studies; f) Production drilling, power plant design, environmental impact assessment and reservoir evaluation; g) Power station construction and commissioning; h) Reservoir Management and further development, and i) Shutdown and abandonment. The planning includes sourcing for funds right from Project identification to Power station commissioning. Planning and implementation takes about 8 years although this period can be reduced to 5 years if finances are readily available. From the experience of development at Olkaria, it has been learnt that:- a) Timely financing of the projects is very critical; b) Some of the exploration wells could have been used to run pilot plants to generate some power while decisions for further development were being considered; c) Staged development has an advantage of making early use of the existing wells thus reducing early expenditure and producing revenue to take the project forward and build confidence in the resource; d) Appraisal drilling should not be stepped out too far apart from the discovery exploration well. Such step-out wells might destroy confidence in the prospect by being unproductive.

1. INTRODUCTION

The various planning aspects of geothermal projects in Kenya are the most commonly applicable worldwide with perhaps minor modifications. These are:- a) review of existing information of a prospect; b) Detailed surface exploration; c) exploration drilling and well testing; d) appraisal drilling and well testing; e) feasibility studies; f) production drilling, reservoir evaluation, power plant design and environmental impact assessment; g) power station construction and commissioning; h) reservoir management and further development, and i) shutdown and abandonment.

Indicative periods for various aspects are given in Figure 1 and the cost estimated for a green field in Kenya is given in Table 1. The planning and implementation programme is about 8 years. However, with a lot of ingenuity, the programme can be reduced to 5 years particularly if finances are readily available.

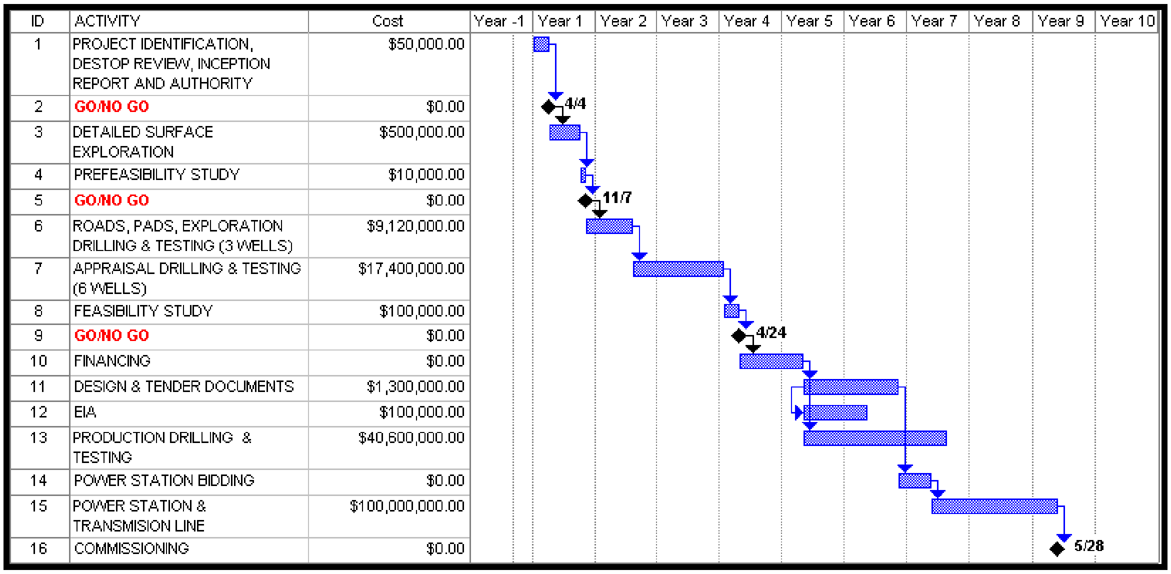

FIGURE 1: Geothermal Development Programme (Green Field)

TABLE 1: Geothermal Project Cost estimates for 70MWe

Project Identification, Desktop review, inception Report and Licensing	$50,000
Detailed Surface Exploration	$500,000
Pre-feasibility Study	$10,000
Exploration Drilling well testing pads and roads (3Wells)	$9,120,000
Appraisal Drilling and testing (6 WELLS)	$17,400,000
Feasibility Study	$100,000
Design and tender documents	$1,300,000
Environmental Impact Assessment (EIA)	$100,000
Production Drilling and Testing	$40,600,000
Power station & Transmission Construction and supervision	$100,000,000
TOTALS	**$169,180,000**
COST PER MWe	**$2,416,857**

