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COMPILATION OF FAILURE DATA AND FAULT TREE ANALYSIS
FOR GEOTHERMAL ENERGY CONVERSION SYSTEMS

PROJECT REPORT

by

F.L. Miller, Jr.

D.E. Zimmerman

Water Resources Center
Desert Research Institute
Las Vegas, Nevada 89109

Grant No. R806457

Project Officer

Roy B. Evans

Environmental Monitoring Systems Laboratory
U.S. Environmental Protection Agency
Las Vegas, Nevada

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ABSTRACT

The failure data for geothermal energy conversion facilities collected to date are compiled and tabled. These facilities have not accumulated sufficient production history to reliably estimate component failure rates. In addition, the improvements made in drilling technology in recent years may have made less pertinent the accumulation of data on well failures. A fault tree analysis has been applied to a double flash geothermal energy conversion system.

The analysis revealed that the probability of contaminating an aquifer from leaks in production or injection wells is higher than the probability of a major leak elsewhere in the system.

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INTRODUCTION

This work was funded by part of grant No. R806457 from the U.S. Environmental Protection Agency. The overall project goals were to assess standard and innovative groundwater monitoring techniques and systems applied to geothermal energy development impacts on associated groundwater systems. The research effort integrated monitoring techniques, legal constraints, geothermal system fault tree analysis and comprehensive solute transport and geochemical models. Results provide a means to assess site specific groundwater-geothermal systems and identify the optimum monitoring methodologies and network design to detect groundwater impacts. The models will also allow an evaluation of potential worst case impacts on the groundwater system.

The initial work for this project consisted of the compilation of failure data from geothermal sites which are presented in this report. The failure data were evaluated and mechanisms by which failure can occur were defined. The probabilistic aspects of failure rate estimation are discussed and the usefulness of fault tree methodology as a tool for studying geothermal energy conversion systems is demonstrated.

GEOHERMAL ENERGY CONVERSION SYSTEMS

The technology for the conversion of geothermal energy to electricity is in a transitional stage of development. The conversion can be performed in a cost effective manner, the types of equipment necessary to operate safely and consistently are known, but the operating experience accumulated to date is insufficient to estimate failure rates with reasonable precision. Operating experience in the United States is limited to the Geysers Known Geothermal Resource Area (KGRA) which is located 180 km north of San Francisco, California. This is an unusual KGRA because it is a dry steam system rather than one of the more common liquid dominated systems being developed elsewhere in the United States. Internationally, electrical power production with capacities of 10MW or more from liquid dominated systems are on-line in Japan, Mexico, New Zealand, and El Salvador, (Greider, 1979). A number of different technologies are available for the conversion of geothermal energy to electricity. The selection of the power conversion unit is controlled primarily by the chemical and temperature characteristics of the geothermal reservoir. Generally there are two basic types of systems. The flash system allows the geothermal fluid to flash to steam which is then used to drive the turbine. The other is a binary system which utilizes a secondary fluid such as freon or isobutane which is heated by the geothermal fluid to drive the turbine.

A double flash power generation system (Figure 1) will be used to demonstrate the fault tree methodology. All systems are somewhat similar in that they require production wells, a system of pipes and valves for moving fluid from the wells to the plant, a power conversion unit, and in most cases, injection wells for disposal of spent fluids. The number of both production and injection wells and the amount of surface piping are dependent on the type of power conversion unit selected and the chemical and temperature characteristics of the geothermal reservoir. The

FIGURE 1: Double flash energy conversion system.
From Sung, et al, 1980.

double flash system uses the geothermal fluid as the actual working fluid and has the same components as a single flash system but uses a second flash tank for increased efficiency. In the double flash system, unflashed fluid exiting the first stage (high pressure) flash tank enters a second flash tank. In the second flash tank (low pressure), another pressure drop produces additional steam. This system can be designed with either one or two turbines. In the case of the one turbine system, steam from both levels of flashing drive a single turbine. In the two turbine system, the first turbine is driven by the steam from the high pressure flash. The second turbine is powered by a combination of steam exiting the first turbine and the steam produced in the low pressure flash tank. The power plant at Wairakei, New Zealand is currently the only multi-flash system in commercial operation, (PIC, 1979). As can be seen in Table 1, the double flash system is the most common system considered for proposed plants in the United States.

