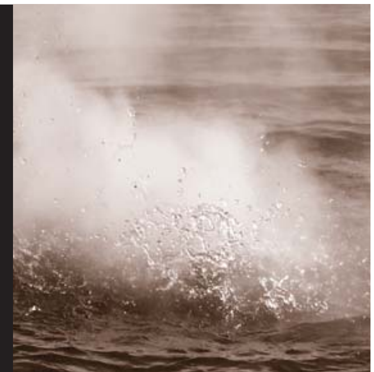

Rocky Mountain Oilfield Testing CENTER

Ormat: Low-Temperature Geothermal Power Generation

Naval Petroleum Reserve No. 3, Teapot Dome Field, Wyoming

Final Report for the period of September 2008 - February 2010
Completed March 2010

U.S. DEPARTMENT OF ENERGY

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Ormat: Low-Temperature Geothermal Power Generation

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ABSTRACT

In many oil fields, a large volume of water is produced with the oil. In a majority of the fields, water is a waste stream and has a temperature below 220 °F. Because of the large volume, this water may still be hot enough to be capable of generating significant electrical power for facility consumption. To verify this concept, the U.S. Department of Energy's (DOE) Rocky Mountain Oilfield Testing Center (RMOTC) has developed a program to test low-temperature power generation from oilfield waste streams. The program started with a Cooperative Research and Development Agreement (CRADA) between Ormat Nevada, Inc. and the DOE.

The test unit was an air-cooled, factory integrated, skid-mounted standard design 250 kW Ormat Organic Rankine Cycle (ORC) power plant. This unit was installed at the Naval Petroleum Reserve No. 3 (also known as Teapot Dome Oil Field) north of Casper, Wyoming. The ORC power unit was designed to use 40,000 bpd of 170 °F produced water from the field's Tensleep formation to vaporize the working fluid, isopentane. The projected gross power from the unit was 180 kW (net of 132 kW). Because of the lack of sufficient cooling water for the system, an air-cooled unit was designed. The unit was put into service in September 2008 and operated until February 2009 when the unit was shut down because of operational problems. During this period, the unit produced 586 MWhr of power. The operational problems, caused by operating in excess of the unit capacity, resulted in changes in the control system and repairs to the generator/turbine system. The unit was briefly tested following maintenance and repair but was shut down because of field and well issues. The unit was restarted in September 2009. Between September 2009 and the end of February 2010, the unit produced 478 MWhr of power at a more consistent rate than before the extended shut down.

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DESCRIPTION OF NPR-3 AND ITS GEOTHERMAL POTENTIAL

The Rocky Mountain Oilfield Testing Center (RMOTC) is located at the Teapot Dome Oil Field, also known as the Naval Petroleum Reserve No. 3 (NPR-3). The field is 35 miles north of Casper, Wyoming (Figure 1). NPR-3 is operated by the Department of Energy as both a producing oil field and a test site for new and developing oil and gas and renewable energy related technologies.

The field is a 9,481-acre operating stripper well oil field offering a full complement of associated facilities and equipment on site. There have been 1,319 wells drilled in the field with 589 of them plugged and abandoned. Of the 730 remaining wellbores, 300 are producing wells in nine producing reservoirs ranging in depth from 250 to 5,500 feet. The remaining wellbores are temporarily shut-in or are used for testing.

Two formations at NPR-3, the Tensleep and Madison formations, produce sufficient hot water for the generation of low-temperature geothermal energy. The current flowing water resource from these formations is 45,000 barrels of water per day (BWPD). The present and potential areas for Tensleep and Madison production are shown in Figure 2. The average production temperature for the Tensleep is 195-200 °F and for the Madison is 200-210 °F. It is projected that with minor work on existing wells, the rate for the combined Tensleep and

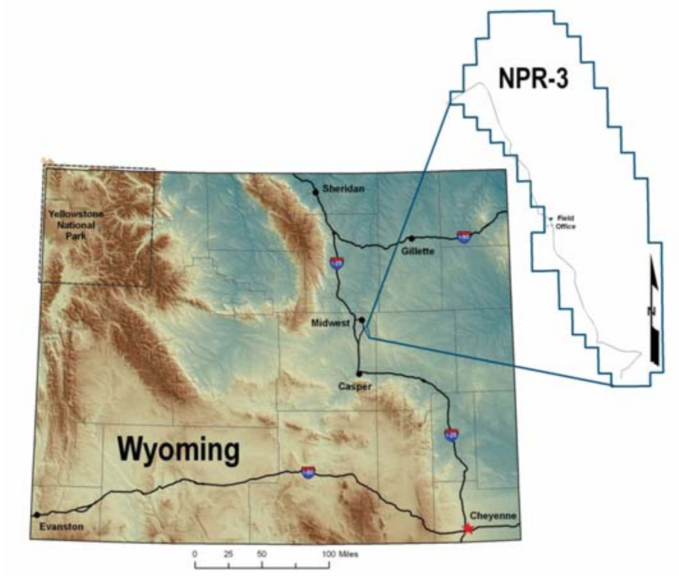

Figure 1. Location map for RMOTC.