2. INFORMATION REVIEW OR RECONNAISSANCE

This aspect involves collecting information from previous geological, geochemical or geophysical studies made in an area and which relate to mapping of young volcanic activity, hot springs, steam jets, groundwater boreholes and even known traditional utilization of geothermal resources. For example, Olkaria was well known as source of red earth by the Masai community for applying on their hair. Early white settlers were known to have utilized steam jets to make some kind of oil that was exported to

France. In Eburru, the early white settlers condensed the steam jets to get drinking water and dry pyrethrum. The pyrethrum drying plant is still in existence today.

Where there is substantial scientific information, it is re-interpreted and gaps that can be filled in a more detailed investigation phase are identified. This desk review may reveal that temperature determined by geochemical methods is not reasonably attractive to warrant more detailed survey. It may also mean that the methods of interpretation previously used were not well refined and re-interpretation may indicate the existence of a more attractive resource than previously envisaged.

It is also now more important that environmental considerations are brought in at this stage because in some cases it might stop future development. Some areas may not be developable because of being in traditionally prohibitive areas even though the resource itself is very attractive.

If both the scientific, cultural and environmental considerations are attractive, it is good to have a reconnaissance trip to the area. This is to confirm the data review findings and discuss with the local community and administrators of their expectations of a project of the kind planned. The reconnaissance would also include the assessment of access roads, communication, accommodation, and security.

The outcome of this stage is an inception report recommending detailed surface work. This report would have technical reviews of all the available information and a detailed proposal for carrying out the work based on the desktop review. The report details the work programme, duration, staff requirement, transport and the budget.

3. DETAILED SURFACE EXPLORATION

3.1 Data collection and interpretation

The detailed surface exploration programme usually covers the geology, geophysics, geochemistry, heat flow measurements, hydrogeology, and baseline environmental studies. In areas that had not been covered by detailed geological mapping, the required work would include the following:

- Lithological mapping
- Petrogenesis and volcanology
- Structural geology
- Hydrogeology
- Geo-hazard and environmental geology

At this stage, detailed mapping of geothermal manifestations, mode of and geological controls on their distribution is very important in developing the conceptual model of the geothermal system. The study of volcanological features detailing the eruption trends, history and ages is also import ant in determining the type and existence of heat sources. Detailed structural mapping is very important in the rift system, as the geothermal reservoirs are dependent on fractures rather than lithology. Some of these fractures become drilling targets, as they are known to control the upward movement of geothermal fluids.

The study of geo-hazards and environmental impacts is becoming more important as there are certain situations when these two aspects can stop the development of a geothermal resource. A volcanically active geothermal area can jeopardize humans and installations in case of an eruption. Reservoirs that are associated with active magmatic gas injections can become un-utilizable because of high acidity.

In geophysics, a whole suite of measurements is taken including gravity, seismic and resistivity. Gravity is important in determining the occurrence of a magmatic heat source at reasonable depth reachable by meteoric waters. It is also useful in mapping structures although it has been very difficult in the rift structure unless there are rocks of very contrasting densities. Micro-earthquake mapping can be useful in mapping active fractures that allow upward flow of geothermal fluids. Teleseismic can be used to map magmatic heat bodies. The resistivity methods have been the most consistent and extensively used geophysical method with very good results. We initially started using the DC type of resistivity measurements. Because of the efforts required to penetrate depths greater than 1km, we have tended to rely on the TEM and MT methods.

Resistivity methods are capable of mapping the reservoir itself and that makes it more attractive to use. A large number of measurements are required covering large areas initially at intervals of 1km and later at even lesser spacing. We are currently developing a method to combine the interpretation of seismic and resistivity (joint geophysical imaging) data in an attempt to define hidden fractures as critical targets for drilling high steam productivity wells.

The use of geochemical investigations has also been important in determining the subsurface temperature of fluids. Areas with widespread hot springs, fumaroles and boreholes are easy unlike those with little of these manifestations. In such cases, soil gas sampling in holes augured to one-meter depth has been done to map fractures. The soil gas measurements have been made for CO_2, air, and radon along grid lines 1km apart and at intervals of 0.5km. There are obvious problems of interpreting soil gas data, as they can be misleading.

