UCID - 16717

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.

MASTER

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

**ENVIRONMENTAL ASPECTS OF GEOTHERMAL ENERGY DEVELOPMENT
SALTON SEA/IMPERIAL VALLEY AREA**

Kathy Tonnessen

March 1975

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

etb

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ENVIRONMENTAL ASPECTS OF GEOTHERMAL ENERGY DEVELOPMENT

SALTON SEA/IMPERIAL VALLEY AREA*

by Kathy Tonnessen

Geothermal energy, the natural heat of the earth is currently the subject of a significant amount of investigation, experimentation and development as a source of potentially large amounts of electrical energy. These projects are concerned with three different types of geothermal energy:¹

- 1) dry steam geothermal - being developed at Geysers, California,
- 2) hot, dry rock - which is the resource under investigation by Los Alamos Scientific Laboratory, Lawrence Berkeley Laboratory, and Battelle PNW Laboratory. This approach involves deep dry rock fracturing and subsurface heating of injected waters, and
- 3) hot brines - which are the hot, often highly saline fluids such as those which underlie the Imperial Valley of California.

It is the last category of the resource is of most interest to LLL which is currently involved in a program involving the tapping of that thermal resource by development of a "Total Flow" concept¹ passing the well-head product consisting of approximately 20% steam and 80% hot brine through a nozzle producing the kinetic energy to turn a specially designed turbine which in turn drives a generator producing electricity. Spent brines would then have to be disposed of either by reinjection, evaporation or controlled release into surface aquifers.^{2,3}

LLL experiments involving materials performance and the effect of the corrosive brines on turbine and nozzle components are currently being conducted at a commercial well, Sinclair #4, by the Geothermal Energy and Mineral Co. near Niland, California in the vicinity of the Salton Sea (Geothermal Resource Council). This area within the Salton Sea/Imperial Valley

* Work done under the auspices of the U.S. Energy Research & Development Administration.

KGRA (Known Geothermal Resource Area as defined by the USGS) has been pinpointed as an area of anomalously high heat flow and as a region of large reserves of extremely hot, saline geothermal brines. There has been some commercial drilling in this area, but development on a wide scale has not been feasible thus far due to the problems of scaling corrosion and brine disposal.^{4,5}

More widespread development of the geothermal brine resources of this area will necessarily be accompanied by certain environmental problems. The impact of the development of this energy source in the Imperial Valley must be weighed against the benefits of increasing reserves of electrical energy, and possibly supplies of fresh water (desalinization)⁶ and valuable minerals reclaimed from the brines. Thus, it is necessary to consider the environmental setting and the probable impacts which would result from such development in order to mitigate any adverse conditions; to select the least harmful method of waste disposal; to select the optimum site for development and to develop a consciousness of the necessity for protection of the natural environment and present land use in that particular area.

Those environmental impacts considered to be the most likely to be encountered in the Salton Sea/Imperial Valley area and the most harmful to the natural environment will be discussed as "Major Impacts." Those factors which would represent a minor hazard or which are not an inherent problem in the Salton Sea/Imperial Valley area will be considered under the heading of "Minor Impacts." It must be pointed out that for many factors considered there is, at present, no definitive way of assessing the effect upon the Imperial Valley ecosystem. Therefore, research into the nature of these problems prior to development and constant environmental monitoring

during the developmental stages will be necessary to minimize disruption of the land and its existing uses.

The principle environmental problems associated with geothermal energy can be generalized as those of (1) gaseous emissions, (2) land pollution, (3) subsidence potential, (4) seismic considerations, (5) water pollution, (6) biological effects and (7) social effects.⁷

Despite these inherent problems, geothermal energy has been hailed by some as a source of "clean energy" using natural heat of the earth to generate power — without combustion.⁷ Although there may be no particulate pollution attendant with geothermal energy, there are other impacts associated with its development, particularly that of waste disposal of spent brines.