FAILURE DATA BACKGROUND

Current equipment used to generate power from a geothermal resource requires a fluid with a minimum reservoir temperature of 200°C for economical power production (PIC, 1979), although technological advances currently being made should allow power production from lower temperature reservoirs in the future. The high temperature, pressure and often poor water quality of geothermal fluids are conducive to failure of equipment. A number of reports have qualitatively identified the factors contributing to failure and these are summarized in Table 2. Of the factors listed in Table 2, the problems associated with high temperature, poor water quality and the geologic environment are most significant.

Through a literature search and contact with geothermal operators it was found that detailed data on failures were generally not available. The best documented failures have been those associated with wells. Unfortunately, even these data are often

TABLE 1: PROPOSED U.S. GEOTHERMAL POWER PLANTS

<u>Site (KGRA)</u>	<u>Utility or Plant Operator</u>	<u>Year of Start-Up</u>	<u>Capacity MW</u>	<u>Plant Type</u>
Salton Sea, CA	SDGE*	1985	50+	Flash Binary
Salton Sea, CA	SCE**	1982	10	Single Flash
Salton Sea, CA	Magma	1982	49	Double Flash
Westmorland Prospect (Salton Sea, CA)	Republic	1982	50	Double Flash
Brawley, CA	SCE	1980	10	Single Flash
Heber, CA	SCE & SDGE	1982	50	Double Flash
East Mesa, CA	SDGE	1981	48	Double Flash
East Mesa, CA	SDGE	--	10	Binary
Desert Peak, NV	Sierra Pacific	in planning	20-50	Double Flash
Roosevelt Hot Springs, UT	Rogers Engineering Co.	in planning	52	Double Flash others being considered
Valles Caldera, NM	Public Service Co. of New Mexico	1982	50	Double Flash

Source: Petroleum Information Corporation, 1979 and Anderson, 1979.

SDGE* - San Diego Gas and Electric Company
SCE** - Southern California Edison

TABLE 2: GEOTHERMAL EQUIPMENT FAILURE CAUSES

<u>Initial Condition</u>	<u>Resulting Failure Mechanism</u>	<u>Possible Failure Point</u>
High Temperature	1) thermally induced stress 2) thermal cycling	All components Well casing problems most severe
Poor Quality Fluids	1) corrosion 2) scale 3) abrasion 4) dissolved gases	All components
Geologic Environment	1) drilling and cementing problems associated with loss circulation zones	Well casing
High Pressure	1) pressure induced stress	All components
Present Stage of Development	1) inadequate materials 2) inadequate design and workmanship 3) lack of operating experience	All components
Natural Disasters or Accidents	1) landslides 2) earthquakes 3) accidents as a result of personnel error 4) vandalism or terrorism	All components

Source: Sung et al, 1980; Summers et al, 1979.

lacking in such important items as discharge rates, detection method and cause of failure. Failure data on equipment such as surface piping and the energy conversion components are also limited.

On the basis of the failure data collected, a review of geothermal site plans and consideration of possible fluid release points the following six components were considered for failure analysis: 1) production wells; 2) wellhead assembly; 3) piping system to plant; 4) power plant; 5) piping system to disposal system and 6) injection wells/disposal systems.

PRODUCTION WELLS

Well failure can occur in two distinctly different operational modes. Failure can occur during the drilling of the well or can take place during production. The incomplete nature of well failure data can be expected considering the environment in which data can be gathered. Failures hundreds or thousands of meters below ground can only be investigated by a series of remote techniques.

