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UNITED STATES OF AMERICA
ATOMIC ENERGY COMMISSION

IN THE MATTER OF	)	
	)	Amendment to Source
KERR-McGee Corporation	)	Material License
Kerr-McGee Building	)	SUB-1010
Oklahoma City, Oklahoma	)	Docket No. 40-8027

FINDINGS OF FACT AND CONCLUSIONS OF LAW

FINDINGS OF FACT

THE PROCEEDINGS

1. Kerr-McGee Corporation ("Kerr-McGee"), the Applicant herein, is a Delaware corporation, having its principal office in Oklahoma City, Oklahoma. It has built and is operating a plant near Gore, Oklahoma, in the eastern part of the State of Oklahoma, for the purification and conversion of yellow cake to uranium hexaflouride (UF_6) under an operating license from the United States Atomic Energy Commission, being License SUB-1010, granted on February 20, 1970, based upon an application submitted on September 25, 1969.

2. In operation, Sequoyah Facility produces as a by-product a liquid acid raffinate containing low level radionuclides as a waste product. (KMX 1 Application;

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KMX 3E [Figure 1]).* The initial design of the plant contemplated the discharge of the liquid acid raffinate to a deep disposal well located near the point of discharge. Such well was drilled to a total depth of 3,110 feet (KMX 3A[C-H]), with the proposed disposal zone being the Arbuckle Formation which was located in the lower 1,665 feet of such well. (KMX 3A). This strata is saturated with a highly mineralized liquid containing a total of approximately 140 parts per million dissolved solids and $Radium_{226}$ at a concentration of approximately 1400 pCi/l. (KMX 3E[Supp. 3]).

3. The use of the deep disposal well was not permitted when License SUB-1010 was issued. Pursuant to subsequent amendments to such license, holding ponds were constructed and equipment installed to neutralize the acidic raffinate initially with lime slurry, and later with ammonia. The resulting neutralized raffinate has been stored in the ponds until permission to use the well could be secured, or a permanent method of disposal could be determined. (KMX 3E[Supp. No. 3]).

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*The symbol "Tr." refers to the page or pages of the Transcript of Proceedings. The symbol "KMX" refers to Kerr-McGee's Exhibit and the symbol "SX" refers to Staff's Exhibit.

4. In May, 1970, Kerr-McGee made application for Amendment to License No. SUB-1010 to permit the injection of Sequoyah Facilities' entire liquid waste remaining after treatment into permeable members of the Arbuckle Formation. On October 15, 1970, the Atomic Energy Commission ("Commission") refused such amendment, but asserted that Kerr-McGee could appeal such decision. Kerr-McGee requested, and the Commission granted, permission to withdraw its application for amendment without prejudice to a future application. (KMX 1 Application).

5. After further study and investigation of the size, structure and containment potential of the Arbuckle Formation underlying the deep well, Kerr-McGee filed an Application for Amendment to License No. SUB-1010 to permit subsurface disposal of raffinate wastes produced at its Sequoyah Facility, dated May 10, 1972. (KMX 1). By letter, dated September 29, 1972, the Deputy Director of the Commission advised Kerr-McGee that its request for amendment had been denied. At a meeting between representatives of Kerr-McGee and the Commission held on November 20, 1972, additional information was submitted by Kerr-McGee for the consideration of the Commission. The Deputy Director of the Commission, by

letter dated March 14, 1973, affirmed the denial of September 29, 1972. On April 5, 1973, Kerr-McGee requested a hearing on the matter of the denial, pursuant to the provisions of 10 CFR 2.103. (Notice of Hearing). On July 10, 1973, the Commission issued a Notice of Hearing, published in the Federal Register at 28 FR 18,921, directing that a hearing be held to consider the application of Kerr-McGee. (Tr. p.49).

6. The Notice of Hearing required the Atomic Safety & Licensing Board ("Board") to consider and initially decide as issues in this proceeding whether pursuant to the Atomic Energy Act of 1954, as amended, and in accordance with 10 CFR 40.32(c) and (d):

A. The licensee's equipment, facilities and procedures proposed for use pursuant to the requested amendment are adequate to protect health and minimize danger to life or property; and

B. The issuance of the amendment will be inimical to the health and safety of the public.

Further action on environmental matters was to be considered by the Deputy Director on remand of the application in the event the Board makes an affirmative finding with respect to Item A, and a negative finding with

respect to Item B. (Notice of Hearing).

7. At the request of the Board, a Joint Statement of Proposed Issues, dated September 21, 1973, was prepared by Kerr-McGee and the Staff, which set forth the following issues to be considered by the Board:

A. Whether the Webbers Falls fault exists and, if it does, at what distance is it located northeast of the proposed disposal well?

B. Whether the South fault exists and, if it does, at what distance is it located southwest of the proposed disposal well?

C. Whether additional faults exist within the disposal formation (fault block) that may act as either barriers to fluid movement within the fault block or conduits for fluid movement within the formation?

D. Whether the nature of the faults comprising the fault block are such that the faults will act as barriers to fluid movement under increasing fluid pressure?