MAJOR IMPACTS

Waste Disposal (State of California)

Once geothermal energy is developed on a commercial scale in the Salton Sea/Imperial Valley area, the true impact of the potential water pollution/waste disposal problem will be felt. For each well at a generating capacity of 4.5 MW, at least 12.5×10^6 ft³ of brines per year will have to be disposed of.¹ Commercial power production of 1000 MW would require approximately 200 such wells. What makes the problem important as far as environmental impact is the highly saline nature of the brines, and the particular vulnerability of the surrounding agricultural land. This land supports year round cultivation and produces as many as four crops annually. The composition of the brines increases the potentially damaging effects that release to the surface would cause. In addition to sodium, potassium and manganese salts, the brines include zinc, boron, ammonia, lead, cesium, copper, cadmium and silver.¹

There are a number of options which may be used for disposal of the brines once the heat and kinetic energy of the resource has been utilized. These include: reinjection down into the rock strata, controlled release of the brines into the Salton Sea or Gulf of California, and possible use of evaporation ponds to allow for the evaporation of the fluids and the disposal of the solid salts at some designated site. The relative impacts associated with each alternative must be considered from the point of view of the salinity and chemistry of the brines, the effect on the surrounding land of accidental brine release, and the quality of the surface and ground waters of the area.

Reinjection of the spent brines may not only be the solution to the waste disposal problem, but may actually be necessary in order to mitigate possible subsidence effects which may be the consequence of withdrawal of large amounts of fluids from unconsolidated rock at subsurface locations.⁸ Experiences at oil fields⁹ and other geothermal installations (Wairakei, New Zealand) indicates that removal of fluids may result in compaction of rock strata and sinkage of the earth. Reinjection may serve to prevent this particular impact if the fluids were returned to the original reservoir.¹⁰ If this is found to be unnecessary, then the waste water may be reinjected into the same or different strata, back into the production well after use, or into another well drilled for disposal purposes. The brines, once they have been partially flashed to steam, as a consequence of reduced pressure, will be more concentrated in salts. Reinjection of this material might require the addition of make-up water to dilute the brines and prevent plugging of the wells or the reservoir pores. This will allow for movement of fluids back into the reservoir. Actual reheating of the fluids and renewing of

the resource is a slow process -- one which will probably not replenish the reservoir with high temperature waters within a short length of time.

Further study of the geologic nature of the Salton Sea/Imperial Valley area must be made in order to answer the questions associated with the necessity and advisability of reinjection. Factors which must be considered include: composition of the spent brine, pressure build-up within the reservoir, the extent and communication of the underground reservoir, the possibility of recharging the reservoir and reheating the spent brines, possible plugging of the reinjection well by saline materials and the nature of the underlying rock (porosity and permeability).

The possibility of desalinization of the brine or material reclamation must be considered in light of the effect such an alteration of the brine composition will have on reinjection. It may be that reinjection is necessary to prevent subsidence and that the brine material will have to be used for that purpose despite the potential for subsidiary uses of the resource.

The Salton Sea, a 230,000 acre inland body of very saline water, is located just 2.4 miles northwest of the site of the present LLL experiment. It was classified as an agricultural sump by an Act of Congress in 1922 and has remained as the disposal site for the saline (4000 ppm TDS) agricultural run-off which flows into the Sea from the New and the Alamo Rivers via an elaborate series of tile drains, ditches, and irrigation canals.³ At present, the saline level of the sea is slightly higher than that of sea water (37,000 ppm TDS, as compared with 35,000 ppm for sea water³) with a continual increase due to the concentrating effect of evaporation from the sea surface and the continued inflow of saline agricultural run-off.

Dumping of geothermal brines into the Salton Sea might appear to be a possible alternative to the waste disposal question were it not the recent development of the Salton Sea and surrounding shoreline as a recreational/fishery resource.¹¹ Introduced species of salt water fish (Corvina and Sargo)¹² have provided the basis for a sport fishery which is now declining due to the increase in salinity.¹³ The quality of the Salton Sea waters is now being closely monitored by the Regional Water Quality Control Board, based in Indio, to insure against further degradation of the waters of the Salton Sea.⁵ This intention was expressed in a resolution passed by the Board prohibiting any geothermal run-off into the Salton Sea.³ Should the salinity of the Sea continue to increase and the recreational value of the land around the Salton Sea correspondingly decrease, then it may be possible to obtain licenses to dump into this body of water. Piping the spent brines through Mexico and into the Gulf of California is another alternative, although one which may be prohibitively expensive. These alternatives should be kept in mind once development of geothermal resources in the Salton Sea/Imperial Valley is realized on a large scale.