Failures during drilling operations can result in uncontrolled discharge from the well bore. This condition is known as a blowout and is of particular concern due to the length of time uncontrolled discharge can last. This type of failure is both difficult and costly to repair. Blowout of a well is possible when the formation fluid pressure exceeds the pressure of the drilling fluid in the well bore. This can occur in zones of lost circulation, where the formation being drilled is either very permeable, has an extensive fracture or fault system, or is cavernous. Drilling fluid is lost in these zones and can reach the point at which the formation fluid pressure exceeds the pressure of the drilling fluid column. Blowout preventers are required safety equipment during the drilling of geothermal wells. If a significant pressure drop occurs a blowout preventer consisting of either rubber annular bags or rams will seal against the drill pipe, (Maurer, 1975).

To control the movement of formation fluids around the outside of the well both during drilling and production, the well bore size is reduced a number of times. At each reduction in hole diameter the bore is cased and cemented. An example of the casing and cementing of wells at Wairakei, New Zealand is shown in Figure 2.

Much of the drilling and completion technology for geothermal wells has come directly from petroleum industry experience. Some of these materials and tools have proven inadequate in the high temperature, pressure and corrosive nature of geothermal fluids and have resulted in well failures. This has led to the development of a number of techniques and materials designed specifically for use in geothermal wells. Many individuals from both private and governmental sectors feel that drilling equipment and technology currently in use have proven sufficient to prevent well blowouts, (Hartley, 1978; Micheals, personal communication, 1980; Stelling, personal communication, 1980). The incentive to prevent this type of failure is definitely borne by the geothermal developer because of the high costs of drilling operations and subsequent costs of controlling a well blowout. A typical well at the Geysers costs between \$825,000 and \$1.6 million to drill and complete. If the well can be approached following a blowout, it is sometimes possible to stop the discharge by pumping water or other fluids into the bore to quell the well. Following quelling, the bore could then be cemented and cased and drilling could continue or the bore could be abandoned. If these methods fail or are not possible a second well can be deviation drilled into the discharging well.

Casing failure in a well that is under production is one of the most costly and difficult problems a geothermal operator must deal with. Failure of a well casing can range from a minor fracture to a complete collapse. Discharge can be very minor or can constitute the total flow of the well resulting in a blowout condition.

FIGURE 2. TYPICAL CASING DESIGN AT WAIRAKEI, NEW ZEALAND.
FROM DEFFERDING, 1980.

Indications of well failure can be as obvious as visual discharge at the surface or as subtle as a change in the fluid chemistry. Other indicators of casing failure are a reduction in flow or temperature, change in the steam/water ratio, or inclusion of sand or other formation material in the production fluid. Once a casing failure is suspected a number of techniques can be used to locate and define the problem area. Caliper logs which measure the inside diameter of the casing, along with temperature and pressure logs can be used to locate areas of failure. When a failure is located mechanical tools can then be used to make lead impressions of the casing. These impressions can define the severity of the failure, (Dominguez, et al, 1975, 1978). Failure of the cement between the casing and the formation usually occurs with casing failure. Cement bond logs are sometimes successful in determining the quality of the bond between the casing-cement and cement-formation boundaries, (Pettitt, 1980). If repairs are possible, a smaller diameter casing will be cemented in place over the failed area. If repairs are not possible or are unsuccessful, the bore is usually filled with cement and abandoned.

A number of inter-related factors contribute to casing failure. These factors are 1) thermal stresses or thermal cycling; 2) inadequate cementing of the casing; and 3) corrosion. The following scenario describes the inter-relationships of these factors and what is considered the most probable cause of failure:

During drilling of a well, formations are encountered that are highly permeable. When the well is cased and cemented a poor cement bond between the casing and the formation is achieved in these zones, allowing the casing to differentially expand and contract. The well is completed and put into production. The casing is subjected to high temperature variations causing thermal

stresses. (The term thermal cycling is used to describe the expansion and contraction of the casing as it is alternately put on production and then shut-in as energy requirements or maintenance of the well or power plant dictate). The casing subsequently fails in the zone where the cement bond is poor due to the thermal stresses associated with production. Failure can occur by this mechanism very early in the life of a well or can occur much later when the casing is further weakened by both corrosion and thermal cycling.

