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SEISMIC RISK ASSESSMENT OF OIL AND NATURAL GAS SYSTEMS IN UTAH AND RECOMMENDATIONS FOR RISK REDUCTION

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FOREWORD

The Utah Seismic Safety Advisory Council, established in 1977, is charged to prepare assessments of earthquake hazards and associated risks to life and property in the State of Utah, and to make recommendations for mitigating hazards that may be found.

This report presents an assessment of earthquake risk for oil and natural gas systems in Utah. The report includes recommendations for reducing risks that are deemed reasonably manageable within available resources. The recommendations are set forth as judgements of the Seismic Safety Advisory Council in terms of effectiveness of the suggested action for reducing risk to life, health, and property.

This report is divided into a summary of findings, a discussion of earthquake effects upon oil and natural gas systems in general, an assessment of the earthquake vulnerability of such systems in Utah, and recommendations for earthquake risk reduction to such systems that deal primarily with policies and procedures rather than technical solutions.

The report presents, first, an overview of earthquake risk to oil and natural gas facilities and lines, and then describes primary systems in Utah in terms of the risk factors. The purpose of the report is to highlight important systematic relationships that affect public service or that may affect public safety. The vulnerabilities of particular types of oil and gas system components to earthquake effects are discussed, and guidance is provided by which system operators may undertake detailed evaluations to establish priorities for mitigation efforts in accordance with aspects or components most vulnerable, or in accordance with elements of greatest importance to the continuing operation of the systems, or for conditions posing the greatest hazards to public safety. Emphasis in the report is placed upon safety considerations more so than upon functional considerations of the systems, although continuing availability of natural gas supply is an important consideration not to be ignored.

This report, like several others of similar nature dealing with various types of utilities, reveals the complexity of large systems serving entire communities, counties, and even larger regions. Such systems are made up of innumerable small and not so small components that must work together for effective and reliable distribution of the utility product. In some cases, such as with oil and natural gas systems, health and safety factors require special attention because of the hazardous nature of the products carried in the networks that traverse developed areas. To achieve areawide service, some components and some lines in the systems are more important than others in the sense that more of the service population can be affected by unplanned failures. The perspective sought from the reader of this report, then, is of a system whose proper performance is reliant upon the correct operation of individual components. Such a perspective helps significantly to understand how earthquakes can cause inconvenience, injury or death, and economic loss to populations and businesses remote from the epicenters of the earthquake events. Such a perspective also helps one to realize that unnecessary earthquake risk to oil and natural gas systems is, indeed, a matter in which the general public has a direct and proper interest.

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SECTION 1

INTRODUCTION

The earthquake vulnerability of oil and natural gas sytems located in Utah has been subject of separate study by the Seismic Safety Advisory Council for two reasons: (1) Fuel is an essential resource needed for commerce and heating energy throughout the State, and (2) the resource is hazardous even under ordinary conditions and moreso in an earthquake event. In some circumstances, fuel is indeed a critical resource, such as during periods of cold weather and for operating engine driven vehicles that may be important in emergency response and recovery activities.

Many areas within the State of Utah are completely dependent upon the availability of natural gas for heating purposes. Since this fuel is distributed through an underground piping network, rather than being stored at the location of use, any interruption in service will have immediate impact upon users. Thus, in contrast to stored supplies in which earthquake damage may not have immediate consequences for users, interruption in the flow of fuel through a piping network will have immediate functional consequences and will create immediate hardships.

The danger of fire and explosion associated with oil and natural gas systems is a constant hazard recognized by nearly everyone. The resulting risk to life, health, and property are exacerbated in any situation when leaks and spillage are caused, such as may result from earthquake damage. Although such dangers are coped with almost on a daily basis by the operators of oil and gas systems, risk conditions effecting life, health, and property become more severe when spillage and line ruptures occur in greater frequency and over a large area.

In this report, then, we have examined the vulnerabilities and possible hazards posed by oil and natural gas systems in Utah's earthquake environment. Since there are differences in both the types of facilities and the handling of oil (petroleum) products and natural gas products, these have been examined separately in the report. In the case of oil products, attention has been given to transmission pipelines carrying the product from oil fields to refineries and to the refineries themselves, including the storage of the products. In the case of natural gas systems, attention has been given primarily to the transmission of the product from gas fields and to principal components of the distribution system. Storage has not been a consideration for natural gas supply in this report.

Vulnerability analysis in this report is based upon damage to oil and natural gas supply systems caused by earthquakes in other regions of the nation and the world. Although quantitative data is scarce regarding such vulnerability, there is a fair amount of qualitative information that may be used to study how earthquakes of different strengths have affected the various components and facilities of such systems. These data allow one to estimate degrees of expected damage to the systems under different earthquake intensities, and when such information is compared with estimates of seismicity in Utah, one can draw provisional conclusions regarding vulnerability and risk.

In this report, we do not go beyond a qualitative seismic analysis of oil and natural systems in Utah. In other words, the report contains no quantitative information. Nonetheless, the qualitative analysis leads to identification of those elements of the oil and natural gas systems most vulnerable to earthquake damage from which one may derive appropriate remedies for risk containment.

Recommendations made herein for earthquake risk reduction to oil and natural gas systems generally are of a policy type rather than technically specific. Technical answers to identified conditions of vulnerability are left to the separate owners and operators of oil and natural gas systems.

The view represented in this report is that the general purpose of safeguarding public safety, health, and welfare cannot be left just to the operators of oil and natural gas systems. There exists an overriding public interest in the safe operation of these systems, and to some extent also in the continuing operation of the systems. In this regard, while the Seismic Safety Advisory Council has not observed significant deficiencies in the safe operation of these systems in Utah, there are, nonetheless, good reasons to set forth public policy declarations. First, the fact that reasonably safe and reliable operation of the systems occurs today does not necessarily imply that the same will be true in the future. Second, increasing activity in energy exploration in the State may result in new oil and natural gas businesses and new facilities, some of which may be by new operators. In such cases, guidelines of State expectations for public safety seem entirely appropriate. The basic elements of such policies are set forth conceptually in the recommendations contained in this report.

The Seismic Safety Advisory Council urges adoption and implementation of the recommendations contained herein.

SECTION 2

SUMMARY OF FINDINGS

Principal findings resulting from the seismic risk assessment of oil and natural gas systems in Utah reported herein are identified without elaboration or extensive discussion in this section. More detailed information is provided in Sections 3 and 4. Section 3 provides a general overview of earthquake effects upon oil and natural gas systems, using information drawn primarily from damage assessments of systems in other parts of the world that have been subjected to earthquakes. In Section 4, general information about earthquake damage is applied more directly to oil and natural gas systems located in Utah, with particular attention given primarily to systems along the Wasatch Front, the most populated area of the State. Recommendations for earthquake risk reduction to oil and natural gas systems are presented in Section 5.

Emphasis in this report is given to life safety considerations as a consequence of the hazardous nature of oil and gas products. Discussions generally are separate for oil systems and natural gas systems, since the types of facilities and their functions are somewhat different. However, in both cases the hazards of explosion and fire constitute the most significant risk.

Earthquakes pose life safety and health problems for oil and natural gas systems in several ways. One such hazard is found at refinery facilities for petroleum which, at least in Utah, are located relatively near developed and populated areas. Spillage, resulting from earthquake damage, and consequent fire danger is one such problem. Noxious and explosive fumes that might spill over from refinery facilities, from storage tanks, or from pipelines which transport the products present another problem. Still another problem occurs in the distribution system of a natural gas supply system which poses dangers of explosions if lines are ruptured at service connections to buildings or within the buildings themselves. These types of possible failures are addressed in the detailed sections of this report.

Because fire and explosion hazards are inherent problems for oil and natural gas systems which cannot be avoided, either on a daily basis or as might be caused by earthquakes, one general conclusion of this report is that emergency planning procedures to cope with potential disasters of this type provide the most feasible earthquake preparedness action. While there also are appropriate actions that can be taken in some instances to mitigate the hazards of oil and natural gas systems, these are somewhat limited since the hazard posed by the volatile nature of the products cannot be avoided.

Overall, no significant deficiencies were discovered in this study which make oil and natural gas systems more hazardous in earthquake conditions than are faced routinely and daily by the operators of the systems. Since such hazards are ever present, the operators of these systems are found to have organized their planning and operations to avoid, or at least make manageable, possible disasters. In the case of oil refineries, storage tanks are diked to contain spills in compliance with standard prodecures of the industry and in compliance with standards set by the local government jurisdictions in which the facilities are located. Oil refineries and the principal natural gas supply operator of the State retain emergency crews that are trained and available to respond when line ruptures and/or spillage occurs.

Principal findings of this study are listed below. Importance of the topic was not a basis for the list sequence, and readers will note that the findings are listed more or less in order of their appearance in the discussion sections of the report. The oil and natural gas systems described herein have been viewed mainly in terms of public safety. Consideration has not been given the economic loss that might result to the facilities or the oil and gas products, although such losses could be severe for the operators and owners in the case of strong earthquakes.

Earthquake Response Of Oil And Natural Gas Systems

Surveys of past earthquakes that have affected oil and natural gas systems confirm the observations made above--namely, that fire hazard is the most significant risk faced at such facilities in earthquakes. Fire and explosion hazards result primarily from ruptured tanks and broken pipes used to transport the products. Failed seams of storage tanks, broken inlet and outlet connections, and ruptures in aboveground and underground piping systems are the primary sources of the fire and explosion hazards.

Data from past earthquakes indicate that system failures commence predominantly at earthquake Intensity VIII levels, although poorly constructed or unanchored tanks may show distress and consequent spillage at Intensity VII. Most primary pipelines transporting oil and natural gas products are of a welded-steel type which are fairly resistive to damage from earthquake-induced ground vibrations, although the possibility of pipeline rupture at fault crossings cannot be overlooked.

Evidence thus indicates that oil and natural gas systems are vulnerable to damage by strong earthquakes and are less likely to suffer significant damage by small to moderate earthquakes. Damage thresholds for such systems appear to be in Intensity VIII or greater regions, with the damage becoming more severe as the earthquake intensities increase.

Seismicity In Utah

Seismicity is common in most of the State of Utah with the possible exception of the easternmost portion. The most severe and frequent earthquakes historically have occurred along a central region extending from the north central border to the southwest border. This seismic region is a part an area that has become known as the Intermountain Seismic Belt. Geologic evidence suggests that severe seismicity in the future most likely will occur within this same region, with the Wasatch Fault zone being the zone of greatest risk. Although the probable frequency of strong earthquakes is expected to be very low, the Wasatch Fault is said to be capable of producing earthquakes in the 7.3 Richter magnitude range. This correlates roughly with earthquake Intensity IX levels. Earthquakes in the 6+ Richter magnitude range not only have occurred in historic time in the State, but Utah can expect to experience more such events in the future. This Richter magnitude correlates roughly with Intensities between VII and VIII.