Heat flow measurements aim at assessing the amount of heat being lost naturally from a prospect and is used to conceptualize the amount of energy that could be concealed and the relationship between the geological structures and the discharging features. The heat loss method is used indirectly to determine the size of the reservoir as large heat loss mirrors a large reservoir. The amount of heat lost is also required during later simulation modelling to determine the reservoir potential.

Influenced by the requirement from the World Bank who have funded most of the Kenya’s geothermal development, environmental studies started being carried out routinely since 1985. It is now a requirement for any power project by Kenya’s newly enacted Environmental Management and coordination Act, 1999. The studies would include environmental and social economical aspects. Emphasis is made in the collection of baseline data to ensure that future geothermal development is made in an environmentally sound and a socially acceptable manner. Some of Kenya’s prospects are located in National parks, highly agricultural and traditional lands that require very careful environmental studies that incorporate the local people’s views.

3.2 Conceptual Modelling.

At the end of collection and interpretation of the scientific data, each discipline develops its own conceptual model of the geothermal system without much influence from each other. These models would then be presented and discussed with a view to finding areas of congruence or divergence. Areas of disagreement would then require each discipline to reinterpret or add more data to resolve the differences. Consequently, a unified conceptual model is developed that would be supported by most of the data available from the various disciplines and a single combined project report is prepared. Environmental aspects are also taken on board in determining the drill sites. Generally a maximum of three sites most suitable for exploration drilling would be justified and prioritized.

Although in some countries, 200-300m temperature gradient wells are drilled at this stage we have never tried them as they have been found to be very misleading in fields such as Aluto Langano (Ethiopia).

4. EXPLORATION DRILLING AND TESTING

Based on the conceptual model and environmental consideration, three exploration drill sites are selected and prioritized. The first well is perhaps the most critical well in the development of a resource and should take much longer to drill due to lack of previous experience with the formation and logistics. It is aimed at being a discovery well and is meant to maximize on downhole information. Many cores should therefore be taken and cuttings carefully analyzed to determine the lithology and alteration mineralogy. We have favoured drilling a normal production size well as opposed to slim holes. The reason for this is slim holes most of the time do not discharge and would only be useful for downhole measurements and geological information. The normal production well would allow all the information to be obtained and in addition can be discharged to determine the output of the well and be one of the production wells in case the area is developed further. Although we have not yet done so our new strategy is to put a wellhead generator on the exploration well(s) to start generating revenue while plans for further development are being done.

With early generation, this could create a national interest that could trigger more support. On the other hand, the failure of the first well could kill further development. Given that the cost of a full fledged 2000m well is in the range of 2- 4 million US dollars, the siting of the first well is therefore critical for a developing country where funds are scarce. It is therefore important that detailed exploration study is well conducted.

In case the first well does not strike steam, it would be good to re-evaluate the data from the first well before drilling the second well. When the first exploration well Olkaria 1 (OW-1) was drilled, only 102^{o}C was achieved at 1000m. This almost killed the project but with determination, the data was re-evaluated and OW-2 was drilled several kilometres from OW-1 (Figure 2). OW-2 struck steam and that gave the impetus to drill step-out wells for the Olkaria I power station. At Eburru, although the first well was a discovery well, the other five wells were not very successful because they were located very far from the successful well with an aim of discovering a large reservoir intended for a 120MW power plant. When a first well has failed to achieve the required results, a hard decision needs to be made either to drill the second well or to abandon the area. However, three wells are the maximum even when the funds are available.

If the first exploration well is successful, it would be advisable to drill the second two wells as step-out of the first well. The step-out (appraisal) wells should not be located further than the normal production well separation, usually less than 500m (300m at Olkaria). If there is no scientific information to be used to direct the specific location of these wells, it would be a matter of choosing north, south, east or west of the discovery well. It would be advisable however to target fractures or other geological structures. The separation of 300m is also useful in that a decision can be made to start utilizing one or some of these wells for early wellhead generation.