Analysis of casing failures in the Italian geothermal fields found that failures were more likely to occur after high temperature variations and that the lower part of the casing string was more likely to fail (Cigni, et al, 1975). It was also found that failures were always associated with problems that occurred during drilling operations, principally in the cementing stage. Investigators at Cerro Prieto, Mexico (Dominguez, 1978) and Wairakei, New Zealand (Pritchett, et al, 1978) have also reported casing failures that were closely associated with problems related to cementing of the wells. Geothermal operators in New Zealand and the Phillippines have noted that failure can occur between two casing strings if water droplets are trapped in the cement. When the well is put into production, the trapped water will expand and generate very high collapse forces. Their solution has been to use casing with a wall thickness sufficient to withstand the expected collapse forces. Major contractors in the U.S. who cement wells, feel that improvements in cementing techniques have eliminated many of the problems leading to failure and more emphasis needs to be placed on corrosion as a cause of failure, (Shryock, personal communication, 1980). While this may be true in respect to wells in which lost circulation was not a problem, serious cementing problems still exist in wells that have severe lost circulation zones, (Goodman, 1981). The corrosive nature of geothermal fluids not only affects the steel of the casing but

also the cement. High temperature chemical alterations of the cement have led to casing failure in both Mexico and Italy. Deterioration of the outer casing and cement caused by external corrosion from infiltration of highly mineralized surface water has also led to casing failure at several locations (Ellis, 1979).

The difficulty in identifying causes of casing failure should be recognized. Due to the limited amount of data that can be collected, it is difficult to precisely determine the cause of failure. During the time of data collection for this report both the literature collected and discussions with government and private operators have stressed the rapid technological improvements by the geothermal industry. The California Division of Oil and Gas reported that starting in 1975 there have been no serious problems associated with geothermal well drilling in California, (Stelling, personal communication, 1980). To date we have not compiled enough failure data to statistically verify this, but indications are strong that the improved technology has in fact decreased failure rates in newly constructed wells. As more data is compiled, it may be possible to identify wells more likely to fail by their age.

WELLHEAD ASSEMBLY

The basis for separation of the wellhead assembly from other components of the piping system is the potential for uncontrolled discharge in the event of failure. The wellhead assembly typically consists of several valves which are used to regulate flow from the well. In the event of failure of a pipe line, these valves would be closed to stop flow from the well. Failure of these valves to close due to either corrosion or scale would then result in uncontrolled discharge. Uncontrolled discharge related to wellhead failure also exists if the entire wellhead becomes separated from the well casing. This situation is avoided by proper installation of the wellhead assembly. A well-blowout has occurred at Cerro Prieto, Mexico as a result of poor workmanship

which resulted in the entire wellhead assembly separating from the casing, (Dominguez, 1978).

PIPING SYSTEM TO PLANT

Data on failure of surface equipment has come mainly from the Geysers KGRA. In 1974 a law concerning accidental releases of water with sections applicable to geothermal resources was adopted in California. This law requires operators to report releases to the California Regional Water Quality Control Board. Information on 47 failures at the Geysers were obtained from this agency. Data on surface failures from foreign sources has been very limited. In contrast to the difficulty in identifying and repairing a well failure, failure of surface equipment is relatively easy to detect and repair. This could account for the lack of available data on this type of failure. Costs of repair are relatively low and, generally, technically straight forward.

All components of the piping system are susceptible to failure as a result of corrosion, abrasion or scale formation. Dissolved gases, particularly H_2S , can also contribute to failure. Thermal stresses and thermal cycling of above ground pipes is not as significant a problem as that described for wells. Generally U-shaped sections of pipe are installed in the line to allow for thermal expansion.