From the above general summary of seismicty in Utah, it may be concluded that earthquake strengths in the range potentially capable of causing damage to oil and natural gas systems are possible within that portion of the State coincident more or less with the Wasatch Front region. Principle primary oil and natural gas systems are located within this region, and pipelines carrying the oil and gas products traverse the State, crossing fault zones as they pass into the most seismically active region.

Mitigation Of Earthquake Damage

Although it does not appear to be possible to preclude risks of fire and explosion associated with severe earthquakes, there are actions that can be taken to reduce the frequency of occurrences, to insure against fire and explosion hazards in small to moderate earthquakes, and to reduce the chances of major conflagrations as might be caused by strong earthquakes. Valves at fault crossings of primarly pipeline systems provide a means for prompt control of spillage. Greater care in the design of tank anchorage, greater attention to buckling characteristics of tanks under lateral load conditions, and flexibility at inlet and outlet connections help to reduce the possibility of spillage.

Experiences from earthquake damage in other regions have shown that mobile homes and other structures not permanently anchored to the ground by means of foundations show a high frequency of displacement and failures of temporary supports. Rigid connections where natural gas supply lines enter structures are susceptible to displacement and pose an especially high life safety risk. There are techniques, such as use of flexible connections, to combat this type of hazard.

SECTION 3

EFFECTS OF EARTHQUAKES UPON OIL AND NATURAL GAS SYSTEMS

In order to estimate the expected impacts of earthquakes upon Utah oil and natural gas systems, it is first necessary to review the vulnerabilities of oil and natural gas system components to earthquakes generally. After describing the effects to such systems caused by earthquakes in other regions, the general earthquake situation in Utah is described in order to determine whether or not expected earthquakes can cause damage to oil and natural gas systems, and which components might be more susceptible than others to seismic damage.

EARTHQUAKE HAZARDS TO OIL AND NATURAL GAS SYSTEMS

Oil and natural gas systems are of general interest and concern both because such systems are "lifeline" systems, that is, they are vital to the functioning of urban centers, and because disruption of such systems in an earthquake can lead to extensive fire damage, one of the most costly forms of damage in past earthquakes.

Fires were responsible for extensive damage not only after the San Francisco earthquake in 1906, but also after the Great Kanto (Tokyo) earthquake in 1923, the Long Beach (California) earthquake in 1933, the Fukui (Japan) earthquake of 1948, the Morocco earthquake of 1960, the Alaska earthquake of 1964, and the Niigata (Japan) earthquake in 1964. At least some of the fire damage following such earthquakes has been ascribed to oil and natural gas systems--either due to oil spills or to gasoline tank ruptures.

In the 1933 Long Beach earthquake, for instance, seven of nineteen fires have been ascribed to gas service failures. Thirteen explosions at broken cast-iron gas pipes were reported in Tokyo during the 1923 Kanto earthquake. Damage to Union Oil Company tanks in the 1964 Alaska earthquake led to spills of combustible liquids and to a fire that burned for three days.

One fire in Niigata burned for 350 hours. The fire is believed to have started from sparks when a floating tank roof collided with the tank wall. A total of nine fires started in Niigata, five of which spread, but only two of which caused conflagrations. Besides refinery facilities, the fires burned numerous other structures ([2], p. 172; [14], p. 331; [15], pp. 385, 386, 395, 397; [19], p. 282).

Failures have occurred, then, at refinery tanks and in gas pipelines, and such failures can lead to conflagrations.

In oil systems, from pipeline to tanks and refineries, only some of the structures are susceptible to damage.

Oil shipped by highway or by rail can be halted when transportation systems are disrupted. Underground oil pipelines appear to be vulnerable only to special site-related hazards, such as ground ruptures, landslides, liquefied soils, or to differential movement at the point of connection to other facilities. In other words, in contrast to buildings, tanks, and almost all other structures, oil pipelines have not been damaged by ground-shaking, except perhaps where there has been a difference in the dynamic properties of two horizontally adjacent soil layers. In the San Fernando Valley (California) earthquake of 1971, two petroleum pipelines separated at various points, but only minimal leakage occurred when emergency shutdown procedures were activated. In earthquakes generally, damage to petroleum pipelines has been rare ([1], p. 65; [9], pp. 121, 122; [16], pp. 3, 4; [17], p. 124; [18], p. 126; [19], p. 283).

The vulnerability of pump stations for oil and gas systems depends, of course, upon their design and location relative to earthquake occurrences. But any facilities dependent upon power are subject to at least a temporary shutdown after an earthquake and so need auxiliary means of power if the operation is to continue.

Data about tanks containing combustible materials reveal suggestive patterns in earthquakes. Using a survey by Robert D. Hanson of 21 such tanks affected by the Alaska earthquake, the following patterns are observed (Cf. [14], p. 332).

- Of six tanks with heights greater than diameters, two collapsed, and the other four had extensive buckling of the bottom wall. One of those four had a break at the wall-to-bottom plate weld.

- Another tank with a height of 48 feet and a diameter of 49 feet buckled in the bottom wall. Bottom-wall buckling occurred to only one other tank. For tanks with lower height-diameter ratios, chief failure modes were roof damage, rafter damage, damage to roof and top-wall connections, and damage to roof support columns.

- No damage occurred to three tanks known to be empty.

Surveys made of water tanks affected by the San Fernando Valley earthquake add indirect evidence relevant to the seismic performance of tanks storing combustible materials. The scale of earthquake strength used here for giving a rough assessment of the potential effects of earthquakes upon human works is the Modified Mercalli Intensity Scale (MMI), which ranges from I to XII. A more complete account of the scale is given in Appendix A and also upon pp. 202-205 in [22], and attempts to correlate the MMI scale with ground accelerations are found in [21]. One water tank, affected in an Intensity VII to VIII region, buckled as a result of overload stresses caused by differential settlement and foundation failure. Otherwise, tank failures occurred in areas affected at least at Intensity VIII and generally above. The evidence does not determine whether high height-diameter ratios or high intensities were controlling factors for buckling near the bottom wall. Severing of external connections was commonplace ([1], pp. 135-148).

In the same earthquake, the only damage to refinery tanks was in the form of dislocations of floating roofs and minor tank seepage. Just as buried water reservoirs seem to be vulnerable to damage only at Intensity X and above, so there was no major damage to underground refinery storage tanks ([1], pp. 65, 66, 135-148).

The four major problems for storage tanks, then, appear to be:

(1) Potential buckling resulting from poor siting.

(2) Circumferential buckling of lowest sidewall course.

(3) Roof damage, such as damage to roof seals.

(4) Rupture of external connections, the "most frequent" cause of oil spills ([9], pp. 122, 123).

Such ruptures of external connections have occurred in numerous earthquakes ([11], p. 31).

In addition to tank failure, the other main source of fires following earthquakes has been rupture of gas lines.

Data about breaks or leaks in natural gas pipelines come from the examination of several earthquakes: The San Fernando Valley earthquake of 1971, the Niigata earthquake of 1964, the Great Kanto (Tokyo) earthquake of 1923, the Miyagi-Oki (Japan) earthquake of 1978 (7.4 Richter magnitude), the Tokachi-Oki (Japan) earthquake of 1968, and the Haichen earthquake in China (7.3 Richter magnitude) in 1975. Since existing data are found only in an imperfect form, only provisional and general conclusions can be drawn (Cf. [1], pp. 59-63; [2], p. 176; [8], p. 126; [11], p. 31; [12], pp. 399, 400; [13], pp. 3370, 3373, 3374; [20], p. 345).

The damage rate for cast-iron gas pipes appears to be about 1/2 that for cast-iron water mains at Intensities VIII and IX, and to be about the same as for water mains at Intensity X. Roughly speaking, water mains tend to have damage rates of about one break per kilometer in Intensity VIII areas, and higher rates in higher intensity areas. In the Great Kanto earthquake of 1923, damage rates for cast-iron gas pipes exceeded nine breaks per kilometer in extremely high intensity regions of ground rupture and liquefaction.

In other earthquakes, welded-steel gas pipes generally have performed considerably better than water mains, except in highest intensity areas. In the Niigata earthquake, small diameter (100-200 mm.) welded steel pipes failed at a rate of 0.77 breaks per kilometer in Intensity VIII to IX regions. In the Tokachi-Oki earthquake, the damage rate to welded-steel pipes was only 0.05 failures per kilometer. In the Miyagi-Oki earthquake, the damage rate was a mere 0.017 failures per kilometer. In the Haichen earthquake, larger diameter (530 mm.) pipes had 0.31 failures per kilometer, whereas smaller diameter (50-100 mm.) pipes had a damage rate of 1.6 failures per kilometer. In the San Fernando earthquake, damage rates rose to as high as 5.6 breaks per kilometer, and generally hovered around one break per kilometer in Intensity IX and X regions. In Intensity VIII to IX areas, the overall damage rate was 0.64, with the following rates at given horizontal accelerations:

400-500 cm./sec.^{2}	0.85
350-400 cm./sec.^{2}	0.40
300-350 cm./sec.^{2}	0.12

Hence, welded-steel pipes can leak even in Intensity VIII regions, but most leaks tend to occur in Intensity IX and above areas.

Steel pipes with screw joints suffered numerous leaks in the Niigata earthquake and breaks at rates of 0.5 to 1.0 per kilometer, which were much higher than those for welded-steel pipes in the Tokachi-Oki earthquake.

Gas service pipes in the San Fernando Valley earthquake had damage rates about the same as those for larger steel pipes and in the Miyagi-Oki earthquake had slightly higher rates than those for larger steel pipes. The severely affected portion of the distribution system in the San Fernando Valley earthquake was chiefly in the Intensity X regions.

In the Miyagi-Oki earthquake, much higher damage rates occurred for pipes in cut-and-fill areas, and in areas bordering bedrock and less cohesive soils.

In summary, tank failure and gas line ruptures are known to be possible from a survey of past earthquakes, and such failures can lead to extensive secondary damage. The extent of gas line ruptures depends upon the type of pipe used and the earthquake intensities at which the pipe is affected, as well as site-related factors. Tank failures also depend upon the height-diameter ratios and soil foundations. Ruptures of tanks can be expected at external connections due to relative movement at higher intensities unless external connections are provided with special flexible joints. Other components of oil and gas systems dependent upon power, such as pump or heating stations, may be expected to be without power for at least some time after an earthquake of moderate size (Richter magnitude 6.0 or above). Still other components, such as buildings or stacks, need to be viewed in the light of their lateral load capacities. Buildings can be addressed in accordance with the parameters developed on a methodology presented and described in other reports.