After drilling, the exploration wells are fully tested. Permeability tests are conducted soon after capping the well. A suite of downhole temperature and pressure measurements follow this when the well is heating up from the cooling experienced during drilling. Good wells recover quickly and within one month they develop enough wellhead pressure to discharge on their own. Other wells may require to be assisted to start discharge by compressing and releasing several times. Discharge tests takes a minimum of three months and a maximum of 1 year to determine its full characteristic and long-term behaviour. During discharge tests, steam and brine measurements are made to determine the amount of steam available. Chemical analysis data of steam and brine is useful during exploitation and also for defining the reservoir characteristics.

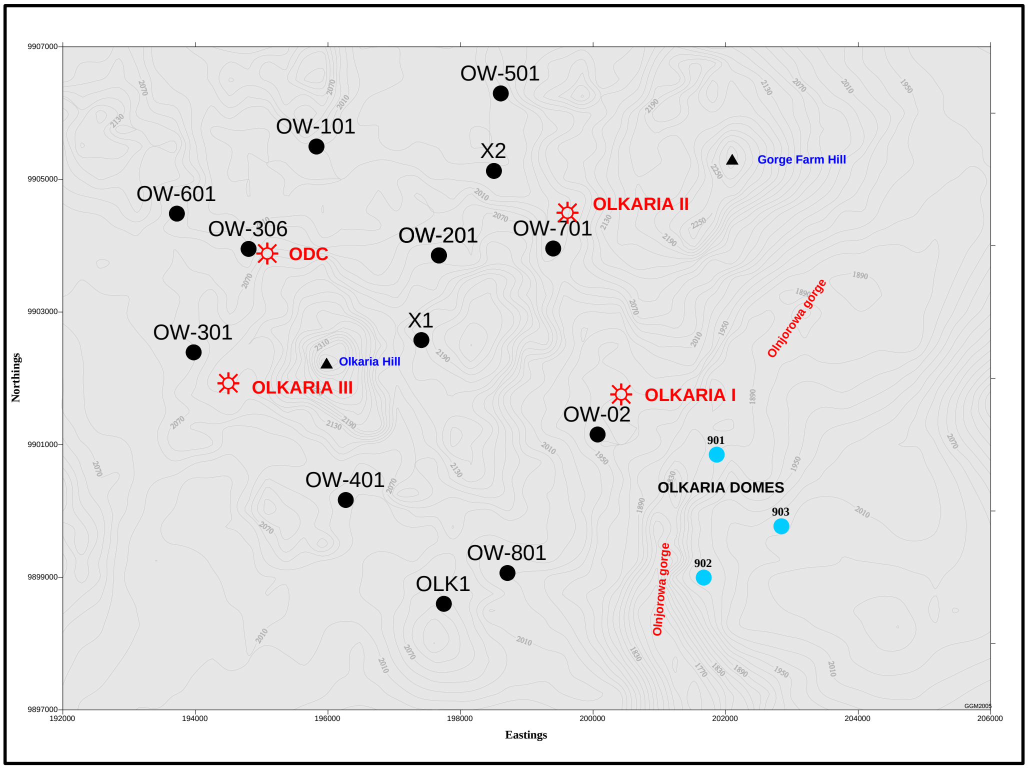

FIGURE 2: Location Map of Olkaria Geothermal Field.

5. APPRAISAL DRILLING

Having discovered a reservoir from the previous stage, its size is determined and reservoir characterized for the purpose of determining the size of the power station to be developed. A reservoir may be fairly large and it would not be advisable to get all the information of the entire reservoir at once. If only one exploration well was successful, appraisal wells would target proving 30% of the required steam for the planned power station. The appraisal wells give the following information:

- data between wells and comparison of downhole with surface information like resistivity;
- reservoir characteristics in terms of temperature, pressure, permeable horizons and chemistry of the fluids
- productivity of the wells, productive depths and the aerial trends
- conceptual model of the reservoir showing upflow and outflow areas.
- drilling experiences gained to be used during production drilling.

6. FEASIBILITY STUDY

The feasibility study is used to determine the commercial viability of the development. Our feasibility studies have been done by consultants and cover the following:

- review data from surface exploration, exploration drilling and appraisal drilling;
- simulation studies;
- environmental issues;
- power market and least cost plans
- power plant design concepts, construction and operation
- legal and regulatory matters
- project organization and management
- project financial requirements
- project economics

The studies develop the initial design concepts, development timelines and carry out economic and financial cost analysis of proposed development. It also reviews the power demand scenarios, transmission infrastructure and evaluates legal and environmental issues. The report would also recommend the number of production wells required, the type of development (either single or staged) and environmental studies to be undertaken depending on the design to be adopted. The power station location is also decided at this stage.