E. Whether the five disposal zones composing the Arbuckle Formation can be assumed to be homogeneous, isotropic, and constant in thickness,

porosity, and permeability, thereby permitting the calculation of the movement of the disposed waste fluid from the well bore?

F. Whether a three dimensional analysis of geohydrologic problems by the finite difference method, based on test data obtained from a single well, can accurately predict the nature and performance of the injection horizons?

G. Whether monitoring by pressure testing at the well head is adequate to detect fluid movement, or whether there is a need for direct monitoring of the recipient formation?

H. Whether in the event of a demonstrated leak in the retention reservoir or fault block the waste fluid can be recovered?

THE CONTESTED ISSUES

Reservoir Studies

8. Extensive reservoir engineering and geological studies have been made of the Arbuckle Formation in which the deep disposal well is completed and in which it is proposed to dispose of the liquid acid raffinate by qualified engineers and geologists on behalf of Kerr-McGee. (KMX 1A, 1F, 2A-I, 3A and 3B).

9. The engineering study included the combined applications of electric well logging, radioactive tracer and temperature profiling, pressure fall-off testing, regional geology and three-dimensional, single phase numeric modeling. The test data studied and the purposes for such study are:

TEST DATA	PURPOSE
1. Electric Well Logs	Formation correlation
A. Caliper Logs	Determination of hole volume
B. Density Logs	Determination of porosity of disposal zones
2. Static Pressure Survey	Establishment of initial undisturbed reservoir pressure
3. Water Injection with Radioactive Tracer Survey and Temperature Survey	Establish that there is no leak in casing or around casing shoe. Determination of permeable intervals accepting fluid and amount entering each zone
4. Shut-in test of 145 hours with Sperry-Sun Pressure Instrument	Provides wellbore pressure performance for reservoir description
5. Water Injection with Radioactive Tracer Followed by Profiling During Shut-in	Confirm permeable zones and existence of counterflow

The test data were used to develop a three-dimensional, single-phase reservoir model compatible with the injection

profile data and with the analysis performed on the pressure fall-off data. (KMX 1A [pp 1 and 2] and 3B [pp. 12 and 13]).

Reservoir Modeling

10. A reservoir model is used to simulate the behavior of an actual reservoir and may be physical, such as a laboratory sand pack, or mathematical, depending on a set of equations to describe the physical processes occurring in a reservoir under a set of assumptions. (KMX 3-A [p. 17]). Mathematical reservoir modeling in multi-dimensions has become a standard tool in the oil industry and in the evaluation of ground water reservoirs. The Commission has used mathematical reservoir modeling, similar to that used by Kerr-McGee, as shown in a report entitled, "Projected Reservoir Performances -Rio Blanco Project, March 1973" (Open File Report NVO-38-33, PNE-RB-26). (KMX 3C [pp. 10 & 11]).

11. Early reservoir models were relatively simple being based on average values for rock properties, porosity and permeability and estimates of average reservoir pressure which were used in determining fluid viscosities and compressibilities.

Average values were used because of limitations on

practical data and capacity to compute the equations. Such models are known as single-cell models and are zero dimensional since all values from point to point are the same. The single cell model is the basic building block for reservoir simulation. (KMX 3B [p. 2]).

12. A material balance is normally used to describe the flow of fluid in a single cell. The addition of single cells to represent varying average properties where such variances occur in a reservoir requires the calculation of the fluid transfer between two or more cells by the use of Darcy's law. Regardless of the number of cells (or dimensions) used, the material balance is the basic equation describing the fluid behavior within a cell and Darcy's law describes the fluid flow between the cells. (KMX 3B [pp. 2 & 3]).

13. The basic equation used in a numeric reservoir model involves a finite difference solution of the partial differential equation describing single-phase, three-dimensional flow of a compressible fluid in porus media. (KMX 1A [p.5], SX B [pp 2 and 3], SX C [p. 1]).

14. The finite difference solution of the equation requires dividing the reservoir into a number of cells or blocks, assigning to each cell appropriate rock properties, fluid saturation and distribution, and fluid

properties. The equation is written in finite difference form for each cell, resulting in a system of algebraic equations which must be solved simultaneously. Analytic solution of the equations is impossible in complex reservoir cases but is ideally suited to digital computation. (KMX 1A [pp. 6 & 7]). Given a value for the pressure and saturation at each cell at the beginning of a time step, new saturations and pressure values are found at the end of each time step. These values in turn represent the starting point for the next time step. This step wise process is continued until the desired amount of time has been predicted and the model completed. (KMX 3B [p. 9]). Reservoir parameters may then be changed and other models computed in the same manner.

15. The reservoir data obtained from the models are compared to the observed field performance data and the model which results in the best agreement between calculated and observed field performance presents the most valid reservoir description. (KMX 3B [p. 9]). The advantage offered by numerical simulation is that by dividing the reservoir into many cells to represent heterogeneity, changing lithology and pressure distribution we may more accurately predict the reservoir performance

by area or by vertical layer. (KMX 3B [p. 3]).

16. Multi-layer reservoirs are best evaluated with a numeric model and with adequate field data one can obtain an evaluation which closely matches measured data and accurately describes subsurface geometry and reservoir properties such as permability, static pressure, volume and boundary distances. A reliable reservoir description is best achieved when information from each source - pressure, geologic and wellbore flow data - functions as a companion to the other. (KMX 3B [pp. 10 & 11], SX B [pp. 3 & 4], SX C [p. 1]).

Engineering Studies

17. The proposed injection rate of liquid acidic raffinate into the deep disposal well on which the engineering study was based was 19 gallons per minute or 652 barrels per day for the first five years followed by an injection rate of 848 barrels per day for the remaining period of injection. (KMX 1A [p. 5]). The static reservoir pressure measured prior to injection was 1,238.45 pounds per square inch gauge ("psig") at a datum of 2,650 feet. (KMX 1A [p. 3]).

18. From the study of electric logs of the well, including caliper and density logs, an initial determination was made of the permeable zones and their porosity

in the Arbuckle formation and of the diameter of the open-hole section of the well. (KMX 3B [pp. 13 & Appendix 1-1]).

19. From the study of the water injection test combined with radioactive tracer survey and temperature survey, it was determined that there were no leaks through or around the casing. Such study also revealed that there were nine porous and permeable zones in the Arbuckle formation, which could be conveniently grouped together into five layers for evaluation purposes. The effective permeabilities of each layer were determined from the injection profile data and the calculated total permeability-thickness. (KMX 3B [pp. 13-17]).

20. From the study of the radioactive tracer survey taken during the shut-in period after injection it was determined that there was strong counter-flow from Layer No. 5, indicative of little or no vertical communication between layers in the Arbuckle formation. Such lack of communication, together with the fact that Layer No. 5 accepted progressively smaller volumes of injected water throughout the injection profile tests, indicated that one or more boundaries were influencing the observed behavior of Layer No. 5. (KMX 3B [p. 15]). Study of the

fall-off pressures obtained during the shut-in period confirmed an influencing boundary and calculation of the distance revealed a nearest boundary distance of approximately 1200 feet. (KMX 3B [pp. 15-17 and Ex. 5]).

21. Geologic information available at the time the engineering study was made revealed two major faults in the area - one (Carlile School Fault) lying about one mile southwest of the well running southwest to northeast and one (South Fault of Warner Uplift) lying about five miles northwest of the well (at nearest point) running southwest to northeast. (KMX 1F).

22. Test data for input into the numeric model consisted of the initial static reservoir pressure, injection rate schedules, pressure fall-off time periods, injection fluid properties, certain boundary distances revealed by geological and pressure fall-off data and values of effective permeability, porosity and thickness of each layer. (KMX 1A [pp. 3 & 4] and 3B [App. 1-2 & 3]).

23. A numeric reservoir model was prepared using five layers to represent the reservoir. The established data formed the foundation of the model and various combinations of data were systematically varied until a "best" match between calculated and observed pressure

fall-off data was obtained. (KMX 1A [pp. 9 & 10]). The variables adjusted in the simulation included the distances between the boundaries and the wellbore of each layer, layer permeabilities, layer pore volumes and the pervious or impervious condition of boundaries. (KMX 3B[App. 1-3]).

24. The model which best matched the observed pressure fall-off data indicates a reservoir of five significant layers with a total pore volume of at least 860 million barrels. Three of the layers are definitely bounded on all sides with Layers No. 3 and 4 bounded on the top, bottom and three sides with the fourth side determined to be not less than 28,414 feet from the well bore. A summary of the reservoir layer properties is as follows

Layer Number	Depth Interval (feet)	Net Thickness (feet)	Porosity (dec.frac.)	Effective Permeability (md)	Area (acres)
1	1,762-1,786	24	0.064	2,469	8,804
2	2,416-2,424	8	0.060	2,279	8,804
3	2,620-2,646	26	0.089	964	≥19,580*
4	2,711-2,774	24	0.099	1,709	≥19,580*
5	2,800-2,860	34	0.058	2,480	645

*Minimum area proved by test program.

(KMX 1A [p. 1 & Figs. 1 & 3]).

25. A numeric model cannot predict the orientation of a system or even the orientation of each layer relative to the other layers, but consistent with the regional geology the five layers are oriented as shown in Exhibit G-7 attached hereto. (KMX 1A [p. 9], TR. pp. 155-157, 349-351, SX B [p.4]).

26. The injection of nineteen gallons per minute (652 barrels per day) for the first five years and 848 barrels per day for the second five years of either the neutralized raffinate in the holding ponds or the acidic raffinate from the plant will increase wellhead injection pressure only 161 psig by the end of five years and by 371 psig by the end of ten years. (KMX 1A [Fig. 4]). The largest increase in bottom hole pressure after five years of injection occurs in Layer No. 5 and the predicted increase in pressure is 183.85 psig. (KMX 1A [Fig. 9]). Thus, the pressure increase at any fault or boundary will be less than 200 psig after five years of injection. (KMX 3B [App. 2-2]).

27. Heterogenous formations are represented by layered models using weighted properties for each of the model

layers and the numeric model used by Kerr-McGee was constructed using five layers to represent the reservoir. The numeric model was also used to investigate the effect of heterogenieties within such layers. A significant change in property, either areal or vertical, such as a change in permeability, is reflected in the measured pressure behavior and the calculated value will properly consider these changes, thus the engineering study has evaluated the areal and vertical heterogeneities which are dynamically significant in the reservoir. (KMX 3B [p. 18]).

28. Numeric models are initially assumed to have radial flow, i.e., flow in all directions from the well bore. However, if there is channeling or flow in a preferred direction, the nature of the flow system will be linear. Linear and radial flow systems have different pressure behaviors which are easily detected in the early-time regions of a pressure fall-off test. No indication of linear flow was observed in the test data and it is concluded, therefore, that the injected material will advance radially in the permeable zones. (KMX 3B [p. 19], SX C [p.1], TR. p. 181).

29. A staff consultant cited a disposal well in

New Johnsonville, Tennessee, which was disposing of material in the Knox Dolomite in an unbounded reservoir where the predicted flow was to be 500 feet from the well bore. The actual flow was discovered to be 2500 feet in a preferred direction. It was asserted that all of the same tests were made on the well as on the well in question but still there was an unpredictable movement. However, in such case the rate and distance of movement was predicted independently of pressure distribution and a numeric model was not constructed or used. (TR. pp. 327-330).

30. Based on the above injection schedule, the approximate distance the injected fluid will move from the well bore at the end of five years in the five layers is as follows:

Layer	Injected Volume (barrels)	Approximate Distance From Well Bore (feet)
1	165,200	700
2	72,700	750
3	440,600	900
4	500,300	900
5	22,600	140

The above figures assume no alteration of the reservoir resulting from chemical reaction between the injected fluids and the reservoir rock. Cavities created by injection

of the raw raffinate will cause the dispersion distance to be less than the calculated distances. (KMX 1A [pp. 2 and 3], TR pp. 224-225). The calculation of the movement of injected fluids did not consider hydrodynamic dispersion and density differences. Consideration of such parameters was variously estimated by consultants for Kerr-McGee and the Staff to cause additional dispersion of 90 to 300 feet. (TR. 173-176, 327). The additional dispersion, which might be present upon consideration of the additional parameters, would result in the dispersion of the raffinate in a diluted form to a maximum of 1200 feet in Layers No. 3 and 4.

31. The maximum dispersion distance of the injected raffinate would result in the raffinate reaching the nearest boundary only on the northeast side of Layers 3 and 4. A leaking boundary (formerly called "East" but since denominated as "North-east" or "Webbers Falls Fault") was simulated by the model providing for cases of no permeability at the boundary and permeabilities of 0.01 and 0.1 millidarcies at the boundary. The best match with observed pressures was the impermeable boundary case. The 0.01 millidarcy permeability case involved such small pressure differences that it is not statistically different

from the impermeable boundary case, and, therefore, the 0.01 millidarcy case, which would allow a 4.4 barrel per day leakage without detection, is a practical limit for the sensitivity of the calculation. It appears that no leakage occurred during the test period. (KMX 1A [pp. 11-13]).

32. Based on observation of the counterflow in the profile testing, which would have reacted differently if there had been leakage between layers, it was determined that no vertical communication existed between layers. Vertical leakage to other formations in the vicinity of the well bore would have affected the observed pressure fall-off data. No effect on such data was observed. It appears there was no such leakage. (KMX 1A [p. 12]).

Geological Studies

33. The stratigraphic column underlying the area where the proposed waste disposal well is located consists of a series of dense and impermeable rocks to a depth of 3,110 feet deep where they lie on igneous rocks or granite. Two sandstone formations - one in the Atoka and one in the Simpson - each about 60 feet thick are somewhat porous, and there are various porous intervals

in the Arbuckle Formation, the basal formation of the stratigraphic column. The Limestone above the Arbuckle (the Everton Formation) is dense to lithographic, having the texture of fine chinaware and is completely lacking in porosity. (KMX 3A [p. 6]).

34. The Arbuckle Formation is found in the Kerr-McGee Waste Disposal Well at a depth of 1445 feet, and has a total thickness of 1,665 feet. The Arbuckle is dominantly dolomite, a calcium-magnesium carbonate usually formed by chemical alteration of limestone, which is nearly pure calcium carbonate. Most of the Arbuckle Formation is quite dense and impervious, but with porous zones resulting from dolomitization and vugs. Porosity is somewhat more common in the lower 1,000 feet of the Arbuckle where the granules and crystals of which the rock is composed are generally larger. (KMX 3A [pp. 6-8]).

35. The Arbuckle Formation considered as a whole is heterogenous, but within the various layers making up the Arbuckle Formation homogeneity is the rule. Certain zones and layers in the Arbuckle - thin green shales, zones of sandstone and chert varieties - can be traced for some distance. The lateral continuity of

the rock types in the Arbuckle is shown by the fact that two or three layers encountered in the Kerr-McGee well have been recognized in the Carter and Leonard Wells two and three miles away. (KMX 3A [p. 8]).

36. Homogeneity in certain zones and layers of the Arbuckle results from the fact that depositional conditions during Arbuckle time were remarkably uniform and wide spread. Brief episodes of sea withdrawal and return permitted the spread of blankets of sediment across the whole area, and lateral continuity is therefore an inherent feature. Permeable zones may be limited by faults or by unequal effects of the dolomitizing agents on the limestone which may cause the size and location of the porous spaces to vary. (KMX 3A [pp. 9 & 10]).

37. The characteristics of the Arbuckle formation, as well as its usually great depth beneath the surface, its confinement between dense shales and limestones above and dense igneous rocks below, makes it the most popular reservoir in the southwest for the disposal of oil field brine and industrial waste. Liquid industrial waste is being disposed of in two wells in the City of Tulsa in the Arbuckle Formation, with injection rates up to 275 gpm, and pressures of 340 psi. Four other wells disposing

of industrial waste are located near Pryor, Oklahoma, where rates exceed 225 gpm, at pressures up to 380 psi. Hundreds of wells near Tulsa, Oklahoma are being used to dispose of oily brine in the Arbuckle Formation. (KMX 3A [pp. 10 & 11]).

38. The portion of the Arbuckle into which Kerr-McGee desires to inject raffinate is bounded to the southeast by the Carlile School Fault, approximately a mile away, and to the northwest by the South Fault of the Warner Uplift, approximately six miles away. These well known faults are recognizable on the surface, and their existence is well established. (KMX 3A [pp. 12 & 13; Ex. CC]).

39. Two additional faults, designated the Webbers Falls Fault and the South Fault, lying to the northeast and southwest of the Kerr-McGee disposal well respectively have been determined through analysis of the subsurface and surface conditions. These faults, together with the Carlile School Fault and the South Fault of the Warner Uplift, create a fault block, or area completely surrounded by faults, in which the Kerr-McGee disposal well is completed, and into which fault block in the Arbuckle Formation Kerr-McGee desires to inject the waste

raffinate. (KMX 3A [Ex. C-C]).

40. Analysis of surface and subsurface conditions in connection with locating the Webbers Falls Fault reveals that the regional dip in the Wapanucka Limestone, the most readily recognized shallow formation in the Kerr-McGee disposal well, is about 200 feet per mile, and such formation should emerge at the surface within a short distance northeast of the well. The Wapanucka Limestone, however, does not appear on the surface within six miles of the disposal well, indicating that a fault close to the well has altered the regional dip as revealed in the Cobb No. 1 Wilson Well in Section 36, Township 13 North, Range 21 East. Surface expression of the fault is indicated by a straight stream course, a precipitious bluff, a bend in the Illinois River, and anomalous "Round Mountains" near the Village of Gore, and southeast of the Sequoyah Facility in Sections 24 and 26, Township 12 North, Range 21 East. (KMX 3A [Ex. CD & CE]). This boundary has also been located by the numeric model. See Finding 20.

41. Analysis of the subsurface and surface conditions in connection with location of the South Fault re-veals that the top of the Viola and the top of the Ar-buckle Formations in the Bruce Harris No. 1 Standifer

Well, Section 5, Township 11 North, Range 20 East, are anomalously low in elevation. Regional considerations indicate the Viola should have been encountered at 1500 feet below sea level, rather than at 2700 feet below sea level, and the Arbuckle at 1800 feet below sea level, rather than 3,010 feet below sea level if there were no fault present. Surface conditions also corroborate the presence of the South Fault. Structural control of the channel of Dirty Creek is strongly suggested by its paralleling the Arkansas River (especially in Sections 26 and 36, Township 12 North, Range 20 East, and Sections 5 and 6, Township 11 North, Range 21 East), the presence of a number of tight 180° bends and several very straight stretches. In addition, there is an abrupt escarpment partly paralleling Dirty Creek and there is a major change in the outcrop of the Hartshorne sandstone formation. (KMX 3A [Ex. CC, CD & CE]). At the proposed injection level the South Fault is approximately 29,500 feet from the disposal well. This distance ties in closely with the investigation of the reservoir area by numeric model in which it was found that such area is contained within a maximum distance of approximately 30,000 feet from the test well. (KMX 1A [p. 5]; KMX 3A [p. 14]).

42. Faults are fractures along which there has been movement of the opposing rock masses, and are very common features of the earth. Several varieties are recognized, but both the Webbers Falls Fault and the South Fault are indicated to be normal faults, i. e., the variety in which the upper block has moved downward with respect to the lower side. Such movement conforms to the downwarping of the Arkoma Basin and concurrent upward movement of the Ozark Uplift. At the time of fracture, the two sides of a fault are tightly pressed against one another and any openings which may have resulted from irregularities in the fault are packed with flour-like rock debris (Gouge). In addition, the displacement by fracturing or faulting breaks up the continuity of the zones or layers and juxtaposes different layers against each other on opposite sides of the fault, thereby preventing the movement of subsurface fluids. A fault has long been considered a clue to the possible location of gas and oil accumulations which are trapped against the fault because lateral movement is prevented by the discontinuity and vertical movement is prevented by the pressure of the two sides being pressed together with irregularities being filled with Gouge. Oil and gas accumulations

are frequently found in such fault traps under extremely high pressure. (KMX 3A [pp. 16 & 17]). Petroleum Geologists and Petroleum Engineers consider all faults as sealing until proven otherwise, since this is almost universally the case. (KMX 3A [p. 19]).

43. Field surveys by Kerr-McGee's consultant of the faults and inferred faults mapped in a photogeologic analysis by the Oklahoma Geological Survey failed to show evidence to support all these postulated structures. The dashed lines indicating "inferred faults" near the injection well are shown by field studies to be lines of vegetation, probably controlled by jointing (cracks that do not extend deep into the earth) rather than faults. (KMX 3A [pp. 15 & 16]). Further, the subject area is very favorable for the phenomenon known as disharmony of structure, i. e., faults and folds may be present at the surface but absent at depth. Structural disharmony is most likely in areas like the Arkoma Basin, which have thick and massive layers of very competent and resistant limestone and dolomite at the base overlain by soft and pliable shale, likewise very thick. The shale may readily yield to stress by faulting and fracturing, but the more resistant and deeper layers simply bend and retain their continuity. For this reason many of

the less obvious faults, like those shown as "inferred faults" on the airphoto analysis made by the Oklahoma Geological Survey, are merely superficial as compared to those faults established by subsurface mapping and pressure analysis which are likely to extend downward into the Precambrian Granite before dying out. (KMX 3A [pp. 3 & 4]).

Monitoring

44. A monitoring program for surface and shallow subsurface liquids from nearby streams, run-off collection ponds and shallow wells will be carried out by Kerr-McGee to provide early warning in the event that there is a loss of confinement of reservoir liquids or injected wastes so that environmental effects will be avoided or minimized through appropriate action. In addition, Kerr-McGee will sample water wells currently in use located in the alluvium of the Arkansas and Canadian Rivers within the subject fault block to insure that no undetected leak is contaminating drinking water supplies. (KMX 3E [pp. 2 & 3]).

45. Monitoring of the disposal well to determine if leakage from the Arbuckle formation to adjacent formations or through faults to upper formations or the sur-

face is occurring can be accomplished by use of the numeric simulation model presently established for the disposal well. Comparison can be made of the observed performance as compared to the predicted performance, and a divergence from the predicted performance will be a warning to search for the cause of such divergence. In the event of a serious divergence, or a sharp break in the observed performance, emergency actions, including procedures to back flow the well, can be initiated. (KMX 3B [pp. 20 & 21]).

46. Monitoring the disposal well by pressure transient testing and use of the numeric model is the most logical method of monitoring to detect escape of formation liquids or disposed waste from the Arbuckle formation. (Tr. p. 338).

47. Kerr-McGee has proposed to dispose of a portion of the neutralized acidic raffinate now stored in its surface ponds in the disposal well in a series of approximately five sequences, conducting a test for pressure fall-off subsequent to each sequence. The results of the fall-off curve would be matched against the numeric model to determine the accuracy of the model. Use of neutralized raffinate will prevent cavitation which would

result from the use of raw raffinate. Such a program of confirmation of the numeric model is recommended by all consultants. (KMX 3E [pp. 3 & 4]; KMX 3C [pp. 13 & 14]; KMX 3B [pp. 20 & 21]; Tr. pp. 311, 312 & 352).

48. The disposal of the neutralized raffinate in the manner proposed by Kerr-McGee could be accomplished without risk. (Tr. pp. 311-312).

49. Kerr-McGee further proposes, upon confirmation of the accuracy of the model, that raw raffinate would be injected, and that pressure fall-off tests would be conducted sequentially during the first year, and at the conclusion of the first year the model would be adjusted for the cavitation expected to occur as a result of the disposal of acidic raffinate. Pressure fall-off tests would be conducted each six months thereafter to confirm the results predicted by the numeric model. In the event of significant mis-match of actual and model predictions, additional consultation would be arranged to evolve the ongoing program. (KMX 3E [pp. 4 & 5]).

50. It was proposed by a consultant for the Staff that if "one were seeking a location for additional ways to monitor for potential leakage that the next most logical thing to do after direct monitoring of the disposal

well would be the drilling of additional monitoring wells, and that such monitoring wells would 'be a useful addition to the monitoring which Kerr-McGee has recommended by themselves.'" (Tr. pp. 338 & 340).

The consultant proposes the drilling of a well north of the disposal well to determine the location of the Webbers Falls Fault, another well between the two wells through the Simpson formation, to be used as a monitor to determine leakage into the Simpson formation, and a third well southwest of the disposal well drilled through the Arbuckle formation to be used to monitor that formation and act as a substitute disposal well. (SX B [letter 12-22-72]).

51. All engineering consultants agree that monitoring the disposal well with pressure fall-off tests and numeric modeling, as proposed by Kerr-McGee, will reveal the size of the fault block and whether it is sealed or not, and that this should be the primary means of monitoring the disposal formation. (KMX 3B [pp. 21, 22 & 23]; KMX 3C [pp. 13 & 14]; Tr. pp. 317-319, 338, 340, 352). The proposed monitor wells would be used to supplement the information obtained from monitoring the disposal well.

52. The total lack of permeability in the Granite formation underlying the Arbuckle formation, and in the Everton zone of the Simpson formation overlying the Arbuckle when coupled with the fact that most faults found in oil and gas operations have been determined to be sealing and no evidence has been introduced contrary to that fact in this cause, makes unnecessary the drilling of monitor wells to verify information which will be available from the pressure fall-off testing and numeric modeling of the disposal well in operation. The cost of drilling and completing such monitor wells, varying between $290,800.00 to $361,500.00, depending upon the completion involved, cannot be justified when the information to be gained from them will only confirm or supplement that received from the monitoring of the disposal well.

Effect of Escape

53. Radium is the radiological toxic agent of primary interest. The maximum permissable concentration (MPC) of soluble $Radium_{226}$ in an unresitricted area is 3×10^{-8} uCi/ml. The $Radium_{226}$ present in the raffinate is 340×10^{-8} uCi/ml, while in the fluid located in the disposal well the concentration is 140×10^{-8} uCi/ml. In view, however, of the concentrations of other materials

in the raffinate solution and the disposal well fluid, the burning sensation and bad taste resulting from consuming either of these liquids in their undiluted condition would make it almost impossible to receive a dose of radionuclide of any significant level. In fact, the consumption of two liters of the undiluted material, if it could be ingested at all, would produce only negligible deposition in the body. (KMX 3D [p. 8, Fig. 1]).

54. The worst possible accident that could occur in connection with the escape of the raffinate or the formation water, or a combination of both, is through a massive fault leak into the Illinois and Arkansas Rivers. The amount of water available in such surface streams adjacent to the disposal fault block would flow at such a rate as to provide adequate dilution of either the raffinate or the formation water to concentrations below permissible limits. (KMX 3D [p. 8, Fig.2]).

55. While it is considered possible for the radium concentration to leak into a well along with the waste water, and perhaps reach maximum permissible concentrations prior to the other chemicals in the waste water reaching such a level that they would be detectable by a potential recipient, the surface and shallow subsurface

monitoring program proposes to monitor the shallow domestic wells in the area, together with all water wells currently in use located in the alluvium of the Arkansas and Canadian Rivers, within the subject fault block, to insure that no undetected leak is contaminating drinking water supplies. Maximum permissible concentrations of radium would therefore be detected, and the population protected therefrom, even though other chemicals were undetectable by those ingesting the water. (Tr. p. 125; KMX 3E [pp. 2 & 3]).

56. Dr. Charles J. Sternhagen, radiologist, testified that based on his understanding of the monitoring program and the precision with which a leak from the reservoir can be detected, that he believes it to be incredible that an accidental release through failure of the well or the reservoir would result in significant exposure to the population in this area.

SUMMARY

56. The Webbers Falls Fault is shown to exist at a distance of approximately 1200 feet northeast of the proposed disposal well by virtue of the following facts:

A. That application of deductive reasoning and of accepted principles of field and subsurface geology shows that omitting the Webbers Falls

Fault requires an anomolous dip in the Wapanucka formation when compared to regional dip established by subsurface control, and that surface expression of the fault is indicated by a straight stream course, a precipitious bluff, a bend in the Illinois River, and anomolous "Round Mountains" northwest and southeast of the Sequoyah Facility.

B. That the transient pressure analysis definitely indicates a reservoir boundary at a distance of about 1200 feet from the proposed disposal well, and the fact that all permeable layers in the Arbuckle formation demonstrate a reservoir boundary at the same distance indicates a sealing fault rather than a permeability pinchout.

57. The existence of the South Fault at a distance of approximately 29,000 feet southwest of the proposed disposal well is shown by virtue of the following facts:

A. That by application of deductive reasoning and accepted techniques of field and subsurface geology it is established that the top of the Viola and Arbuckle formations in the Bruce Harris #1 Standifer Well are anomolously low in elevation, showing that there must be

a fault to the northeast of said well, and that surface conditions, such as the channel of Dirty Creek which parallels the major stream and has a number of 180° bends, and several very straight stretches, an abrupt escarpment probably paralleling Dirty Creek, and a major change in the outcrop of a local sandstone formation, all indicate and corroborate the presence and location of the South Fault.

B. That the transient pressure testing and numeric modeling indicate no truncation within approximately 29,000 feet in two of the five layers, being Layers No. 3 and 4.

58. Extensive geological analysis by accepted field, airphoto and subsurface techniques, and pressure transient testing and numeric modeling have all failed to reveal the presence of additional faults existing within the disposal formation that may act as either barriers to fluid movement within the fault block, or conduits for fluid movement within the formation. If any such faulting served as conduits or barriers, such conditions would have influenced the pressure behaviour in a detectable manner, and would have been revealed in the transient pressure testing.

59. The faults comprising the fault block are normal faults of the kind almost universally regarded by petroleum geologists as agents responsible for trapping and preventing the movement of oil and gas under exceedingly high pressure conditions. While it is impossible to state that the faults will be or will remain sealing, the pressure increase at the fault will be less than 200 pounds after five years of injection. Oil field experience has shown that most faults are sealing and maintain integrity to pressure differentials of several thousands of pounds per square inch.

60. The Arbuckle formation is shown to be homogeneous in various layers, and numerous careful geologists have succeeded in correlating zones in the Arbuckle Formation over wide distances. This is the result of the nature of the depositional environment, and porous and permeable zones often remain constant in thickness and character for distances of several miles. In numeric modeling, heterogeneous formations can be represented by layered models using weighted properties for each of the model layers. In the numeric model used by consultants for Kerr-McGee it was determined that the five proposed disposal zones were homogeneous, isotropic and

constant in thickness, porosity and permeability, and permitted the calculation of the movement of the disposed waste fluid from the well bore, thus confirming that such zones are typical Arbuckle formation homogenous zones.

61. All engineering consultants agreed that a three-dimensional analysis of geohydrologic problems by the finite difference method, based on test data obtained from a single well, can sufficiently predict the nature and performance of the injection horizons. Although there was a difference of opinion as to whether sufficient test data had been gathered in the Kerr-McGee disposal well, all agreed that additional pressure transient testing would result in more accurate predictions of the nature and performance of the injection horizon, and Kerr-McGee has postulated such testing by using neutralized raffinate from the surface storage ponds for testing purposes. The use of such neutralized raffinate for such purposes carries essentially no risk.

62. Direct monitoring of the recipient formation is supplemental to the primary monitoring by pressure testing at the well head and will reveal no information not available by pressure testing at the well head and with down hole instruments combined with numeric modeling, as proposed by Kerr-McGee.

63. In the event of a demonstrated leak in the retention reservoir or fault block, the well can be back flowed and up to 85% of the waste fluid can be recovered from the disposal formation. The remaining 15%, together with any material that has precipitated out, will remain locked in the pore spaces surrounding the well bore, with no chance for further movement.

CONCLUSIONS OF LAW

1. Kerr-McGee Corporation has a valid and existing license for source materials from the Atomic Energy Commission, being License No. SUB-1010.

2. The Application for Amendment to License Number SUB-1010, Docket No. 40-8027, to permit subsurface storage of certain liquids at Kerr-McGee's Sequoyah Facility was validly filed in accordance with the provisions of 10 CFR 40.44.

3. The action of the Deputy Director of the Commission in denying the requested amendment, and the action of Kerr-McGee in requesting a hearing on the matter of the denial were in compliance with the provisions of 10 CFR 2-103.

4. The Notice of Hearing required by 10 CFR 2-104 was validly issued.

5. Except for action on environmental matters as may be required by 10 CFR 40.32(e), which are specifically reserved for determination by the Deputy Director, this Board is to consider as the sole issues in the approval of the Application for Amendment of Source Material License No. SUB-1010 the following:

A. The licensee's equipment, facilities and procedures proposed for use pursuant to the requested amendment are adequate to protect health and minimize danger to life or property; and

B. The issuance of the amendment will be inimical to the health and safety of the public.

6. Determinative of the issues in this cause are the answers to the following questions which have been framed by the parties hereto as a Joint Statement Of Proposed Issues, dated September 21, 1973:

A. Whether the Webbers Falls fault exists and, if it does, at what distance is it located northeast of the proposed disposal well?

B. Whether the South fault exists and, if it does, at what distance is it located southwest of the proposed disposal well?

C. Whether additional faults exist within

the disposal formation (fault block) that may act as either barriers to fluid movement within the fault block or conduits for fluid movement within the formation?

D. Whether the nature of the faults comprising the fault block are such that the faults will act as barriers to fluid movement under increasing fluid pressure?

E. Whether the five disposal zones composing the Arbuckle Formation can be assumed to be homogeneous, isotropic, and constant in thickness, porosity, and permeability, thereby permitting the calculation of the movement of the disposed waste fluid from the well bore?

F. Whether a three dimensional analysis of geohydrologic problems by the finite difference method, based on test data obtained from a single well, can accurately predict the nature and performance of the injection horizons?

G. Whether monitoring by pressure testing at the well head is adequate to detect fluid movement, or whether there is a need for direct monitoring of the recipient formation?

H. Whether in the event of a demonstrated leak in the retention reservoir or fault block the waste fluid can be recovered?

7. Upon affirmative findings to the above questions, and an affirmative answer to Issue No. 1, and a negative answer to Issue No. 2, the Board is authorized to grant the amendment sought by the application of Kerr-McGee Corporation or to condition granting of such amendment as the Board may determine, as provided under 10 CFR 2.721.

8. The provisions of 10 CFR 20.106(e) are not applicable to reduce the maximum permissible concentrations of radium below the 10 CFR 20 Appendix B levels since the Commission has not acted to limit quantities of radioactive materials released in air or water below the levels provided in Appendix B for the area involved in this application.

9. The Board, having found affirmatively as to the Joint Issues, answers Issue No. 1 in the affirmative and answers Issue No. 2 in the negative and finds that the Amendment to Source Material License SUB-1010

should be granted subject to the determination of environmental matters by the Deputy Director.

Respectfully submitted,

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CERTIFICATE OF SERVICE

I hereby certify that true and correct copies of the above and foregoing instrument were mailed to the following by depositing in the United States Mail at Oklahoma City, Oklahoma on the 21st day of November, 1973:

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