Numerous studies have been conducted on corrosion, abrasion and scale rates at specific geothermal sites, but extrapolation of these data into failure rates is limited because of the experimental nature, limited time period and wide variation in fluid chemistries between these studies. Most of these studies have been concentrated in the Imperial Valley area of California where severe corrosion, abrasion and scale problems are associated with brines with salinity values as high as 300,000 mg/l and temperatures above $315^{\circ}C$. Corrosion studies of various metal alloys at the Salton Sea KGRA have been conducted by Lawrence Livermore Laboratory. These studies have shown that steels containing

either molybdenum or chromium and molybdenum withstand corrosion better than the carbon steel pipes that are most commonly used, (McCright, et al, 1980). Test facilities at this site use carbon steel pipe with wall thicknesses of 1.27 cm to compensate for the high corrosion rates. Flow from a liquid dominated reservoir is commonly two phase having both a liquid and a steam component. Tests at the Salton Sea KGRA showed that corrosion rates were higher on the bottom of the pipe where the liquid phase of flow is dominant. Corrosion and abrasion can be expected to be higher where the flow impinges directly on the pipe surface as at an elbow where a directional change in flow occurs. These studies have demonstrated that steels with either molybdenum or chromium alloys would be cost effective in preventing failures. Pipes with these alloys cost about two to three times that of carbon steel but savings in maintenance cost due to corrosion failure could be realized, (McCright, et al, 1980).

Due to the lack of operational experience in the United States and difficulty of obtaining data on pipe and valve failures internationally, the failure analysis of these components will rely heavily on the work by Sung, et al, 1980. This work utilized data from a nuclear reactor safety study known as the "Rasmussen Report," 1975.

POWER CONVERSION SYSTEM

Data collected to date on failure of components in the power conversion system have been sparse due to limited operational experience in the United States. A literature search has revealed little more than conceptual plans.

Equipment used in the power conversion system is shown in Figure 1. The principal components of this system are: 1) flash tanks in which steam is formed by a reduction in pressure; 2) turbine and generator; 3) direct contact condensor; 4) steam ejectors used for removal of noncondensable gases from the condensor; 5) cooling tower; and 6) H₂S scrubber. The power

conversion systems in use at the Geysers KGRA are similar to this system with the exception of the flash tanks which are not necessary due to the dry steam produced from the wells at the Geysers (Kuwada, 1979).

The majority of failures that have occurred at the Geysers have been at the power plants operated by Pacific Gas and Electric Company. Principal failure points in the power conversion system have not been associated with the major components but with the pipes and valves which transmit fluid between these components. Fluids released in these failures are usually contained within the perimeter of the power plant site and have not had a serious impact on the environment, (Snetsinger, personal communication, 1980).

DISPOSAL SYSTEMS

Two methods for disposal of geothermal fluids are currently in use (Table 3). Fluid may be either injected or discharged on the surface. Injection of spent geothermal fluids is considerably more difficult and costly than surface disposal but this method has the advantages of minimizing the environmental impact on surface waters, prolonging the production life of the geothermal reservoir and preventing land subsidence. For these reasons injection studies have been conducted or are on-going at most sites. Injection studies have been conducted at both Cerro Prieto, Mexico (Rivera, et al, 1978; Tsang, et al, 1978) and Wairakei, New Zealand, (Allis, 1980) and additional studies are planned.

Injection of fluids at the Geysers KGRA has been very successful due largely to the low total dissolved solids of the fluid. Problems with precipitation of elemental sulphur in the fracture system at the Geysers reduces the injection rate of individual wells. As a method to control the loss of permeability the wells are shut-in and the rise in temperature is sufficient to melt the sulphur which causes it to then migrate further into the formation away from the well bore, (Chasteen, 1975). Successful injection tests have been conducted at other KGRAs in the United

TABLE 3: DISPOSAL METHODS AT SELECTED OPERATING
GEOTHERMAL SITES

<u>Site</u>	<u>% Injected</u>	<u>% Surface Disposal</u>
Larderello, Italy	20	80 to surface streams
Wairakei, New Zealand	0	100 to Waikato River
Otake, Japan	100	None
Hatchobaru, Japan	100	None
Cerro Prieto, Mexico	0	100 to evaporation ponds and Sea of Cortez
Ahauchapan, El Salvador	30	70 discharged thru 86 km long canal to ocean
Geysers, USA	100	None