The future earthquake vulnerability of oil and natural gas systems thus depends significantly upon the expectation of earthquakes that affect such systems at Intensity VIII or above. In areas where earthquakes are not expected to produce such intensities, oil and natural gas systems appear to be secure from earthquake damage, except perhaps for damage to any unreinforced masonry structures, for localized power outages, for corroded pipe, for poorly sited tanks, or for any facilities not designed to resist lower horizontal forces.

UTAH'S EARTHQUAKE ENVIRONMENT

Locations in Utah vary considerably in terms of expected seismicity, and so in terms of expected damage to oil and natural gas systems. The seismic zonation map of Utah contained in the most recent edition of the Uniform Building Code indicates, for instance, that a large portion of Utah lies in an area of high seismicity, a zone 3 region, whereas other portions of the State lie in zones of lesser seismicity (See Figure 1). More recent research has indicated that a slightly different arrangement of seismic macrozones is warranted, and that, in locations close to the Wasatch fault, even more seismic activity is expected in the future than has been recorded in the limited historical past. The new zones are outlined in Figure 2.

In Figure 2, the zone of highest expected seismicity is Zone U-4 followed by Zone U-3, Zone U-2, and then Zone U-1. A large portion of eastern Utah lies in a zone of negligible expected seismicity.

In Zone U-1, the maximum expected earthquake, based upon the historical record, has a near-field Intensity VI ([5], p. 17). Such an earthquake could damage some oil and natural gas facilities, but most oil and natural gas system structures, including equipment, should be undamaged. Hence, not much direct earthquake damage to oil and natural gas systems is expected in Zone U-1.

So, the only zones where much expected damage should occur are Zones U-2, U-3, and U-4.

In Zone U-4, the maximum expected earthquake, based upon geological evidence, is an epicentral Intensity X. Such an earthquake could damage some components of oil and natural gas systems.

In Zone U-3, the maximum expected earthquake is an Intensity IX, as based upon historical records. Here, again, such an earthquake could damage certain types of facilities in oil and natural gas systems.

In Zone U-2, the historical record indicates that VII is the maximum epicentral intensity ([5], p. 17). Such an earthquake could damage unanchored equipment, gasoline pipes in very poor condition, and some buildings. But such earthquakes are not likely to have much effect upon oil and natural gas systems generally, unless some critical components happen to be impacted directly.

Another way to compare seismic zones is to examine expected earthquake recurrence intervals. However, estimated recurrence intervals for the different zones may be misleading unless one takes into account the diverse sizes of the zones. Zone U-1 is about 261,000 sq. km., Zone U-4 is only about 14,000 sq. km., Zone U-3 is about 29,200 sq. km., and Zone U-2 is about 76,400 sq. km.

Table 1 indicates the expected recurrence intervals of epicentral intensities equalling or exceeding the given intensity somewhere within the zone. If one recognizes that recurrence intervals for given intensities located in the zone are a result of either having epicentral intensities in the zone or attenuation from earthquakes lying outside the zone, then one can bear in mind that the intervals in Table 1 do not take into account attenuation from the outside zone.

Not all earthquake epicenters are expected to lie close to oil or gas facilities or structures. But, Table 1 indicates that large earthquakes are expected that could damage vulnerable facilities.

Given the wide differences in area among the various zones, a more direct measure of the vulnerability of a given facility or piece of equipment comes from estimates of recurrence intervals for intensities equalled or exceeded at sites randomly chosen within a given zone.

Table 2 indicates clearly that sites in Zone U-4 are considerably more susceptible to levels of ground-shaking that cause damage. At the same time, structures and equipment that are designed to resist the effects of lower intensities are much less likely to suffer damage.

In summary, not only does Utah have considerable seismicity, but certain portions of Utah have much more expected seismicity than others. When recent geological evidence is added to historical records, only California clearly has a higher expected seismicity among the contiguous United States than the seismicity in Zone U-4, a macrozone that compares in seismicity even to portions of Nevada and other high risk areas of the United States (Cf. [15], pp. 17, 18, plus adjustments in the methodology).

In the next section, findings concerning the general vulnerability of components of oil and natural gas systems and concerning the seismicity in various portions of Utah will be applied to more specific data about the location and types of components of oil and natural gas systems in Utah. Concentration upon components in Zones U-4 and U-3 is largely justified as a result of the comparatively low seismicity in other parts of the State, where recurrence intervals are extemely long.

SECTION 4

VULNERABILITY ANALYSIS OF UTAH OIL AND NATURAL GAS SYSTEMS AND MITIGATION CONSIDERATIONS

The only previous surveys of the possible seismic response of oil and gas systems in Utah were in conjunction with the U.S. Geological Survey (USGS) study on possible earthquake losses in the Salt Lake City area [3] and an in-house examination by Mountain Fuel Supply Company of its transmission lines crossing the Wasatch fault [4]. The chief purpose of the USGS study was to provide worst-case scenarios of eathquake losses for use primarily as a public information document regarding risk distribution. The purpose here is to survey the earthquake vulnerability of oil and gas systems in Utah in order to determine whether preventative (mitigation) programs can be feasibly undertaken that would lessen the impacts of future earthquakes upon these systems and, if so, to identify public policies that would facilitate such actions.

As indicated in Section 3, primary oil and gas system facilities and structures of concern lie in those Utah regions of highest seismicity, which are also the most densely populated areas within the state. In this section, descriptions of oil pipelines, of oil refineries, and of the principal natural gas system in Utah are given in that order.

To date, with the exception of the Pineview oil and gas fields in seismic Zone U-3, major Utah oil and gas fields are outside zones of significant seismicity (See [25]). Since future developments of oil and gas fields may occur in more seismically active zones, these require studies of earthquake effects to collection and transmission or transportation facilities that are not treated here.

OIL PIPELINES

As indicated in Section 3, underground oil pipelines appear to be vulnerable only to special site-related earthquake hazards such as ground ruptures, landslides, liquefied soils, or differential movement at their points of connection to other facilities. Dependency upon power also entails a possible need for auxiliary sources of power to maintain supply in the event of an electrical outage.

Figure 3 presents a rough outline of major oil pipelines in Utah in terms of the major seismic zones. Figure 4 presents a sketch of those pipelines in relationship to the Wasatch fault in Davis County, the principal area of convergence of major lines in the State. As Figures 3 and 4 indicate generally, some fault-related hazards do and must exist for pipelines that extend from eastern portions of the State or from Wyoming into Davis County, because these lines necessarily must cross the fault zone. In fact, once into the region west of the Wasatch Mountains, these pipelines run parallel to the fault zone for considerable distances.

Information on the Pioneer pipeline was gained from telephone conversations with Steve Theede, engineer with the pipeline company. Pump stations for the pipeline are located at Sinclair, Tipton, Pilot Butte, and Union, Wyoming, and are outside zones of significant seismicity. The pipes, laid in place in about 1952 in accordance with American Petroleum Institute standards, have manual, motor-operated valves at the abovementioned pump stations. As Figure 4 indicates, the pipeline crosses the Wasatch fault at the mouth of Weber Canyon. In addition, the pipeline may be vulnerable to site-related damage where it extends up Weber Canyon near the Weber River. The line runs at high pressures between 1,800 and 1,900 psi.

Chevron has two pipelines of interest, a 10-in. line which first enters Utah in Uintah County running predominantly in a westerly direction and an 8-in. line that enters Utah in Box Elder County running predominantly in a southerly direction. Both pipelines converge in Davis County.

According to Jerry Brower, engineer on the Chevron line, the 10-in. lines were constructed in 1949 and 1955 and are of welded steel. Heating pumps are located at twenty-five mile intervals in Kimball Junction, Woodland, and Hannah. The furnaces are fired off crude oil, and the pumps have a backup engine. Pumping is needed to overcome frictional losses in the lines. All pumps are located outside and have steel shanty control buildings. Pressures vary in the lines from 500 to 600 psi at Kimball Junction to 100 psi near Salt Lake City. According to Chevron's geophysical studies, the pipeline appears to cross the fault near Live Kiln Gulch in Salt Lake County and not near Victory Road as the line proceeds to the refinery in southern Davis County. There are automatic valves installed near Red Butte so that a rupture in Live Kiln Gulch can be valved. Velocity of flow is a mere 3 to 4 miles per hour.

The Chevron 8-in. line is completely computerized for leak protection, and the 10-in. line is due to be likewise programmed. The 8-in. line traverses Hansel Valley near the Hansel Valley fault but does not cross the Wasatch fault. In Davis County, the line is close to the railroad right of way. A pump station exists near the Utah-Idaho Valley, where the line could be valved if there were ruptures in Hansel Valley.

An 8-in. Amoco pipeline runs parallel to the Pioneer pipeline. According to Kevin Andehn, engineer for the Amoco pipeline, the line goes up the south wall of Weber Canyon. A telemetering station is located in Casper, Wyoming. There are hand-operated blockgates in Woods Cross, and in Farmington, near Devil's Canyon, and near the mouth of Weber Canyon. The blockgate near the mouth of Weber Canyon, near a gravel pit, appears to lie in an area of faulting (Cf. [26]).

In summary, all four major oil pipelines in Utah appear to cross an active fault at some point. In addition, there are undoubtedly other site-related hazards that exist, given the extent of different geological conditions that the lines traverse. Specific but potential hazards in Weber Canyon, an area generally known to be unstable, are relatively unknown. Apparent problems may exist near the mouth of Weber Canyon, but, given the lack of mapping of geological hazards in Utah, other potential problems are speculative. It appears that Chevron has provided valves that probably would be adequate for coping with ruptures at known faults. Automatic valving is preferred at points before the lines cross known faults.

According to the USGS report on earthquake risk in the Salt Lake City area, if the lines that provide fuel for the Salt Lake City airport and Hill Air Force Base are ruptured, emergency operations would be hampered since fuel for airplanes would need to be trucked ([3], p. 292). The possible rupture of such lines, though, does not lead to mitigation measures unless alternative routes or more resistant pipes were available.

OIL REFINERIES

Figure 5 shows the location of five major refineries in Davis and Salt Lake Counties. Figure 6 shows that the Wasatch fault lies close only to the Amoco refinery near Victory Road. Additional information from Bruce Kaliser, engineering geologist at Utah Geological and Mineral Survey, indicates that the Phillips refinery may be in an area of upwater ground water seepage, a condition that might create liquefaction problems during an earthquake.

Background information about regulations and practices for construction of refineries comes chiefly from Gary McIff, Salt Lake City Fire Department, and Richard Harvey, Administrator, Environmental Health Division, Davis County Health Department.