The outcome of the feasibility study is the bankable report that is used to solicit for funding from financiers for further development. The financing required would include cost for detailed power station design, a full Environmental Impact Assessment (EIA), production drilling, power station construction, transmission line construction and construction supervision consultancy.

It is also possible that the funding could be broken into two parts. The first part could be for design, EIA and production drilling, while the second part could cover the power station construction, and supervision.

7. PRODUCTION DRILLING, POWER STATION DESIGN, EIA AND POWER STATION CONSTRUCTION

The outcome of a feasibility study is a critical basis on which the decision to proceed or abandon the project is made. If the feasibility study has a positive result, the next stage involves production drilling, detailed design of the power station that incorporates results of detailed environmental impact assessment and the construction itself. In this phase, production drilling progresses in parallel with the other activities.

7.1 Production Drilling

Based on the feasibility studies the production drilling proceeds most of the time without problems as the locations, depths and direction are already decided from the results of the exploration and appraisal drilling. Very few cores would be obtained during this phase; the ones taken would be to fill in the information gaps missed during appraisal drilling. If the re-injection wells had not been identified from the failures of the appraisal and exploration wells, then they are included depending on the method of disposal recommended in the feasibility studies.

For Olkaria I, the disposal method recommended was infiltration in a pond combined with surface evaporation. At this time, there was very little experience in re-injection world wide. Where re-injection had been tried, bad experience of thermal breakthrough had been realized, for example Hotchubaru in Japan. Over the years, it was discovered that there was a lot of advantage in re-injection particularly with hot brine. Chemical tracers that could withstand hot reservoirs have become available allowing studies to be made before the actual re-injection was done. Studies also allowed the safe handling of brine without causing chemical scaling in the delivery pipes and in the reservoirs. Based on such studies it was possible to design a hot brine re-injection system right from the beginning at Olkaria II.
Testing of production wells is carried out in the same way as testing of exploration and appraisal wells that is, as each well heat up or after compressing in case it does not develop enough wellhead pressure. This is because each well exhibits its own characteristics sometimes different from the neighbouring wells. The production drilling would continue until the required steam is obtained for the planned station according to the feasibility study. It is usually important to have excess steam at start-up time of the station as the initial wells draw down is much faster.

7. 2 Detailed Power Station Design

The detailed power station design is done simultaneously with the production drilling. The steam gathering system is done continuously as the wells are tested because some of the equipment like separators and the pipes are sized according to the output and location of the wells. The power station and the electromechanical equipment, substations and transmission line can be designed well ahead provided that environmental information is available.

7.3. Environmental Impact Assessment

We have used the exploration drilling results to decide whether to collect meteorological data well in advance of the power station design, which requires at least one year’s data.

Olkaria geothermal field is located in Hell’s Gate National Park, which was gazzetted in 1984 after the development of Olkaria I power station. Olkaria II was the first station to require a full EIA in order to fulfil the World Bank financing requirements and also to take care of the concerns of the park. Environmental considerations made the transmission line route to be changed several times. Fortunately at this time a full-fledged environmental section had been developed for the Olkaria Geothermal Project. Although a consultant conducted the EIA (Sinclair Knight and RPS, 1994), it gave KenGen good experience in conducting EIA. It became very clear that careful environmental consideration was necessary. It is now a statutory requirement that any power station development must have an EIA approved by the National Environmental Management Authority (NEMA).

The EIA is normally carried out concurrently with the detailed power station design as the designs are supposed to incorporate mitigation of the environmental impacts identified. These are; air pollution from waste gases, brine disposal, noise reduction and impacts on flora and fauna during construction and operation of the station. Social impacts are also supposed to be addressed in the management and monitoring programmes.

A comprehensive environmental assessment study takes a minimum of one year. There is high level of concern on the environment in most of the communities and given that the environmental law has been entrenchment in the new draft constitution, environmental issues can no longer be taken for granted. The development of Olkaria geothermal field in Hell’s gate National Park is a clear demonstration that geothermal is environmentally friendlier than fossil fuel sources. However, the environmental impacts must be carefully identified, mitigated and continually monitored.