States, but these tests were of short duration and provide little data for failure analysis. Injection tests with fluids of poor quality in the Imperial Valley of California have met with severe scaling and plugging problems, (Vetter, et al, 1979; Howard et al, 1978). Major differences in fluid chemistries exist between dry steam reservoirs such as the Geysers KGRA and liquid dominated KGRAs and the amount of fluid requiring injection is significantly higher at liquid dominated KGRAS, (Table 4). Injection at the Geysers accounts for 20% of the dry steam produced with the balance being evaporated in the cooling tower. Estimates of fluid injection at a liquid dominated reservoir utilizing a flash type system are as high as 87% of the total fluid produced, (PIC, 1979).

Injection of geothermal fluids in Japan is required by law. Injection of fluids at Otake, Japan have been relatively successful. Precipitation of CaCO_3 has reduced the injection rates of some wells requiring additional wells to be drilled, (Defferding, 1980). At Hatchobaru, Japan fluids with total dissolved solids concentration of 4,700 mg/l at the production wellhead are successfully injected but require treatment with hydrochloric acid to reduce scaling.

Fluids are generally contained in ponds prior to injection to allow settlement of solids. At the Geysers, overflow of sediment ponds has occurred three times. In each case, an airlock formed in the injection line causing the water level to rise in the pond. The pond high level warning devices failed and the ponds overflowed.

Determination of failure rates for the components utilized in an injection system is not possible at this time. Due to the unique nature of the Geysers KGRA these data would not be representative of other KGRAS where failures could be expected to be significantly higher.

Table 4. ESTIMATES OF GEOTHERMAL WASTES FROM SELECTED EXISTING POWER PLANTS

Power Plant Location	1977	Reservoir Type(a)	Reservoir Temp, °C	Fluid Production Rates(b)				Total		Gas Wastes	
	Output, MWe			Well Flow		Condensate(c)		Dissolved Solids			
				T/Mh	T/yr x 10 ⁶	T/Mh	T/yr x 10 ⁶	ppm	T/yr x 10 ³	% gas/steam wt	T/yr x 10 ³
The Geysers, U.S.	520	DS	200	7.5	4.2	1.7	7.74	600(d)	4.65(d)	0.8	273
Larderello, Italy	420	DS	220	8.9	32.7	1.3	4.78	NA	NA	5	1640
Wairakei, New Zealand	193	FS	260	44.8	75.7	1.8	1.47	4,400(e)	333	2.2	333
Cerro Prieto, Mexico	75	FS	270	31.5	20.7	1.3	0.854	20,000(e)	414	1.2	49.7
Hatchobaru, Japan	50	FS	290	20	8.76	0.8	0.350	4,700(e)	41.2	0.3	5.26

(a) DS = dry steam; FS = flashed steam.

(b) Tonne/Mh. = 1000 kg/Mh. Yearly rates of 8760 hr/yr assume continuous well flow.

(c) Condensate flow varies with weather conditions.

(d) TDS at The Geysers in condensate. It varies from 300 to 1000 ppm with weather conditions.

(e) TDS of wellhead fluids. At Cerro Prieto, fluids in the evaporator pond have about 75,000 TDS.

From Defferding, 1980.

PIPING SYSTEM TO DISPOSAL SITE

Although failure rates for these components are not available, mechanisms by which failure can occur can be identified. These pipes are susceptible to failure by the same mechanisms described for the piping system transmitting fluid from the wells to the power plant. Corrosion rates which are temperature dependent could be lower in the injection piping system but if the fluids pick up oxygen from the atmosphere this could increase corrosion rates, (Defferding, 1980). Problems with scale deposition are expected to be considerably higher in all components of the injection system. Significant chemical changes occur when a fluid is flashed and a reduction in temperature occurs. The resulting chemistry of the fluid with respect to saturation of calcium and silica ions in particular, and the formation of scale are very complex, (Vetter et al, 1979; Howard et al, 1978).