Those experimental and exploratory wells currently in operation in the area of Niland, California are able to make use of evaporation (holding) ponds for disposal of their spent brines because of the limited amounts of waste material being produced.¹⁴ This is a solution for small scale operations only. It is also potentially hazardous to the surface environment due to the possibility of leaking of brine materials from the shallow open depression and the disruption of the surface ecosystem. This alternative makes poor use of large areas of land and could not be considered for use in a commercial operation.⁶

Because of the composition and temperature of the brines, any release of this material into the environment is likely to result in some degradation of the surrounding land, contamination of surface and ground waters, destruction of surrounding vegetation and wildlife habitat and general alteration of the natural ecosystem of the area. In light of the possible environmental consequences, there must be a comprehensive study and consideration of the most viable waste disposal method before full scale development of a geothermal field.

The potential for large scale water pollution as a result of accidental brine release is not as great in the Imperial Valley area as in most other areas within California. The ground water of this region is of bad quality, being highly saline (500-50,000 ppm TDS).⁵ All potable water used in the Imperial Valley comes from the Colorado River. The surface waters: Salton Sea, New and Alamo Rivers, are of equally poor quality, being extremely saline. The only source of water which must be strictly protected from such brine pollution would be that of the irrigation inflow water.¹¹

Subsidence (U. S. Department of Interior)

The problem of subsidence has been studied in the Imperial Valley as a possible environmental impact of geothermal development because of the high tectonic activity of the region and the potential for disruption of the gravity flow irrigation system within the valley.¹⁵ Evidence of subsidence due to geothermal operations has not been discovered in the Imperial Valley. In areas of extensive commercial development, the Wilmington oil fields of Long Beach, California, and the geothermal field at Wairakei, New Zealand, where there has been large scale withdrawal of fluids, subsidence has been observed. There is at present a natural subsidence rate of about 1 cm/year

in the Imperial Valley.¹⁶ In order to discriminate the natural movements from those resulting from geothermal development, the County of Imperial, with the cooperation of a number of State and Federal agencies have established a bench mark network extending throughout the Imperial Valley, with the requirement that all geothermal developers tie into this system.¹⁷ In this area, removal of large volumes of geothermal fluids, with no reinjection into the proper strata may result in the compaction of the underlying rock strata as the particles move together as the fluid is withdrawn. The extent of such subsidence would depend upon the nature of the rock reservoir, the consolidation of the rock structure, the flow of recharging water in the reservoir and the weight of the overburden. Reinjection of waste waters may or may not mitigate this effect.¹⁰ It is important to project the extent of such subsidence before full scale development takes place, in order to insure the integrity of the Imperial Valley irrigation system. Constant monitoring of earth movements will be necessary during development and the impact of well spacing on this phenomena should be considered.

Noise Pollution (U. S. Department of the Interior)

This environmental impact presents a real problem at the Geysers, California due to the large volume of steam leaving the wellhead. In the hot brine fields of the Imperial Valley, only about 20% of the fluid flashes to steam at the wellhead, thus reducing this impact. Noise may then be a problem in the vicinity of the power plant during full scale development. It is more an occupational concern than one of regional importance. Due to the relatively isolated nature of the present geothermal sites — surrounded by large tracts of agricultural land noise would have only a site specific

impact upon employees at the site and on fauna in the immediate vicinity.

Land and Resource Use Alternatives (U. S. Department of the Interior)

The question of land use alternatives is one that must be considered prior to geothermal development in the Imperial Valley/Salton Sea area. At present most of the land in the area is being intensively farmed while those lands bordering the Salton Sea on the east and west have been developed (during a boom in 1950's and 60's) into recreational area and state parks and wildlife refuges.¹² Therefore there may be a real conflict in the Imperial Valley between industrial vs. non-industrial use — relating to geothermal development vs. agriculture vs. recreation. Economic considerations and value judgements will have to be the deciding factors determining whether the land in this area will be multi-use (as it is in Larderello, Italy, with orchards and vineyards existing harmoniously in fields next to geothermal steam lines and generators) or intensively developed for one primary purpose. This area of land planning will have to be developed by the county authorities, as zoning and other land development regulations is within their sphere of influence.

It would appear that the small tracts of land required for geothermal plants could be operated with minimal impact upon the surrounding farmland. There is a possibility that the development of geothermal energy on a large scale in the Salton Sea/Imperial Valley could have an adverse effect upon the recreational use of the area if objectionable aspects of that development (waste brine disposal into the Salton Sea, visual pollution of cooling towers or artificial fog, noise and air pollution) were widespread enough to constitute a nuisance that would significantly downgrade the area as a recreational resource.