According to Mr. McIff, the Amoco refinery may be as safe as any other refinery in the country. Furthermore, the company has taken affirmative action to control leakage of underground pipelines in order to keep contaminants or combustibles off the water table. Developed and populated areas are generally separated from the refinery, and the closer neighborhoods are at a higher elevation. According to EPA regulations, a separator is required for all flammable liquids. Amoco has its own fire brigade, and Salt Lake City ordinances are very stringent on requiring dikes around storage tanks of flammable products. In addition to being able to contain the contents of the largest tank in the compound, Salt Lake City ordinances require a 6-in. freeboard for the dikes so that foam products used in firefighting do not cause a spillover. Recovery systems also can pull flammable contents back into the refinery and send refinery water into the Jordan River.

According to Dave Pingree at the State Fire Marshall's office, refineries in Davis County employ the Flammable and Combustible Liquids Code [27]. According to Section 2-2.3.2 of that code, impounded liquids should be diked, or in an impounding area that has a capacity "not less than that of the largest tank that can drain into it" ([27], p. 20-25). Hence, the code requirement for dikes provides some protection against spillage, although not enough protection against spillage from several tanks that could rupture in a great disaster.

According to Richard Harvey, further protection is afforded by the fact that refineries in Davis County, like the Amoco refinery in Salt Lake County, are relatively isolated from residential neighborhoods. Commercial areas are somewhat closer, although they are still relatively remote from the refineries. In most cases, problems that could exist as a result of earthquake disaster would be confined to the refineries themselves.

The Husky and Chevron refineries are very isolated from neighborhoods. Of all the refineries, Phillips is the closest to residences. The refinery adjoins a trailer park, and other residences exist somewhat close to the refinery.

One problem for neighborhoods and commercial establishments could occur if liquid petroleum gas were somehow to escape from vessels and the vapors were to be blown by winds from the southwest. Trapped gases in houses could cause explosions. According to Gary McIff, such an escape of vapors is a remote problem. The vapors are heavier than air and would remain in the impounded basin if the air is calm. Even if the wind were blowing, the vapors also dilute in a short period of time. Sparks from railroad tracks that are close to all of the refineries could ignite such vapors so that trains possibly would need to be stopped. Generally, only confined vapors pose a problem (in the form of flashovers, or rapidly spreading flames).

According to Noel DeNevers, Professor of Chemical Engineering at the University of Utah, liquid petroleum gas has proved to be lethal, but moreso when transportation is by rail or truck than in regard to refinery accidents. Such gas cannot be smelled or seen and can lead to deflagrations. Hazards increase when the vapors are trapped in houses or other areas where flames may ignite them (such as by a gas water heater). Winds generally dilute such gases, and precise rates of dispersions can be calculated given release rates and wind velocities.

According to Bob Moss, safety engineer at the Chevron refinery, 3-in. to 4-in. welded-steel lines run into the propane and butane (LPG) pressure spheres. Check valves are automatic on the lines going in, and a fusible link exists on lines going out. Although the Chevron refinery has not experienced a major leak, Mr. Moss did admit that a break, say, in the outlet, could lead to a major fire hazard, especially if winds were relatively calm.

According to Spiro Bavelas, engineer at the Caribou refinery, the facility was constructed in 1968 and was designed for seismic forces in accordance with Zone 3 standards of the Uniform Building Code. Some flexibility exists in connections to storage tanks for thermal expansion and contraction. Tanks may be anchored by virtue of excavations 2 feet into the soil so that the round base is restrained by the soil against lateral movement. However, all but four tanks (32' x 87') have high height-diameter ratios. Recent Caribou design practice, at other facilities, is to have diameters less than heights.

Information about the Chevron refinery was gained both from a telephone call to and a tour of facilities with Curtis Anderson, engineer. The Chevron refinery was first built in the late 1940's, and was expanded in 1955, 1958, 1961, and 1972. Extensive soil investigations took place before facilities were constructed. Some of the tanks have height-diameter ratios that approach or barely exceed unity, but most such ratios are low. Current design practices appear to be adaptations by the Chevron engineering offices of Uniform Building Code standards to the special requirements of refinery facilities. Major pipe ways run through the facilities and have flexible loops for thermal expansion. Rigid connections may exist at tanks. Spherical pressure tanks contain liquid petroleum gas. The refinery also contains six power distribution substations designed by Utah Power & Light Company and a reservoir that can contain up to

1,000,000 barrels of petroleum. According to Bob Moss, safety engineer, communications within the facility are mainly limited to the use of telephones.

In general, then, this brief survey of oil refineries finds no known special design problems that are relevant to earthquake safety. Some of the tanks and other facilities may have been constructed in accordance with seismic standards of their day, although this cannot be concluded with certainty. A large earthquake may be expected to damage some of the facilities, but problems that may arise should be confined to the facilities themselves, where potential safety concerns exist on a daily basis. One problem that may extend beyond refinery fences is that of flashovers in neighborhoods as a result of liquid petroleum gas leakage. Such a problem should be given some attention by those who have more intimate knowledge of wind patterns and the behavior of such vapors. Should such a problem be real, it is not known whether any design practices could mitigate the problem, and evacuation of neighborhoods may need to be a part of emergency planning.

According to the USGS report on a major earthquake in the Salt Lake City area, the "probability of major fires and pollution, caused by pipeline breaks and damage to refineries, is high" ([3], p. 292). Except for certain measures, though, such as use of flexible connections at tanks, or use of larger dikes, it is not known what improvements could be made in design or other practices in order to avoid such a problem. The isolation of refineries from neighborhoods and commerical establishments strongly suggests that most problems resulting from any earthquake disaster will be confined to the refineries themselves. While such losses to facilities and petroleum products might cause severe hardship to the private companies and to users dependent upon the products, this sort of risk is a part of any operation that deals with hazardous materials.

NATURAL GAS SYSTEMS

In Utah, the only natural gas system located in zones of significant seismicity is operated by Mountain Fuel Supply Company. Northwest Pipeline and Utah Gas Company serve Moab, and El Paso Natural Gas and Utah Gas Service Company serve both Monticello and Vernal. Otherwise, all Utah cities that receive natural gas are served by Mountain Fuel Supply Company [6].

The USGS study of earthquake risk in the Salt Lake City area suggests the upper limit of loss that may occur in an earthquake, given the present scatter of data on gas pipeline response, present understanding of tectonics of the Wasatch front, and current distribution of pipelines. In the USGS study, in which a strong earthquake is postulated to occur in near proximity to Salt Lake City, two transmission lines were deemed likely to rupture at fault crossings, some damage was speculated for pumping stations, and a maximum of 380 breaks were estimated in mains and services (190 breaks in mains), 320 of which are in Salt Lake County ([6], pp. 278-282). As the evidence in Section 3 indicates, numerous breaks in natural gas lines could occur in Intensity IX and X regions. So, emergency preparedness programs are needed by the operators in the event of an earthquake as large as that postulated in the USGS study.

Most of the information about the Mountain Fuel Supply Company system was provided by A.J. Marushack, vice president of operations at Mountain Fuel Supply Company.

Figure 7 provides an outline of the Mountain Fuel transmission system as it relates to seismic macrozones in Utah. At present, most of the storage and supply lies outside zones of significant seismicity, although new discoveries north of Coalville could place some supplies in Zone U-3.

Only six stations or storage facilities lie in zones of significant seismicity. The three older stations are the Salt Lake or Sunnyside station, the Sunset station, and the Coalville station, all built in 1929. The Salt Lake and Sunset stations now serve as city gate stations, that is, stations to shift flows from the transmission to the distribution networks. The Coalville station, having a brick veneer structure, serves as a border station where major transmission lines break off to Weber County, Davis County, and Salt Lake County, respectively. In an assessment of the Salt Lake or Sunnyside station, the USGS report indicated that building collapse would not likely damage transmission lines and valves ([3], p. 280). Mr. Marushack similarly claimed that the lightness of the abovementioned structures likely would preclude damage to the very strong pipes.

The storage near Coalville is a tight aquifer that has been studied by USGS. The other facilities in zones of significant seismicity are the Allen station and the Lark station, both booster stations and both built in the 1960's in accordance with Uniform Building Code standards at the time. Each booster station has standby power.

Pump alignment at the booster stations may pose a problem if either station is affected by a major earthquake. The Lark station may be more critical since two turbine-driven boosters are mounted on heavy-duty skids. Such skids are known to jump around in earthquakes. At the Allen station, one unit has similar problems, but two other units are integral compressors grouted to a reinforced-concrete block which in turn is secured on a reinforced-concrete mat. The two integral compressors are likely to move with the block in the event of intense ground shaking.

As Figure 7 implies, natural gas transmission lines must cross the Wasatch fault at various points. Some of the places at which transmission lines are in the fault zone of deformation are as follows:

--Sunset Measuring Station

--2200 North near the Warm Springs fault in Salt Lake City

--3500 South in Salt Lake City

--7000 South in Salt Lake City

--Near the Point of the Mountain

--Between Salem and Price

Fault crossings also may occur near Wellsville, near Brigham City, and near the University of Utah. In the distribution system, numerous lines cross the fault up and down the Wasatch Front. Hence, in any earthquake large enough to rupture the ground, some pipes can be expected to leak, at least in the distribution system. At the same time, evidence about displacements, magnitudes and pipe leaks at least suggests that if earthquake intensities and magnitudes are large enough to result in fault offsets, leaks resulting from ground shaking also are likely (for part of the evidence, see [28], pp. 70-73).

Since flows in the transmission system generally move in one direction, system redundancy is somewhat limited in the coldest months when demand for gas is large. Loss of any one of the four main transmission lines proceeding westward from Coalville would lead at least to a temporary loss of natural gas supply, and the other lines would not be able to feed those areas affected by the lost lines. Similar remarks can be made for the line from Carbon County to Utah County. For ten months of the year, however, use of gas is much more limited, so that possilbe system redundancy is greater once interruptible customers are cut off.

Another possible source of concern, presumably dealt with to a lesser extent on a daily basis by Mountain Fuel crews, is the operation of distribution regulators, which monitor demand downstream. If a leak occurs downstream, then the regulators increase flows, because they sense an increase in demand. So, in the expression of A.J. Marushack, a downstream break leads the regulator to "feed" the break. Since crews in Salt Lake City alone handle an average of five distribution breaks per day, it appears that crews already are prepared to cope with the effects of pressure regulators, at least under normal circumstances. An earthquake event would simply increase the number of breaks to be repaired.