INJECTION WELLS

Injection of fluids into a geothermal reservoir is done at depths either above or below the main reservoir to prevent cooling of the main reservoir. At the Geysers, injection is done at depths below the main reservoir and as far as possible from existing production wells. The wells used for injection are generally production wells which were poor producers. Since these wells are completed in zones of high temperature they are susceptible to failure by the same mechanisms described for production wells. Temperature variations probably do not reach the extremes encountered in production wells and failures related to thermal cycling could be lower in injection wells. As discussed previously, problems with scaling are more intense and therefore failures could be higher by this mechanism. A significant problem with injection of fluids is the plugging of the formation where injection takes place. The formation of precipitates can increase greatly when two fluid with different chemical composi-

-tions and temperatures are mixed. Individual production wells at Cerro Prieto, Mexico have produced fluids from several different depths within the well. The differences in chemistries and temperatures between these zones has resulted in scale formation severe enough to force abandonment of the wells, (Dominguez, 1978).

POTENTIAL FLUID RELEASE RATES

PRODUCTION AND INJECTION WELLS

Failure of well casing can result in discharges that range from very minor amounts to the total flow of the well. The rate of discharge is controlled by the type of failure and the flow rate of the well. Discharge rates associated with casing fractures could be relatively small, while casing collapse could involve the total discharge of the well. Fluids may discharge directly into the surrounding formations or if the casing cement is deteriorated, flow may move through the cement and discharge at the surface or into formations different than where the original failure occurred. Production and injection flow rates vary widely between different geothermal reservoirs. In some areas pressures are not high enough in the reservoir for flow to occur naturally. In these cases and where flow rates are low, pumps can be used. Table 5 lists maximum known flow rates at KGRAs in the United States. These numbers represent the highest probable discharge rate in a production well blowout. Data for injection well flow rates are rather limited but generally are higher than those for production wells. The injection rates given in Table 5 represent rates during injection tests and do not necessarily represent the maximum flow rate possible.

TABLE 5: MAXIMUM FLOW RATES OF PRODUCTION WELLS
AND REPORTED FLOW RATES OF INJECTION
WELLS IN THE UNITED STATES

<u>KGRA</u>	Production Well <u>tons/hr</u>	<u>Salinity</u>	Injection Well <u>l/s</u>
Salton Sea, CA	227	250,000-330,000	---
Westmorland, CA	263	20,000-70,000	---
Brawley, CA	32	100,000	---
Heber, CA	200	14,000	185**
East Mesa, CA	336	2,500	14
Beowawe, NV	680	1,400	---
Roosevelt Hot Springs, UT	454	7,800	---
Valles Caldera, NM	23	6,000	---
Raft River, ID	---	---	79
Geysers, CA	68*	---	76
Niland, CA	---	---	38

*Average flow rate

**Estimated value

Sources: Anderson, 1979; Chasteen, 1976; PIC, 1979;
Ahmed et al, 1980; Defferding, 1980.

SURFACE INSTALLATIONS

Discharge rates from surface installations are a function of the type of plant and the particular design used. For the demonstration of the fault tree analysis, the system shown in Figure 1 is used. Potential fluid loss points (Figure 3) and potential discharge rates in the event of failure from components with common flow rates (Table 6) have been defined for this system by Sung, et al, 1980. The system in Figure 1 was designed to produce 50 MW and would require a production rate of 53,000 l/min from a reservoir of 182°C.

TABLE 6: POTENTIAL DISCHARGE RATES IN A DOUBLE FLASH
ENERGY CONVERSION SYSTEM

Potential Loss Point Groups (m³/min)

<u>Production Wellhead</u>	<u>Common Pipe (including manifold)</u>	<u>Flash Units</u>	<u>Common Pipe</u>	<u>Injection manifold</u>	<u>Injection Wellhead</u>
4	4-53	53*	53*	8-53*	8*

*less fluid flashing to steam
From Sung, et al, 1980

FIGURE 3: Potential fluid loss points for a double flash energy conversion system. From Sung, et al, 1980.