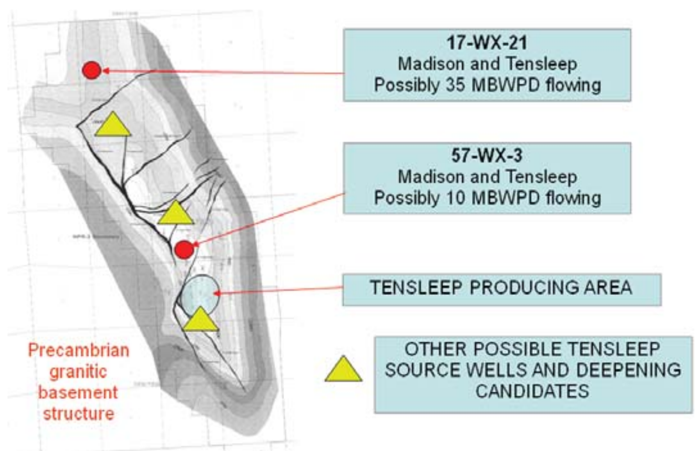

Figure 2. Potential geothermal supply wells at NPR-3.

Well	Zone	Rate, MBWPD		Comments
		Low	High	
17-WX-21	Madison	20	25	Flowing
17-WX-21	Tensleep	4	10	Needs perforating
41-2-X-3	Tensleep	1	3	Flowing
41-2-X-3	Madison	6	12	Needs deeping
48-X-28	Tensleep	2	6	Flowing
61-2-X-15	Tensleep	2	6	Flowing
61-2-X-15	Madison	6	12	Needs deeping
57-WX-3	Madison	2	6	Flowing
Total all other Tensleep Production		40	60	Pumping
Total Flowing Production		43	80	Projected
Total Pumping Production		86	160	Projected
All Potential Production		**126**	**210**	**All on pump**

Table 1. NPR-3 Projected Geothermal Potential

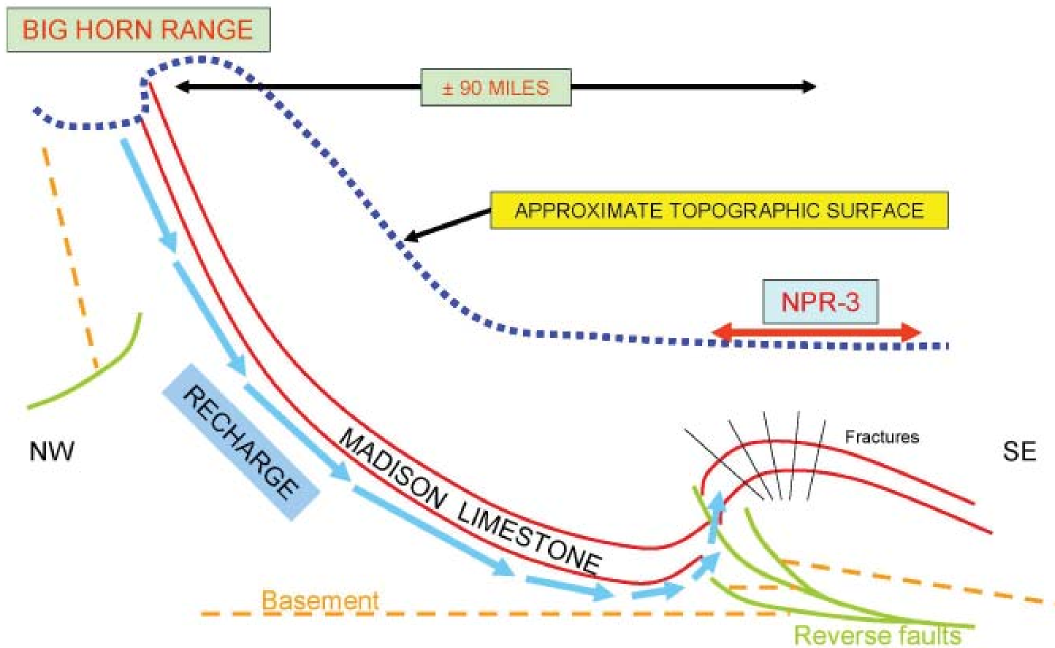

Figure 3. NPR-3 recharge system.

Madison produced water would be between 126 and 210 MBWPD (Table 1). The water resource in both the Tensleep and Madison formations are continuously recharged from mountains to the west, Figure 3. Currently, the hot water in the oil field is a waste stream and is treated through a series of treatment ponds and then discharged into an adjacent stream.