Numerous control valves exist in the Mountain Fuel system. In the transmission system, valves are strategically placed so that ruptures from fault movements can be isolated. In the distribution system, not only is there one valve per house, but there also are numerous other valves so that blocks of approximately 5,000 service connections can be isolated. The transmission line is monitored automatically so that rapid changes in pressure can be identified, and so that leaks can be distinguished from changes in demand. In the distribution system, a similar monitoring mechanism is being installed, although rapid changes in demand occur more frequently and are somewhat more difficult to distinguish from leaks.

The monitoring mechanism in the transmission system does not necessarily identify simultaneous breaks until the first break has been repaired. The longest shutoff time for a break, according to A.J. Marushack, has been 14 hours. To repair main lines, special crews must be dispatched from Salt Lake City or from Rock Springs, so that it may take more time to repair a transmission break in Cache County or Box Elder County than in other areas closer to the crew dispatch locations.

According to Mr. Marushack, a large inventory of pretested pipe is readily available, if only to handle leaks that occur routinely. In addition, there is at least 40 feet of each size of transmission pipe available in Salt Lake, Coalville, or Green River. This small quantity of transmission pipe could be inadequate for a major earthquake.

Two types of pipe are used in the Mountain Fuel system, welded steel and polyethylene. Welded steel is used for all piping systems that operate above 60 psi and currently for all piping with diameters of 6 inches or larger. The polyethylene pipe used, according to Mr. Marushack, is as strong and ductile as welded-steel pipe. Butt fusion is used to join pipes. Further flexibility to movement is achieved as pipe is "roped" from one side of a two-foot trench to the other. Whether such flexibility is maximal, especially at fault crossings, is a technical question to be answered by a treatment of more recent alternative designs for pipelines crossing faults (Cf. [7], [8], [9]).

Connections in houses and other residences have only limited flexibility. Thus, they are susceptible to rupture caused by differential movement of building and soil. Some concern exists especially for mobile homes, where differential movement has posed hazards in past earthquakes.

Another source of possible system interruption is the Mountain Fuel control room located in the main offices in Salt Lake City. The eight-story office building was constructed in 1954 before standards for earthquake design were much used in Utah. It is possible that a severe earthquake could severely damage the building and lead to dysfunction of the system control room inside. However, should the control capabilities be lost in Utah, duplicative monitoring capabilities for the transmission system also exist outside zones of significant seismicity.

The overall seismic vulnerability of the principal natural gas system in Utah can only be estimated roughly on the basis of data conveyed in this and the previous sections.

Given the information in Table 1 and Figure 7, one may reasonably presume that the vulnerability of the natural gas system is associated mostly with the level of seismicity in Zone U-4.

At Intensity VIII, some pipe leaks may be expected to occur, although estimates of numbers of leaks would be speculative. The number of leaks could lead to disruption of service for some neighborhood, but may not cause more than crews already are prepared to handle on a daily basis. Earthquakes of Intensity VIII, according to Table 1, are expected every 39 years in Zone U-4.

As Intensity IX levels are reached, more breaks are expected, even for pipes of the quality used in the Mountain Fuel system. In addition, such intensities can cause breaks in the transmission system. According to data in Table 1, an earthquake of Intensity IX may be expected to occur every 133 years. Were such an earthquake to affect, say, one or more of the transmission lines extending west from Coalville, and were such an earthquake to occur during heating seasons, some areas might need to plan upon being without heat until lines are repaired.

Every 450 years, an earthquake large enough to cause extensive damage to the natural gas supply system might be expected. Such an earthquake might have fault offsets large enough to rupture even two of the four main lines extending west from Coalville, or else the line leading from Carbon County into Utah County. In addition to requiring repairs on the transmission system, such an earthquake also could cause extensive damage in the distribution system. The 380 breaks postulated in the USGS report appears at present to be an upper limit on earthquake damage to the distribution system, although improved information on natural gas system response to earthquakes that may be developed in the future should be used to arrive at a more definitive upper limit. At any rate, such an earthquake likely would lead to a shutdown of major parts of the system for many hours. In addition to possible fire hazards posed by such an earthquake, water pipes may freeze if the event occurs during cold weather, and gas fireplaces will become useless at least until the system is restored.

Evidence thus suggests that the natural gas supply system in Utah is inherently vulnerable to large earthquakes that may occur over long spans of time. Emergency procedures are thus extremely important in order to mitigate secondary hazards, such as fires, that may result. According to A.J. Marushack, Mountain Fuel Supply Company has a "comprehensive emergency plan which encompasses natural emergencies."

Appropriate mitigation measures that can be taken now appear to correspond fairly well with those already undertaken by Mountain Fuel Supply Company. Further investigations might be undertaken to increase flexibility or redundancy within the transmission system where it is located in fault zones of deformation, and further investigations might be made of service connection vulnerability, especially for mobile homes. But, most attention, it appears, needs to be placed upon emergency procedures, including public safety awareness programs similar to those already undertaken by Mountain Fuel Supply Company.

MITIGATION AND PREPAREDNESS CONSIDERATIONS

Topical design practices for construction of oil and gas systems, and routine hazards that are managed in conjunction with such systems, support a general conclusion that they are vulnerable generally only to large earthquakes.

Only minor weaknesses in design practices were uncovered in this study. Possible weaknesses in storage tanks, pipe connections at points of likely differential motion, and natural gas service connections for mobile homes are the most noteworthy. As knowledge of seismic design and of Utah's seismic environment increases, further weaknesses may become more apparent. Even today, some of the design practices used in such systems are outmoded, but costs associated with retrofitting vulnerable facilities, such as tanks, can be prohibitive, especially when risks are uncertain.

Given the quality of design practices in Utah's oil and gas systems, much of the attention to earthquake safety therefore should be directed towards emergency procedures that lessen the secondary effects of such large earthquakes.

At Intensity VIII, some natural gas leaks may result from ground shaking, and some problems may occur at refineries, and are likely to be confined to those refineries.

At Intensities IX and above, however, since ground displacements and effects from other geological hazards can occur, both oil and natural gas systems are vulnerable to earthquake losses. But, with proper emergency procedures, such losses or service interruptions may be reduced. Use of further geological knowledge and of present technical earthquake design practices also may aid to some extent in reducing expected losses.

One geological area of possible concern for both oil and natural gas pipelines is Weber Canyon which has unstable characteristics. Two oil pipelines and one major natural gas pipeline run through Weber Canyon and exit across a fault zone of deformation. In a study of geological hazards in Morgan County, Bruce Kaliser has identified landslide areas. Although the exact location of pipelines is not known, the data produced by Mr. Kaliser suggest that landslide areas may affect pipelines near Gateway and Enterprise ([29], figures 9, 15). At the mouth of Weber Canyon, pipes may run in alluvial and Lake Bonneville sediments, where there are geological hazards from north of Enterprise to Stoddard ([29], plate 2). Areas of mudstone, sandstone, marl, and conglomerate present the most hazardous conditions.

One other potentially hazardous geologic condition has been observed in a few instances that is common to all buried utility lines, including those carrying oil and natural gas. The condition occurs as a result of excavation, such as for surface mining of gravel, next to buried lines. As a consequence, if the walls of the excavation are steeply sloped and unstable, a sharp earthquake potentially could cause loss of soil support for the line in an area that once was secure from earthquake damage. Thus, local governments that issue permits for such excavation have a responsibility in safeguarding existing buried lines, as do the operators of the utilities.

SECTION 5

RECOMMENDATIONS FOR REDUCING EARTHQUAKE RISK TO OIL AND NATURAL GAS SYSTEMS IN UTAH

The following recommendations result from a study of the expected impact of earthquakes upon existing oil and natural gas systems and facilities in Utah. The study, titled "Seismic Risk Assessment Of Oil And Natural Gas Systems In Utah," provides information upon the extent and nature of hazards posed by earthquakes to oil and natural gas facilities and systems. The recommendations that follow are based upon the findings of this study resulting from particular consideration of such systems in the State of Utah.

Although natural gas is a utility product of special importance to most communities in Utah, the temporary loss of such supply that might be caused by a severe earthquake appears to be of secondary importance when compared with the life safety and public health hazards associated with the product. Consequently, life safety and health considerations for oil and natural gas systems have received the greater amount of attention in this report and in the recommendations which follow.

Earthquakes pose life safety and health problems for oil and natural gas systems in several ways. One type of hazard is found at refinery facilities for petroleum products which, at least in Utah, are located relatively near developed areas. Spillage, resulting from earthquake damage, and consequent fire danger is a major potential problem. Noxious and explosive fumes that might spill over from refinery facilities, from storage tanks, or from pipelines which transport the products present another type of problem. Still another problem occurs in the distribution system of the natural gas supply system if lines are ruptured at service connections to buildings or within the buildings themselves.

Because fire and explosion hazards are inherent problems for oil and natural gas systems which cannot be avoided, either on a daily basis or as might be caused by earthquakes, special attention to emergency planning, preparedness, and response to such dangers appears to be the most effective means to prepare for eventual earthquakes, although there also are appropriate actions that can be taken in some instances to mitigate the hazards.

Overall, no significant deficiencies were discovered in this study which make oil and natural gas systems more hazardous in earthquake conditions than operators of the system face routinely and daily. Hence, the recommendations which follow are intended more to highlight appropriate preparation and mitigation actions than to imply that particular deficiencies exist in any of these areas. The recommendations should be considered as policy guidelines intended to establish a level of performance for systems in the State rather than an indication of existing gross deficiencies which should be corrected. Recommendation 4, dealing with natural gas service connections to mobile homes, which past earthquakes in other regions of the nation have shown to be particularly vulnerable to earthquake damage, is an exception to this general statement about the group of recommendations.

1. It is recommended that earthquake safety policy pertaining to oil and natural gas systems in the State emphasize the importance of emergency planning and preparedness to reduce life safety and health dangers posed by fire, noxious fumes, and explosions that might result as secondary effects from earthquakes, and that operators of oil and natural gas systems be called upon to demonstrate that such emergency planning and training of personnel is a continuing activity.

   Study findings indicate that operators of oil and natural gas systems in the State of Utah are very much aware of the fire, noxious fumes, and explosion dangers associated with their products and that routine procedures exercised on a daily basis by the operators are so designed to cope with such problems. Study findings further indicate that designs for the oil and natural gas systems take into consideration these hazards and that established national and local standards pertinent to safeguarding against the hazards are followed. As well, for those operators of systems whose operational plans were examined during this study, none were found to be lacking in emergency planning procedures and safety operations. While the investigations for this study were by no means comprehensive, it nonetheless must be noted that no significant deficiencies were discovered. This policiy recommendation therefore should be viewed as an important guideline for the future which establishes State concern that possible problems be considered. The recommendation should be utilized as a means to represent public concern about the problem and to maintain the attention of oil and natural gas systems operators in their future activities and operations.