8. POWER STATION CONSTRUCTION AND COMMISSIONING

A 50-70 MW geothermal power plant takes about 2 years to construct and commission. This stage includes the following:

- steam gathering and brine re-injection system;
- power house, electromechanical equipment, cooling towers and blow down re-injection system;
- substations and transmission line; and
- commissioning.

Transmission line can be an issue particularly if the wayleave acquisition is not handled in good time and professionally. This is because transmission line can be fairly long and traverse very many land ownerships. Land compensation may be required in some parts while in others outright purchase may be the solution. Power lines, just like power stations require environmental impact assessment to be conducted.

9. FIELD MANAGEMENT AND MONITORING

Field management and monitoring is a very important aspect of geothermal development project planning. It is soon realized that the steam supply to the power station is declining as the pressure in the wells decline. In order to keep the power station at optimum operating capacity, more make up wells are required to be drilled and connected in good time. Some of the wells reduce in output because of chemical scaling caused by boiling in the reservoir and occasional work-overs are required. Some of the work-overs in Olkaria have been to deepen shallow wells with successful results of increasing steam output.

One of the successful management methods of the reservoir has been re-injection of the waste brine from the wells. As steam is continuously discharged, the reservoir becomes depleted resulting in an increase in enthalpy. Re-injection can greatly replenished such reservoirs provided a careful re-injection programme is used backed by controlled tracer injections to avoid thermal breakthrough in the producing wells.

Olkaria I started by cold re-injection as all the separated brine from wells and the power station condensate was collected in a single pond. The re-injected brine returned to some of the neighbouring wells quickly and was stopped after some time. 20 to 30 tons of hot brine separated from several wells was re-injected on one side of the field and this has been found to support the reservoir relatively well. The cold re-injection has been restarted from another side of the field from the original well and monitoring of the effects is being carried out. There is a plan to interconnect Olkaria I and II steam fields to allow sharing in future.

10. SHUT-DOWN AND ABANDONMENT

As a geothermal reservoir is exploited, it declines in pressure and steam output. In addition, the surface equipment may start failing to an extent that it is no longer economical to run the plant and as such require to be shut down and abandoned. Since geothermal resources are renewable, so far no geothermal field has been abandoned. The oldest geothermal field at Laderello (Italy) is still operational. However, some plants in the Geysers (USA) have been shut down due to over development (Sanyal, 2000). In Waireki field in New Zealand, the equipment has continued to be modified as the reservoir characteristics change and some equipment are replaced with modern ones.

Olkaria I plant has now reached its expected economic life of 25 years. The reservoir and most of the equipment are still in very good conditions. It is planned that a detailed study of the reservoir and the existing equipment will be undertaken with an objective of extending the life of the plant.

11. CASE HISTORY OF OLKARIA DEVELOPMENT

11.1 Olkaria I

Drilling of geothermal wells at Olkaria started in 1956 when X1 and X2 (Figure 2) shallow wells were drilled without much success due to poor drilling experience. No information is available why the two wells were drilled at the location. Later Betty carried out some resistivity measurements in 1966 and found encouraging results of finding a geothermal resource.

During the world oil crisis of 1970, UNDP and the Kenya Government carried out a reconnaissance survey along the Kenya rift that included Lake Magadi, Olkaria, Eburru and Lake Bogoria. Based on this reconnaissance survey more detailed work was done in Olkaria that included detailed geology, geophysics, geochemistry, heat flow measurements and hydrogeology. Although discharge of X2 was successful, it was not continuous.

Based on the scientific findings, the first well OW-1, was drilled in 1973 to the south of the present Olkaria I in an area which had strong fumaroles. At 1000m, only 102 $^{\circ}$C was realized. This area is now well established to be the outflow of the Olkaria geothermal system.

The scientific results were revaluated again and a decision was made to drill into the current Olkaria I area defined by a low resistivity. In 1974, OW-2 was drilled and because it proved steam, 5 other wells were drilled as step-out wells by 1976. These wells proved the existence of an exploitable steam resource.

Feasibility studies conducted by Virkir and Sweco (1976) recommended the development of a 2 x 15MW station. The construction of the power plant commenced in 1979 with World Bank funding and the first unit was commissioned in 1981. Production drilling was done while the power station was being constructed. By the time the second unit was commissioned in 1982, 25 wells had been drilled with more steam than the station could utilize. More knowledge of the reservoir was becoming available which indicated that the reservoir was progressively better northwards. A case was made to the World Bank and other financiers for the extension of the station by another third unit. The third unit was commissioned in 1985. The development of Olkaria I therefore took about 15years.

11.2 Olkaria II power station

In 1980, an experts' technical review meeting was held in Nairobi to deliberate on the next development stages of the greater Olkaria field (GENZL, 1980). In this meeting, the scientific and drilling results were reviewed. Several wells spread far apart were sited to test several scientific theories. Some of these theories were that faults and fractures were the major conduits of geothermal fluids, the main ones being Ololbutot fault, Olkaria fracture and Olkaria fault.

In 1984 another scientific review meeting was held to evaluate the drilling results (KRTA, 1985). It was concluded that the western part of Olkaria had a separate geothermal system upflow with high CO_2 content and that an area north of Olkaria I existed a field with similar fluid chemistry to Olkaria I. OW-701 was then sited to prove this with much success. By 1988 five additional appraisal wells had been drilled and the field was then committed for a 2 x 30 MW development.

In 1989 a consortium of four companies carried out a feasibility study for the power plant and a full EIA was undertaken between 1990 and 1994 (Sinclair knight and RPS, 1994). By 1993, the required 33 wells for production, re-injection and monitoring had been drilled. A numerical simulation study of the field performance under exploitation was completed in 1993. Although the power station designs were done between 1991 and 1994, they could not be approved until environmental issues were fully incorporated. These included use of water from Lake Naivasha.

In 1996, donors introduced energy sector reforms in Kenya some of which became conditional for further funding for the construction phase. The designs were reviewed in 1997, financing was approved in 1998 and a new supervising consultant, different from the designing one, was appointed. The tender documents prepared earlier by the previous consultant were revised and some design aspects changed to take into account changes in technology.

Construction of Olkaria II then commenced in September 2000 and commissioned at the end of 2003 after 3 years (Mwangi, 2005). Olkaria II power plant therefore took about 17 years to be realized. A case has been made to expand Olkaria II by adding a 35MW third unit.

11.3 Lessons Learned

- Timely financing of the projects is very critical.
- Some of the exploration wells could have been used to run pilot plants to generate some power while decisions for further development were being considered; for example in Olkaria West (Olkaria III site) and Eburru.
- Staged development has an advantage of making early use of the existing wells thus reducing early expenditure and producing revenue to take the project forward and build confidence in the resource and in the abilities of the country to implement geothermal projects.
- Appraisal drilling should not be stepped out too far apart from the discovery exploration well. Such step-out wells might destroy confidence in the prospect by being unproductive.

11.4 Staff Development

When the UNDP undertook the Geothermal Project between 1970 and 1976, there were no Kenyans trained and with the experience in geothermal technology. Although few scientists and technicians took immediate short training under the project in Italy and New Zealand, overseas expert principally carried out the project.

However, from 1981, when Kenya started operating its first geothermal power station, it became clear that geothermal was going to play an important role in Kenya’s power sector. More staff were employed and trained in various disciplines. The training schools were at Pisa (Italy), Auckland University (New Zealand), Kyushu University (Japan) and United Nations University (Iceland). All these schools are now closed except the UNU in Iceland.

The first three Kenyans were trained in Iceland in 1982 and by 2004, 35 Kenyans had been trained in Iceland alone (Table 2) which is the highest number in Africa (Fridleifsson, 2005). Five MSc graduates from Kenya have been trained. In 2006 there was one undergraduate and two MSc students in Iceland. The drilling rate using consultants was very low as it took 6-10 months to drill a 2000m well, which now takes about 2 months. By 1990, full- time consultants and experts had been phased out, and the geothermal programs are now managed and performed entirely by KenGen staff.

TABLE 2: Number of Fellows from four African Countries and their specialization 1979-2004

	Ethiopia	Kenya	Tunisia	Uganda
Geological Exploration		1		2
Borehole Geology	3	4		1
Geophysical Exploration	3	7		1
Borehole geophysics	1			
Reservoir Engineering	5	6	1	
Chemistry of fluids	3	6		2
Environmental Studies		6		
Geothermal Utilization	5	1	5	
Drilling Technology	2	4	6	6
Total	22	35	**12**	**12**

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