There will probably not be a tremendous impact regarding population influx since geothermal energy development after the completion of the drilling stage is not labor intensive. There will necessarily be some increase in the worker population of the Valley which will have to be accommodated by providing essential services.

The factor of site dependence of geothermal energy development may be considered as either a plus or a minus regarding best and most economical use of the land. With geothermal energy production all the impact is in one spot (excluding transmission lines) — drilling, exploration, tapping the resource and converting it to electrical power.⁷ However, there is a drawback in that the development must be located at the site of the resource regardless of any previous land use it may have supported. In the Imperial Valley there may be pre-emption of a great deal of commercially valuable farmland if large scale projects are realized. If the current use is that of recreation or merely preservation of the natural state of the land (refuges, parks, wilderness area), then there may be some disruption due to this development. This would appear to be a very general problem inherent to the western states where the surface manifestation of these isolated geothermal hot spots (geysers, mud volcanos, mineral hot springs) have become foci for the development of sightseeing, recreation and park areas.¹⁸

In the area of resource use, again the question of water resources must be discussed. Development of geothermal resources, like most other forms of energy in the west, may be plagued by increased water requirements for cooling towers and for make-up water for reinjection wells. All available high-quality water in the valley must be transported from the Colorado River

and is primarily reserved for important human and agricultural needs. It might be possible to further tax the Colorado River supply for these requirements.

MINOR IMPACTS

Air Pollution (U. S. Department of the Interior)

Being a noncombustible energy source, geothermal resources have the advantage of not contributing particulates and many objectionable hydrocarbon emissions into the air. However, there are certain natural products, among them H_2S , CO_2 , radon-222, methane and ammonia, which may escape during geothermal development and thus present an environmental hazard.¹⁴ H_2S is a problem at the Geysers steam geothermal installation, where a new technology for removal of the gas, by combination with SO_2 (producing water and elemental sulfur), is being tested. If it appears during preliminary testing of the geothermal facilities in the Imperial Valley that H_2S is being released at unacceptable levels, such a technology can be used to lessen the impact. Again the impact to human populations would be minimal due to low population density of the Imperial Valley area and the relative isolation of the existing geothermal fields from residential areas. The existence of radioactive radon in the gaseous emissions from the geothermal plants and in the water from deep geothermal wells has been demonstrated by the Regional Water Quality Control Board.⁵ Tests will have to be run at each developed site to determine the levels of such radioactivity and whether they are excessive.

Seismic Effects (U. S. Department of the Interior)

Pressurized reinjection of fluids has resulted in the occurrence of microseismic events,¹⁹ particularly in areas near seismically active fault zones, such as the San Andreas fault. In the Imperial Valley area, microearthquakes are a daily occurrence with larger quakes occurring in 1940 and 1966 (the latter registering 7 on the Richter scale^{20,21}). The problem in this area will be in determining the effect of reinjection of geothermal fluids on microearthquake activity²² against such a background of geologic activity. It has even been suggested that such artificially induced tectonic activity may serve to relieve strain in the underlying strata and would thus reduce the frequency of major seismic events, which have been particularly destructive to the irrigation systems of the valley.

Surface Ecological Effects

Any type of industrial development is necessarily accompanied by certain environmental impacts which cannot be eliminated, but which can be minimized. Construction of access roads and of the well itself will necessarily result in soil erosion, destruction of local flora and fauna, and a certain amount of visual or aesthetic pollution. The impact to human populations will be minimal since the disturbed area will be in a nonresidential location. The fact that all commercial activity (drilling, tapping of the resource, and conversion to electrical power) will be carried out on site may be viewed as an environmental advantage, minimizing the land use for this production.

Any aspect of geothermal development, particularly improper waste disposal, may have adverse effects upon the local flora and fauna. In the Imperial Valley, 82 species of birds have been observed to use the southern shore of the Salton Sea as a permanent habitat or as a resting place along the migration route.²³ State officials have attempted to protect the productive fields in this area from scavenging bird flocks by producing fields of food crops for the migrants in the State of Wildlife Refuge. Air, water, noise pollution, or simply increased intrusion by man into the area may result in fewer numbers of birds and an altered ecosystem.