DESCRIPTION OF THE CRADA

In January 2007, Reno-based Ormat Nevada Inc., which develops and operates geothermal power plants in Nevada, California, and Hawaii, entered into a Cooperative Research and Development Agreement (CRADA) with the U.S. Department of Energy to perform a validation of an Ormat organic Rankine cycle (ORC) power system to generate commercial electricity from hot water produced at a typical oil field. The purpose of the project, conducted at RMOTC, was to validate the premise that a binary geothermal power generation system that uses the hot water produced by an oil field can reliably generate commercial electricity. The power system tested was an air-cooled, factory integrated, skid-mounted standard design Ormat ORC power plant similar to the standard design Ormat Energy Converter (OEC) installed at the Rogner Hotel in Austria.

Prior to installation of the power system, the hot water in the oil field was a waste stream and was treated through a series of treatment ponds and then discharged into an adjacent stream. The electricity produced from the unit described above was used to power field production equipment. The ORC power unit was interconnected into the field electrical system and the produced energy was metered and monitored for reliability and quality. Ormat supplied the ORC power unit while the DOE installed and operated the facility for a 12-month testing period.

POWER GENERATION UNIT

The unit was designed, constructed, and supplied by Ormat Nevada Inc. Design was based on Ormat's experience and operation of geothermal power plants in Nevada, California, Hawaii, and Austria. The purpose of the initial testing was to validate the premise that a binary geothermal power generation system that uses the hot water produced during normal oilfield operations can reliably generate commercial electricity.

Following are original design information and the performance expected. The resource was expected to be flowing at the inlet to the power unit at the relatively low temperature of 170 °F. At the design ambient tempera-

Table 2. OEC Projected Performance at Design Temperature

Flow Rate	584,000 pounds per hour
Inlet Temperature	170 °F
Outlet Temperature	152 °F
Ambient Temperature	50 °F
Generator Gross Power	180 kW
Net Power Output	132 kW

Figure 4. Organic Rankine Cycle (ORC) 250 kW low-temperature geothermal system at NPR-3.

ture of 50 °F, the anticipated performance is given in Table 2.

This unit has a nominal rating of 250 kW and has three main components: an 8-foot by 40-foot vaporizer skid which also contains the turbine, generator, and instrumentation cabinet; and two 8-foot by 40-foot finned-tube condensers (Figure 4). The unit was wired directly into a 480-volt leg of the field power distribution system. The power from the unit is metered and monitored for reliability and quality. For field safety purposes, the Ormat unit was installed such that the unit shuts down if the main field power is interrupted.

RESULTS AND DISCUSSION

The air-cooled power generation system was installed in August 2008. The design of the unit was based on a relatively low produced water temperature of 170 °F and an average ambient temperature of 50 °F, Table 2. At design conditions, the nominal 250 kW unit would produce a gross power of 180 kW (net 132 kW). However, between initial design and installation, two major changes were made. With the equipment, the pump for the working fluid, isopentane, was incorporated into the turbine-generator package. By incorporating this feature, the parasitic electrical load of the unit was decreased from 48 to 25 kW. On the field side, the Tensleep production facility was upgraded and an insulated, produced water storage tank installed. This upgrade kept the produced water temperature in the 195 to 198 °F range.

The higher inlet water temperature permitted the system to operate nearer the optimum/maximum net power output of 225 kW. The operational results are divided into two phases. The first phase is from September 2008 to February 2009, the period from initial startup of the unit until shutdown for repair and maintenance. The second phase is from September 2009 to January 2010. The period between the two phases was when the unit

Table 3. Design & Operational Data

	Design	Operational Results	
		Phase 1	*Phase 2*
Flow rate, bpd	40,000	12,000 to 40,000	11,500 to 35,000
Total hot water used, bbl		3,047,192	2,257,747
Inlet water temperature, °F	170	195 to 198	196 to 198
Outlet water temperature, °F	152	80 to 170	47 to 150
Average ambient temperature, °F	50	-7 to 85	-2 to 58
Generator gross power, kW	180	105 to 305	160 to275
Daily avg. net power output, kW	132	80 to 280	135 to 250
Overall avg. net power, kW		171	206
Average net power, last 30 days of each phase, kW		207	217
Total power produced, kWhr		586,574	478,054