2. It is recommended that standards be established for storage tanks of petroleum products to include consideration of tank anchorage to foundations and the design of improved earthquake resistance at inlet and outlet connections to the tanks.

   This recommendation is made in recognition that storage tanks appear to be especially vulnerable to earthquake damage as a result of anchorage techniques, or the lack of anchorage, and also as a result of differential movement between tank and ground which affects the inlet and outlet piping connections. Ruptures at tank bases and at inlets and outlets result in spills of the hazardous products which can be avoided, or at least reduced in frequency of occurrence, through improved design.

3. It is recommended that pipelines carrying petroleum and natural gas products be valved at or near all crossings of known or suspected faults.

This modest expense in the overall cost of a pipeline system would provide a means for prompt control of potential spillage at fault crossings, thereby mitigating a risk which normally cannot be avoided.

4. It is recommended that the Public Service Commission establish standards for natural gas service connections to buildings and structures that are not permanently secured to the ground.

Studies of earthquake damage in California reveal that mobile homes and other structures not permanently fastened to the ground or not on permanent foundations have high susceptibility to displacement and support failure. In those instances when natural gas supply is connected to the mobile home or other temporary structure, the likelihood of supply pipe rupture is very large, especially when rigid piping connections are used. Such a problem can be significantly reduced by means of a flexible connection between the ground and the structure so that when it shifts, as it probably will, the gas supply line is less likely to be ruptured.

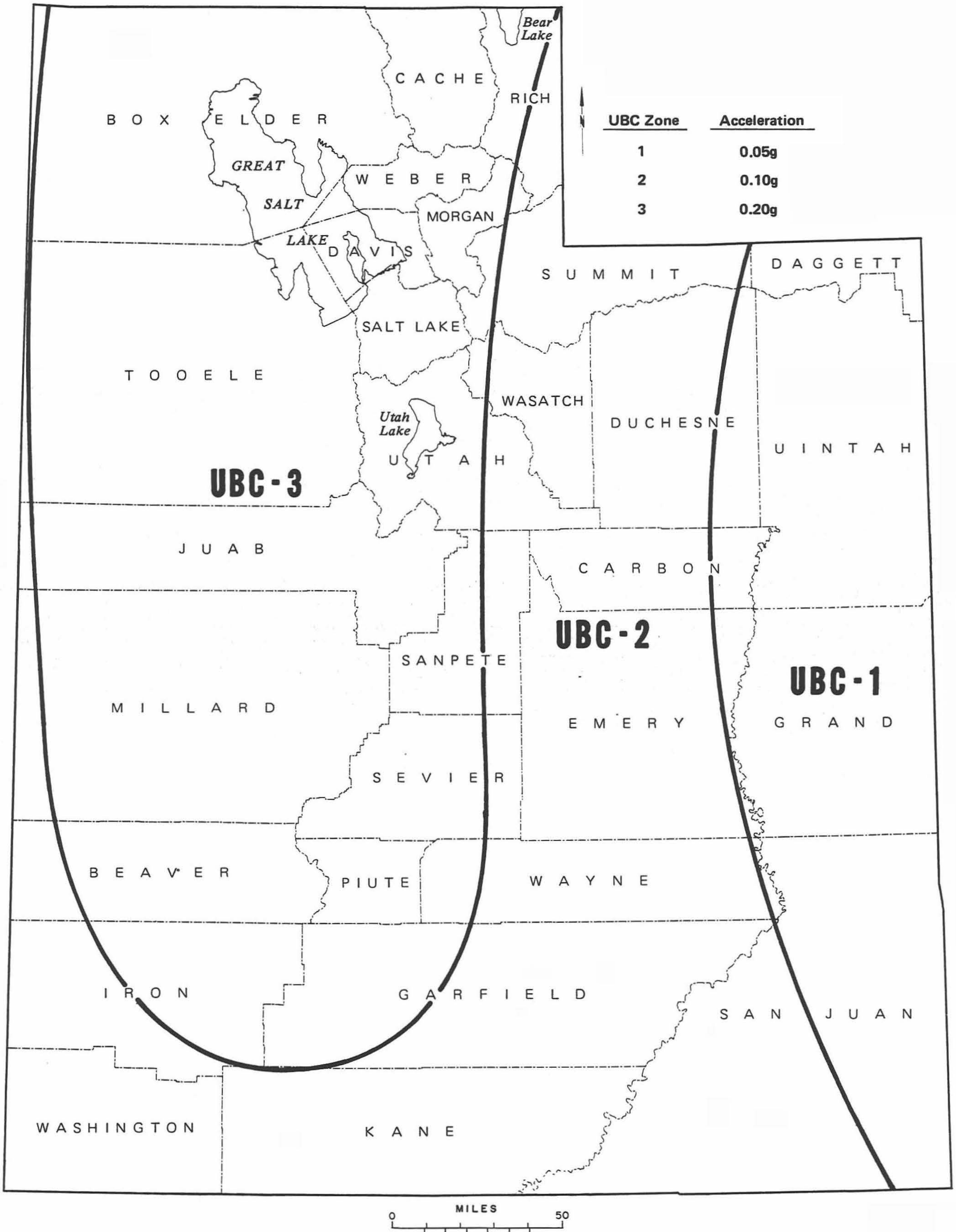

Figure 1

SEISMIC ZONES—1976 UNIFORM BUILDING CODE
STATE OF UTAH

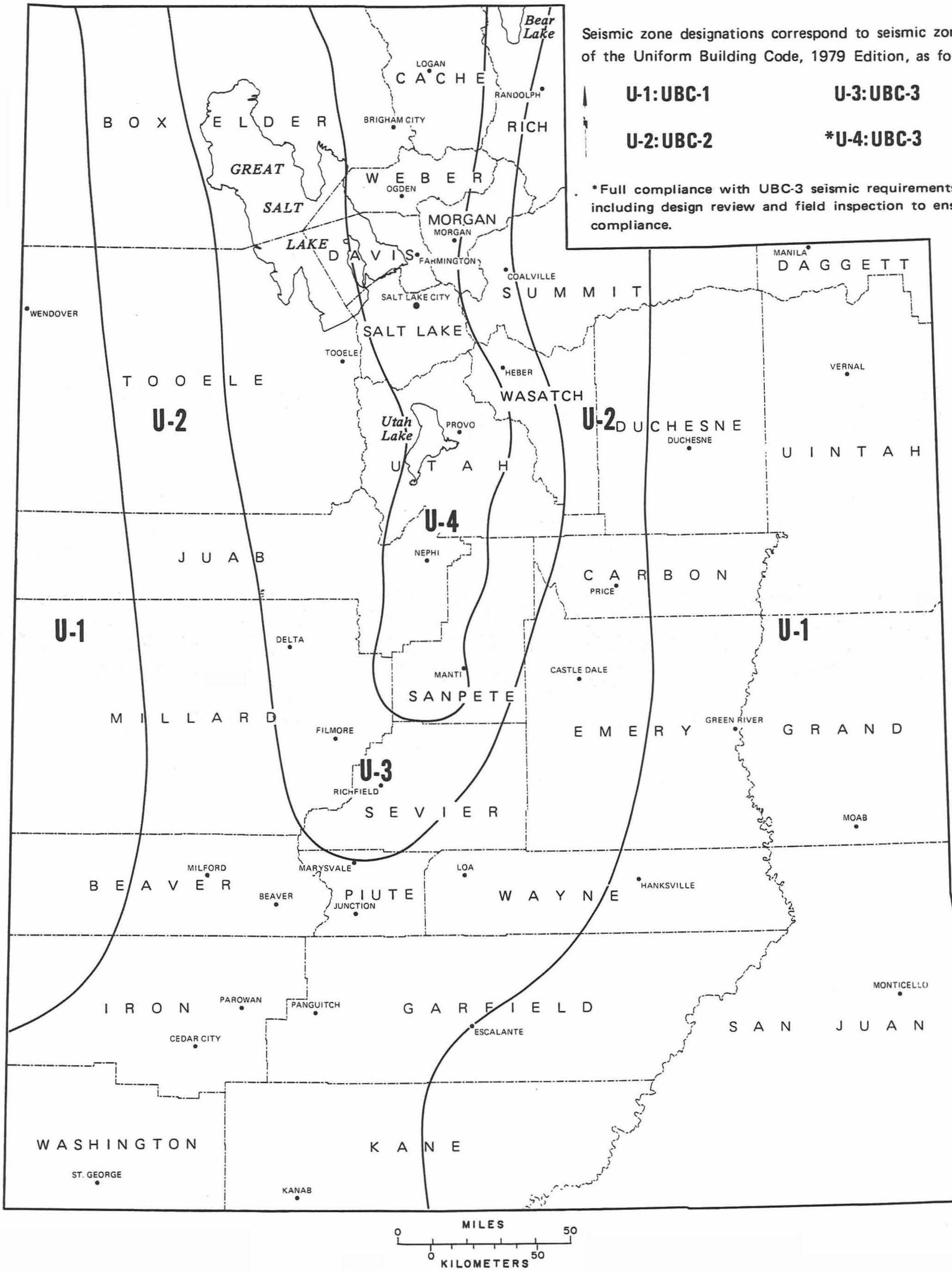

Figure 2

SEISMIC ZONES

January 1980

(Recommended by the Utah Seismic Safety Advisory Council)

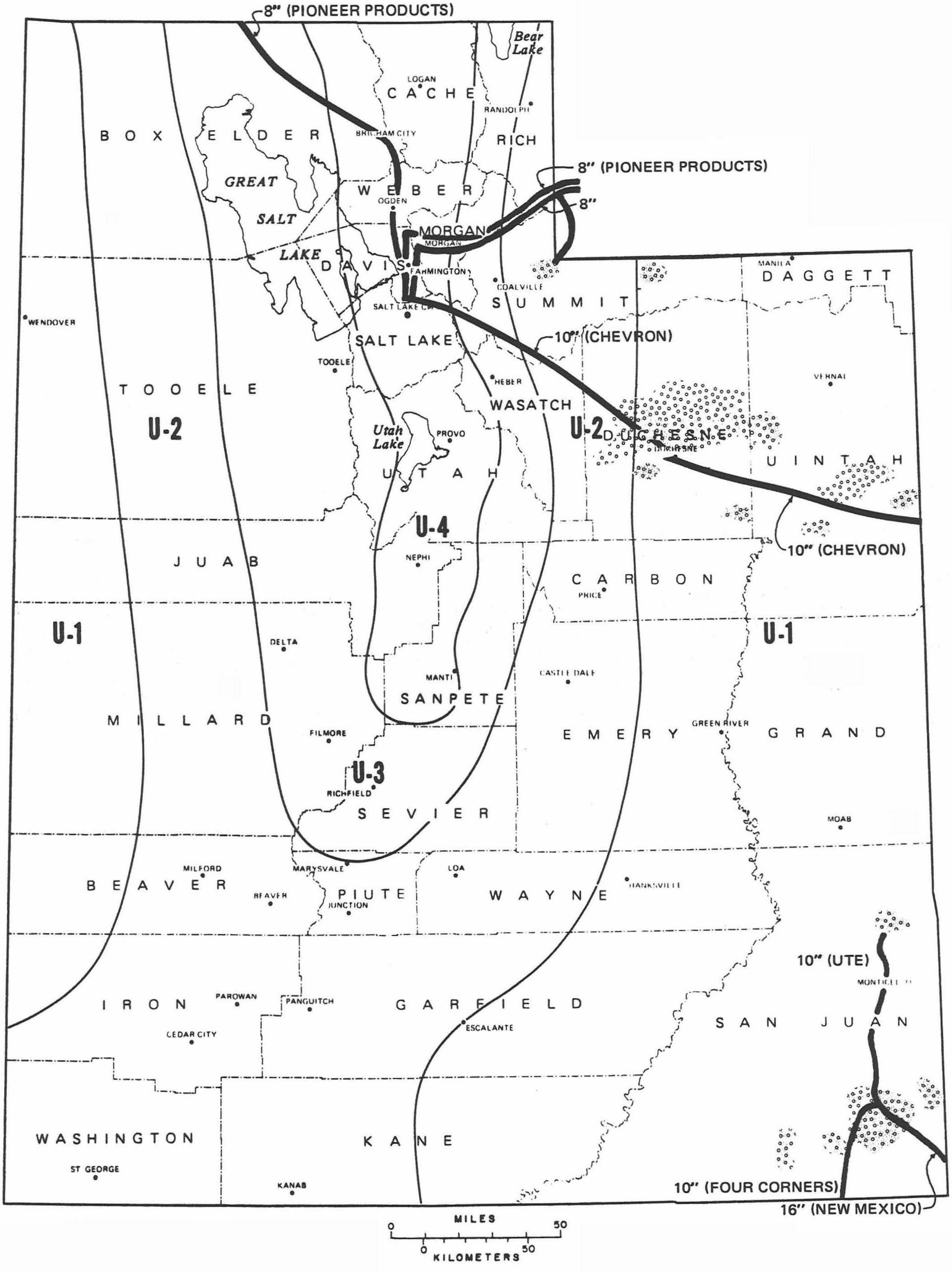

Figure 3

OUTLINE OF MAJOR OIL PIPELINES AND OIL FIELDS IN UTAH
Source: Reference [25]