Blowout prevention is essential in this agricultural valley to protect economically valuable cropland from accidental release of the waste brines.

A summary of U. S. Department of the Interior¹⁴ recommendations for mitigation of possible adverse environmental effects follows:

- 1) Require subsidence monitoring and detection throughout the exploratory, developmental and operation stages;
- 2) Use add-on technology to reduce the impact of noise pollution (mufflers and silencers);
- 3) Analyze of gaseous discharges at the wellhead to determine whether state ambient air quality standards are being met. If not, then control devices, scrubbers and filters should be installed to minimize this problem;
- 4) Sample brines at the wellhead and analyze chemical composition. Subsequent monitoring of the disposal program to insure against accidental release of the waste into the ecosystem.
- 5) Seismological monitoring to determine a pattern in earthquake/micro-earthquake activity associated with geothermal development;

- 6) Require stringent controls for blowout prevention;
- 7) Study the feasibility of reinjection as a necessary step towards reducing subsidence effects or for the recharging of the reservoir. Attention should be paid to the risk of inducing seismic activity by this practice;
- 8) Develop a comprehensive land use plan which would balance cost/benefits associated with single use or multi-use (geothermal/recreation/agriculture) of the Imperial Valley/Salton Sea area; and
- 9) Dissipate unused heat in the fluids via cooling towers, while attempting to minimize this environmental impact of visual/aesthetic pollution.

Possible environmental research projects associated with development of geothermal resources within a very specified area of the Imperial Valley are:

- 1) Geological: Subsidence, microearthquake activity, ground water contamination, composition of the brines, effects of withdrawal and reinjection of fluid into the underground reservoir;
- 2) Sociological: Recreation use (in man-hours), population level and possible increases (and its effects on land use, tax structure and community composition), land use, agricultural use, effects on fisheries;
- 3) Chemical: Salinity of existing valley water (from New and Alamo Rivers and along the irrigation system), agricultural

potential of the valley, composition of the specific brine deposits, continual monitoring of surface water salinity level, determination of the effects of increase in salinity (artificial) and the rate of natural increase in salinity in the Salton Sea, investigation of possible reclamation of minerals from the brine, study of extent and nature of release of non-condensable gases from wells;

- 4) Biological: Vegetation changes, waterfowl migration (also impact of loss of refuge land on the problem of avian feeding on croplands), electrocution of birds on constructed power lines which accompany development of the well area, existence of rare or endangered species in the area, consideration of nesting grounds, activity corridors, land features and food supply of fauna of the area, impact of drilling and possible contamination of the fish of the Salton Sea (taking into account the planned development of the fisheries by the State Department of Fish and Game), effects of geothermal development on survival rate and reproductive success of fauna of the area.
- 5) Possible alternatives: Desalinization, reclamation of minerals, fate of the spent brines, evaporation ponds, reinjection, dumping in a river, the Salton Sea or Gulf of California.

REFERENCES

1. Austin, A. L., G. H. Higgins and J. H. Howard, "The Total Flow Concept for Recovery of Energy from Geothermal Hot Brine Deposits," Lawrence Livermore Laboratory Report UCRL-51366, April 1973.
2. State of Calif., Department of Water Resources, Resource Agency, Geothermal Wastes and the Water Resources of the Salton Sea Area: Bulletin No. 143-7, Feb. 1970.
3. State of Calif., Resources Agency, Colorado River Basin Regional Water Quality Control Board, Resolution No. 63-14 - Earth Energy, Inc., Niland Area: Re: Geothermal Waste Disposal into the Alamo River, Dec. 1963.
4. Krikorian, O. H., "Corrosion and Scaling by Steam in Nuclear Geothermal Power Plants," Lawrence Livermore Laboratory Rept. UCRL-73939, 1972.
5. State of Calif., Subcommittee on Geothermal Resources of the Joint Legislative Committee on Public Domain - Calif. State Senate, Geothermal Resource in Calif: The Problems and the Potential, Dec. 1973.
6. U. S. Bureau of Reclamation, Proposed Deep Geothermal Well, Geothermal Resource Investigation, Imperial Valley, Calif. EIS - CA - 73-0188-F, 1972.
7. Hickel, W. J., "Geothermal Energy, A National Proposal," for Geothermal Resources Research, Final Report of the Geothermal Resources Research Conf. Seattle, 1972 (Battelle Research Center).
8. Committee on Interior and Insular Affairs - Congress of the United States, Hearings Before the Subcommittee on Interior and Insular Affairs - Geothermal Resources, Part 2.
9. Gilluly and Grant, "Subsidence, Long Beach Harbor," Calif. Bull. Geological Soc. of Amer., 60: 461-529.
10. Hammond, A. L., "Geothermal Energy: An Emerging Major Resource," Science, Sept. 15, 1972.
11. Imperial Irrigation District, "Historic Salton Sea," June 1960.
12. Pomeroy, Johnston and Baily, Engineers, "A Reconnaissance Study & Preliminary Report on a Water Quality Control Plan for Salton Sea," Dec. 1965.
13. Tonnessen, K., Crow, N., and J. Cohen, Internal Memo UOPKE 74-36, Lawrence Livermore Laboratory, August 20, 1974.
14. U. S. Department of the Interior, Final Environmental Impact Statement on Federal Leasing of Geothermal Resources: Vol. I-IV, Washington 1973.