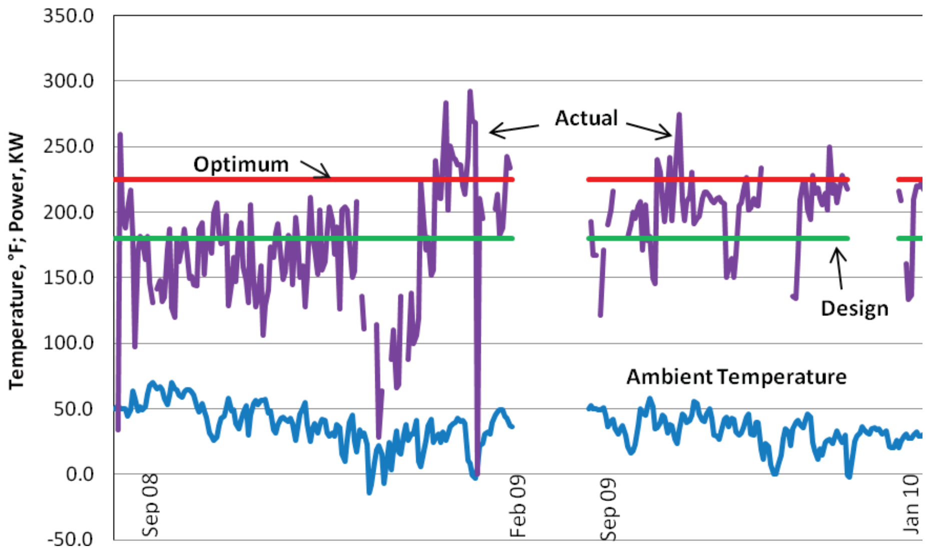

Figure 5. Daily power output and ambient temperature.

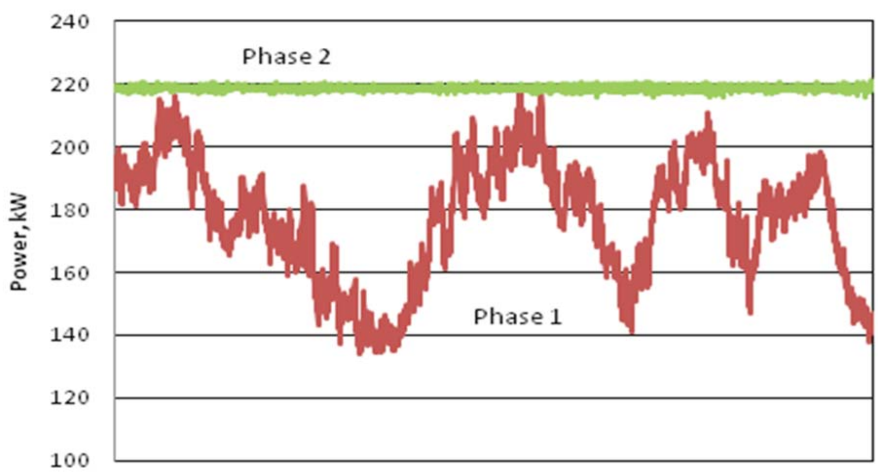

Figure 6. Daily power fluctuation.

was down for repairs and maintenance and for correction of field issues. These corrections are discussed later.

For phase 1, the net power output averaged 171 kW with a range of 80 to 280 kW, Table 3. The output power fluctuated with the average daily ambient temperature when a constant hot water inlet volume was used, Figure 5. The power fluctuation is evident through the normal daily temperature cycle, red line on Figure 6 for phase 1. During phase 1, the unit produced over 586 megawatt hours of power from 3 million barrels of hot water. The online percentage for the unit during this period was 91% considering both field and unit related down time. The down time attributed to unit issues was only 3%. Therefore, the unit had a 97% online percentage. The system related down times were largely the results of the operator's learning curve until the shutdown in February 2009.

In February 2009, the unit was shut down because of equipment problems. These repairs were required because the unit was operated above the net rating of the generator of 225 kW for a two-week period, Figure 5. It was determined that changes in the control system and repairs to the generator/turbine system were needed. The higher than acceptable power generation damaged the front bearing and eventually the outboard bearing on the generator. The unit was removed, repaired, and reinstalled with a new control system. The repairs consisted of replacement of the generator bearings and replacement of the mechanical seal between the turbine and generator. The new control system included the installation of a second hot-water flow control valve, a turbine vibration sensor, and temperature probes on both generator bearings. The startup control for the unit was also changed providing for a smoother startup. The unit was restarted in May 2009 but was shut down to address related field issues with the production wells and electrical system.

To date, phase 2 has averaged 206 kW net power output with a range of 135 to 250 kW, Table 3. The output power fluctuates with the average daily ambient temperature when a constant hot water inlet volume is used, Figure 5. The daily power fluctuation has been decreased; compare green line for phase 2 with red line for phase 1 in Figure 6. During phase 2, the unit has produced over 478 megawatt hours of power from 2.2 million barrels of hot water. The online percentage for the unit, eliminating downtime caused by field activities, has been at 97%. The power output of the unit over the last 30 days has averaged 216 kW with a control set point of 220 kW.

RMOTC

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