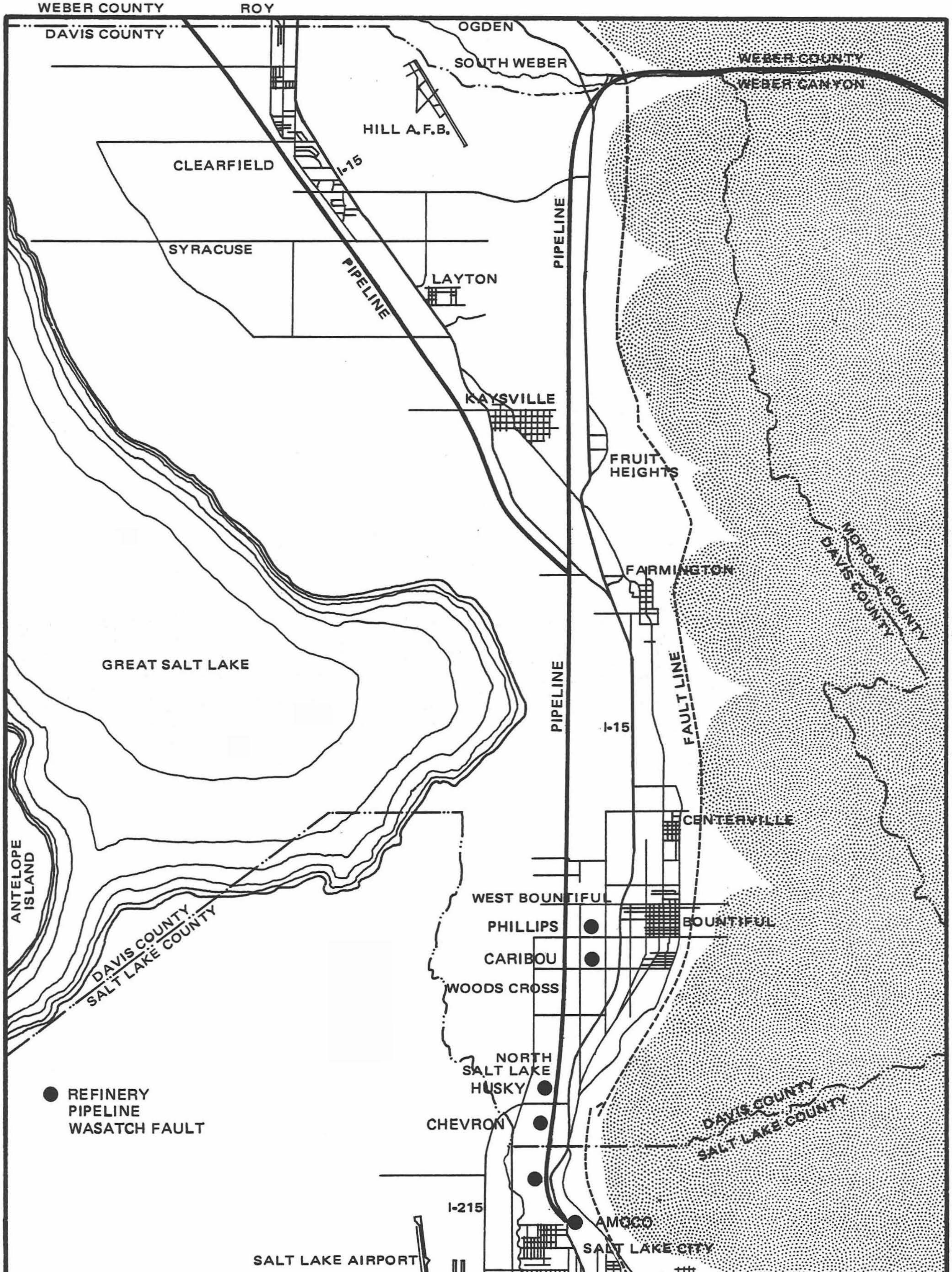

Figure 4

APPROXIMATE RELATIONSHIP OF THE WASATCH FAULT TO MAJOR OIL PIPELINES TRAVERSING DAVIS COUNTY

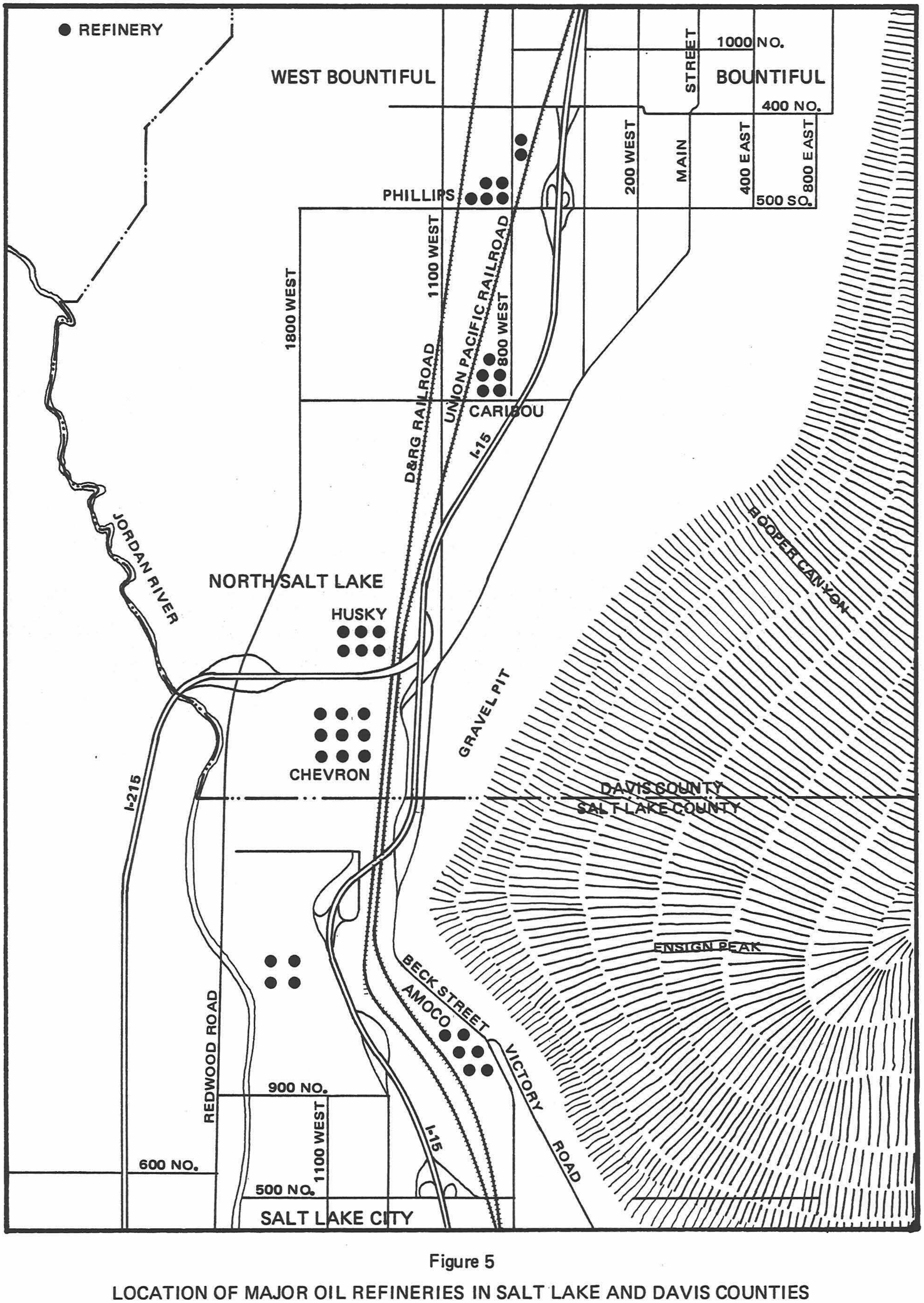

Figure 5

LOCATION OF MAJOR OIL REFINERIES IN SALT LAKE AND DAVIS COUNTIES

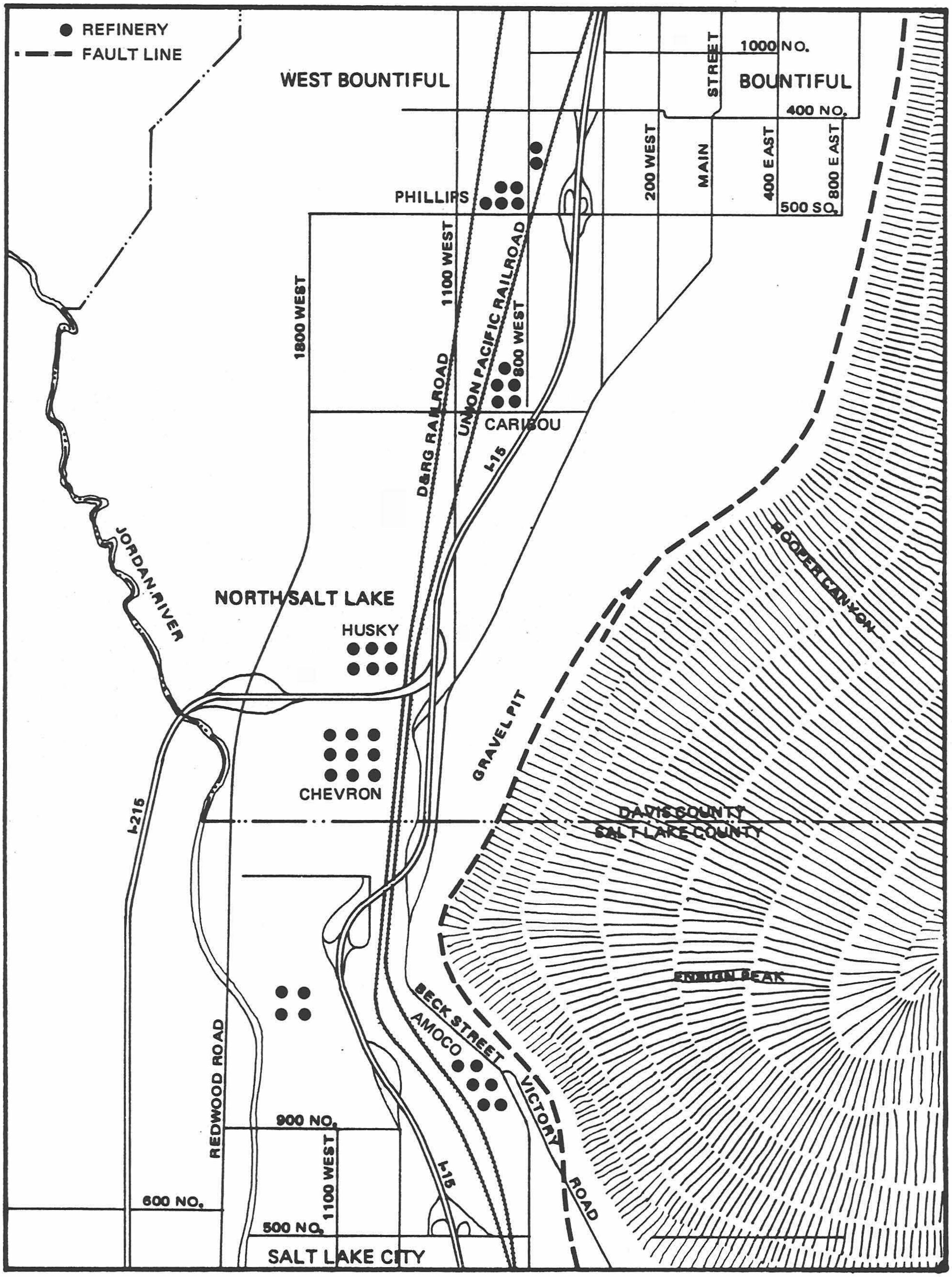

Figure 6

APPROXIMATE LOCATION OF WASATCH FAULT IN AREA OF MAJOR REFINERIES IN SALT LAKE AND DAVIS COUNTIES

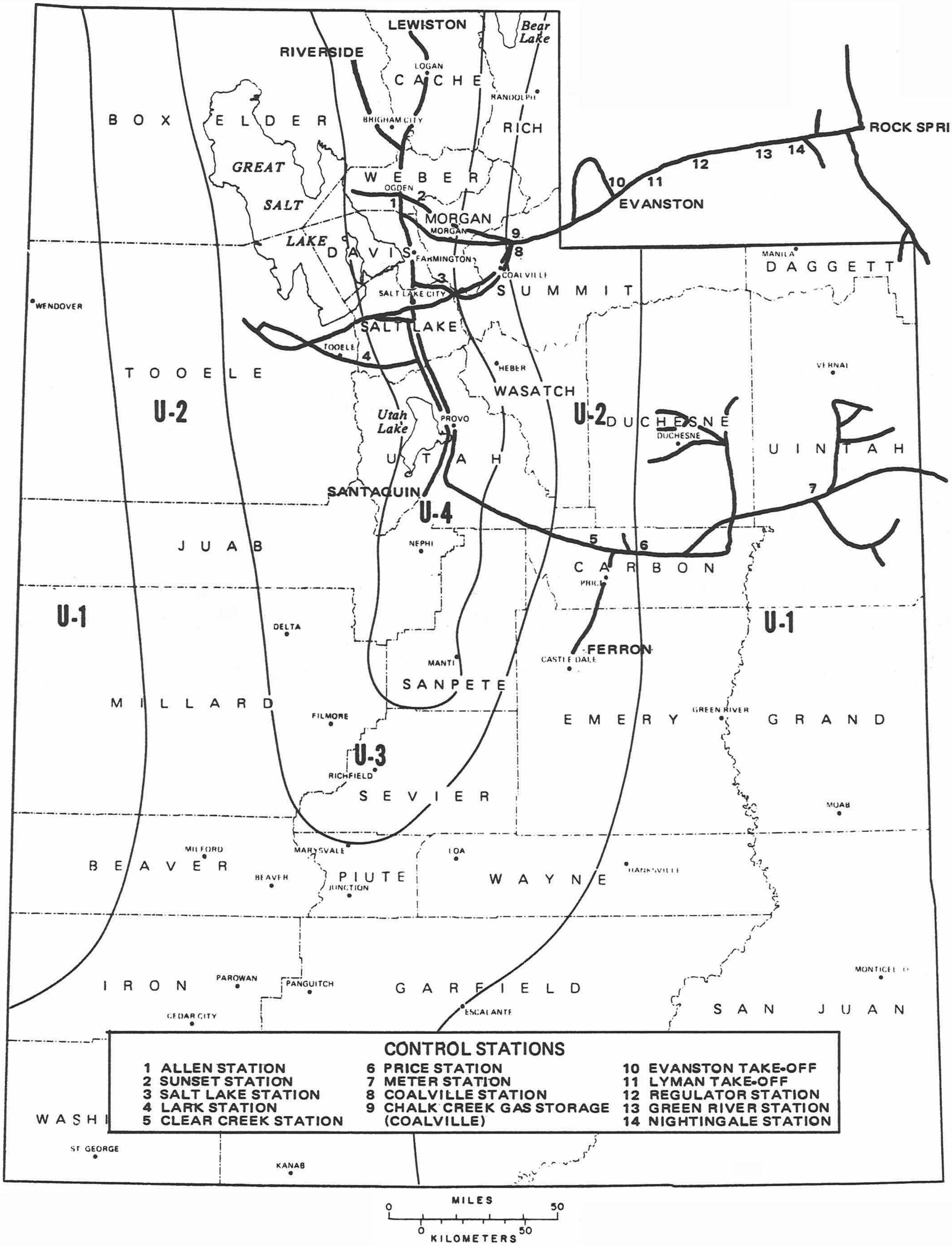

Figure 7

OUTLINE OF MOUNTAIN FUEL SUPPLY COMPANY NATURAL GAS TRANSMISSION SYSTEM IN UTAH

TABLE 1

EXPECTED RECURRENCE-INTERVALS (IN YEARS)
OF EARTHQUAKES WHOSE EPICENTRAL INTENSITY EQUALS
OR EXCEEDS THE GIVEN INTENSITY SOMEWHERE
IN THE GIVEN ZONE

Seismic Zone	Intensity Equalled Or Exceeded				
	X+	IX+	VIII+	VII+	VI+
Zone U-1	3,300	770	200	56	16
Zone U-2	900	190	50	14	4
Zone U-3	1,250	260	65	11	4
Zone U-4	450	133	39	12	4
Cummulative Recurrence For All Four Zones	223	56	15	4	1

TABLE 2

RECURRENCE INTERVALS (IN YEARS) FOR INTENSITIES EQUALLED OR EXCEEDED AT SITES RANDOMLY CHOSEN WITHIN GIVEN SEISMIC ZONES

Seismic Zone	Intensities Equalled Or Exceeded				
	X+	IX+	VIII+	VII+	VI+
Zone U-1	--	--	1.7×10^5	29×10^3	6,300
Zone U-2	10^6	67×10^3	10×10^3	2,000	450
Zone U-3	5×10^5	90×10^3	8,200	1,300	221
Zone U-4	15×10^3	2,400	620	180	54

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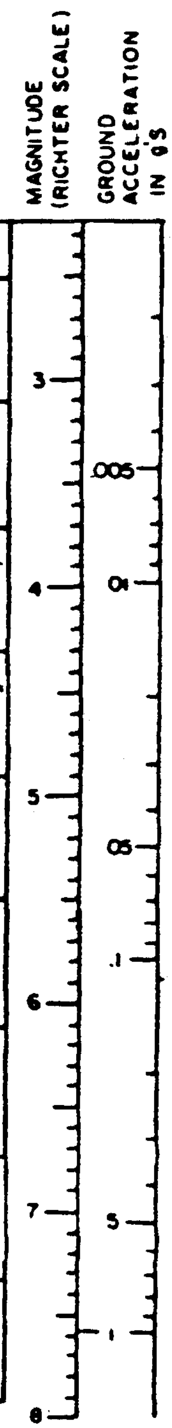
MODIFIED MERCALLI INTENSITY SCALE APPROXIMATE RELATIONSHIP WITH MAGNITUDE AND GROUND ACCELERATION

ABRIDGED MODIFIED MERCALLI INTENSITY SCALE

I	Not felt except by a very few under especially favourable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	Damage considerable in specially designed structures, well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations, ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.



Modified Mercalli Intensity Scale after Wood and Neumann, 1931. (Intensities XI and XII not included).

Magnitude and acceleration values taken from Nuclear Reactors and Earthquakes, TID-7024, United States Atomic Energy Commission.