15. Hess, Hamilton, "Environmental Priorities, Human Needs and Geothermal Power," In Compendium of First Day Papers presented at the First Conf. of the Geothermal Resources Council, El Centro, Calif. 1972.
16. Goldsmith, et al., Geothermal Resources in California - Potentials and Problems, NTIS pub. PB 212-753, May 1972.
17. Univ. of Calif., Riverside/NSF, Proceedings: National Conference on Geothermal Energy: Vol. I-II, Aug. 1973.
18. McCloskey, Michael, Comments on a Paper by Martin Fulcher at the Conf. on an Interdisciplinary Approach to Geothermal Development, June 21, 1973.
19. Raleigh, C. B., "Earthquakes and Fluid Injection," Amer. Assoc. of Pet. Geo. Memoir #18, 1972, pp. 273-279.
20. Brune, J. N., and Allen, C. R., "A Low Stress Drop, Low Magnitude Earthquake: Imperial Valley Calif. Earthquake of March 4, 1966," Bulletin of the Seismological Soc. of Amer. 55: 501-514.
21. Allen, C. R., et al., "Relationship Between Seismicity and Geologic Structure in the Southern California Region," Bulletin of the Seismological Society of America, Vol. 5: 753-797, August 1965.
22. Ward, P. L., "Microearthquakes: Prospecting Tool and Possible Hazard in the Development of Geothermal Resources," Geothermics 1: 3-12, 1972.
23. McCaskie, Guy, "Shorebird and Waterbird Use of the Salton Sea," Calif. Fish and Game Dept., Calif. Fish & Game Quarterly, V. 56, No. 2, pp. 87-95.

DISTRIBUTION

LLL Internal Distribution

A. L. Austin	L-505
B. P. Bonner	L-437
T. T. Chiao	L-421
J. J. Cohen	L-47
W. J. Comfort	L-505
N. B. Crow	L-47
N. A. Delgrande	L-8
A. G. Duba	L-437
D. O. Emerson	L-47
F. J. Fulton	L-426
H. C. Heard	L-437
G. H. Higgins	L-43
A. Holzer	L-13
B. C. Hudson	L-48
P. M. Johnson	L-505
J. S. Kahn	L-41
O. H. Krause	L-153
O. H. Krikorian	L-503
J. K. Lepper	L-421
G. T. Longerbeam	L-153
L. E. Lorensen	L-402
A. W. Lundberg	L-505
E. R. McClure	L-383
S. W. Mead	L-47
C. R. McKee	L-47
A. J. Piwinski	L-437
B. J. Qualheim	L-47
L. D. Ramspott	L-44
R. N. Schock	L-437
L. L. Schwartz	L-47 (50)
J. N. Shearer	L-18
D. R. Stephens	L-437
R. Stone	L-44
K. Street	L-13
R. W. Taylor	L-503
H. A. Tewes	L-47
J. Toman	L-47
D. F. Towse	L-607
H. Weiss	L-505
G. C. Werth	L-13
TID Library	L-9 (5)

External Distribution

Dr. Louis B. Werner (15)
Division of Applied
Technology
Energy Research &
Development Administration
Washington, D.C. 20545

Kathy Tonnessen (10)
67 Laurel Road
Lindenhurst, N. J. 11757

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights."