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1. Adams, J. A., and J. E. Oddo. Geological Trade-offs in Uranium Solution Mining. Pres. at AAPG-SEPM Ann. Convention, Houston, Texas, Apr. 1-4, 1979.

2. Adler, H. H. Concepts of Genesis of Sandstone-type Uranium Ore Deposits. Econ. Geol., V. 58, No. 6, 1963, pp. 839-851.

3. Alvarez, J. J. The Elution and Precipitation Systems at URI's In Situ Solution Mining Plants. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

4. Amell, A. R., and D. Langmuir. Factors Influencing the Solution Rate of Uranium Dioxide under Conditions Applicable to In Situ Leaching. BuMines Open File Rept. 79-084, 1979, 124 pp.; available for consultation at Twin Cities Research Center, Minneapolis, MN,s and from National Technical Information Service, Springfield, Va. PB 299 947/AS.

5. American Institute of Mining, Metallurgical and Petroleum Engineers, Inc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978, Sponsored by South Texas Minerals Section, AIME. New York, Soc. Min. Eng., AIME, 1979, 129 pp.

6. Anderson, J. S., and M. I. Richie. Solution Mining of Uranium. Min. Cong. J., V. 54, No. 1, January 1968, pp. 20-23, 26.

7. Annamalai, V., and F. X. Mcgarvey. Operating Experience in the Recovery of Uranium at the Pawnee and Zamzow Sites. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Tex., Sept. 21-24, 1980, SPE Preprint 9507, 14 pp.

8. Bakhurov, V. G., S. G. Vecherkin, and I. K. Lutsenko. Podzemnoe Vysmchelacivanie Uranovykh Rud (Underground Leaching of Uranium Ores). Atomizdat, Moscow, 1969, 151 pp.

9. Ballard, J. K. Solution Mining. Min. Eng., V. 23, No. 2, February 1971, p. 109.

10. Barnes, F. Q. Uranium--Where are the Reserves? Min. Cong. J., V. 62, No. 2, February 1976, pp. 28-33.

11. Becherkin, S. G., V. G. Bakhurov, and I. K. Lutsenko. Underground Leaching of Uranium from Low-grade In-Situ Ores. Soviet Atomic Energy, V. 21, No. 2, February 1968, pp. 128-133.

12. Berg, D. New Uranium Recovery Techniques. Pres. at Atomic Ind. Forum Internat. Conf. On Uranium, Geneva, Sept. 13-16, 1976, 13 pp.

13. Bhappu, R. B. Economic Evaluation of In Place Leaching and Solution Mining Situations. Pres. at a Short Course in In-Place Leaching and Solution Mining, the Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Nov. 10-14, 1975, 22 pp.

14. Bhappu, R. B. In Situ Extraction and Leaching Technology. Pres. at Inter-Regional Seminar on the Economics of Mineral Engineering, Ankara, Turkey, Apr. 5-16, 1976, 39 pp.

15. Bhappu, R. B. In Situ Mining Technology - Practical and Economic Aspects. Pres. at the Turkish Mining Institute, Ankara, Turkey, Apr. 5-16, 1976, 29 pp.

16. Bishop, A. L. Non-Production Zone Excursion: Detection and Correction. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

17. Bommer, P. M. A Streamline-Concentration Balance Model for In-Situ Uranium Leaching and Site Restoration. Ph.d. Dissertation, University of Texas at Austin, Austin, Texas, August 1978.

18. Bommer, P. M., and R. S. Schechter. Mathematical Modeling of In-Situ Uranium Leaching. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 54-66; SME Preprint 79-28, 13 pp.

19. Bommer, P. M., and R. S. Schechter. Mathematical Modeling of In-Situ Uranium Leaching. Soc. Petrol. Eng. J., V. 19, No. 7, December 1979, pp. 393-400.

20. Bommer, P. M., and R. S. Schechter. Post In-Situ Uranium Leaching Site Restoration-Numerical Analysis. Univ. Texas, Austin, Tex. [in press]

21. Bommer, P. M., R. S. Schechter, and M. J. Humenick. A Streamline-Concentration Balance Model for In-Situ Uranium Leaching and Site Restoration. Center for Research in Water Resources Report No. CRWR-180, Univ. Texas at Austin, Austin, Tex., March 1981, 260 pp.

22. Borkert, J. J., Jr. Evaluation of a Uranium In-Situ Leaching Project. Planning and Analysis Div., U.S. Energy Res. and Dev. Admin., Grand Junction, Co., February 1975, 47 pp.

23. Borkert, J. J., and C. E. Gerity. An Economic Analysis of Open-Pit and In Situ Mining. Min. Eng., V. 30, No. 10, October 1978, pp. 1420-1422.

24. Borkert, J. J., and C. E. Gerity. The Economics of In Situ Mining Versus Open Pit Mining. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 18, Pt. 5, 1979, pp. 107-112.

25. Bossler, J. F., and R. F. Janke. Ion Exchange Resin Evaluation in Uranium Recovery. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 13, Pt. 4, 1979, pp. 79-86.

26. Boyce, T. D. The Relationship Between Ion Exchange Resin Properties and Uranium Recovery in Fluidized Bed Columns. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9508, 8 pp.

27. Brierley, C. L. Biogenic Extraction of Uranium from Ores of the Grants Region. Proc. Internat. Symp. on Metallurgical Applications of Bacterial Leaching and Academic Press, Inc., New York, 1977, pp. 345-363.

28. Brierley, C. L. Microbiology and Uranium Mining: Practices and Problems. Proc. Third Ann. Uranium Sem., Wyoming Min. and Metals Sect., AIME, Casper, Wyo., Sept. 9-12, 1979, pp. 129-133.

29. Brierley, C. L., J. A. Brierley, P. R. Norris, and D. P. Kelly. Metal-Tolerant Microorganisms of Hot, Acid Environments. Tech. Series Pub., No. 14, Soc. for Applied Bacteriology, [in Press].

30. Brookins, D. G. Geochemistry of Clay Minerals for Uranium Exporation in the Grants Mineral Belt, New Mexico. Pres. at 109th Ann. Meeting, Soc. Min. Eng., AIME, Las Vegas, Nevada, Feb. 24-28, 1980, SME Preprint 80-142, 13 pp.

31. Brown, M. R. Kerr Gets First Sales Contract for Uranium for Agnew Lake Mine Production. The Northern Miner, V. 62, No. 18, July 15, 1976, p. 1.

32. Buma, G. Geochemical Arguments for Natural Stabilization Following In-Situ Leaching of Uranium. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 113-124.

33. Buma, G. Property Evaluation Procedures for In-Situ Leaching of Uranium. Rocky Mt. Geochemical Corp., Apr. 29, 1977, 20 pp.; Available from P.O. Box 337, Midvale, Utah 84047.

34. Buma, G. Uranium Solution Mining State of the Art. Pres. at Energy Technology Conf. and Exhibit, Petrol. Div. of Soc. Mech. Eng., AIME, Houston, Tex., Sept. 18-22, 1977, Preprint 77-PET-47, 11 pp.

35. Bunker, C. M., and J. A. Mackallon. Geology of the Oxidized Uranium Ore Deposits of the Tordilla Hill-Deweesville Area, Karnes County, Texas: A Study of a District Before Mining. U.S. Geol. Survey Paper No. 465, 1973, 37 pp.

36. Burger, J. R. El Mesquite In Situ Leach Plant is Mobil's First. Eng. Min. J., V. 182, No. 1, January 1981, pp. 54-57.

37. Carlson, R. H. The Effect of Uranium Leach Conditions on the Kinetics of Hydrogen Peroxide Reactions. Pres. at South Texas Uranium Symp., Corpus Christi, Tex., Sept. 25-28, 1977. [in press]

38. Carlson, R. H. New Techniques for Measuring Oxidant Effectiveness in In Situ Uranium Leaching. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

39. Carlson, R. H., R. D. Norris, and R. Schellinger. Oxidant Effectiveness in In Situ Uranium Leaching. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

40. Carlson, R. H., R. D. Norris, and R. Schellinger. The Role of Oxidizing Agent in the Chemistry of In Situ Uranium Leaching. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Tex., Sept. 21-24, 1980, SPE Preprint 9483, 16 pp.

41. Carnahan, T. G. (Reno Metallurgy Research Center). In Situ Leaching of Uranium. Pres. at the In-Place Leaching and Solution Mining Short Course, Incline Village, Nevada, Nov. 10-14, 1975, 18 pp.

42. Carnine, G. T., and L. R. Darbee (assigned to FMC Corporation, New York, N.Y., a corp. of Del.). Stabilization of Hydrogen Peroxide. U.S. Pat. 3,383,174, May 14, 1968.

43. Carpenter, R. H., and R. B. Bhappu. Hydrometallurgy and Low Grade Ore Potential. Pres. at 107th Ann. Meeting, AIME, Atlanta, Ga., Mar. 6-10, 1977.

44. Chamberlain, P. G. Evaluating Ore Bodies for Leaching with Permeability Measurements. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 7-22; Preprint 79-27, 14 pp.

45. Chamberlain, P. G. Field Permeability Methods for In-Place Leaching. Min. Cong. J., V. 64, No. 9, September 1978, pp. 22-25.

46. Chapman, Wood, and Griswold, Inc. Geologic Map of Grants Uranium Region. New Mexico Bureau of Mines and Mineral Resources, Circ. 31, 1977, 3 pp.

47. Charley, W. R. Economic Considerations of Solution Mining. Pres. at Uranium Resource/Tech. Seminar II, Colorado School of Mines, Golden, Colo., Mar. 12-14, 1979, 13 pp.

48. Chase, C. K., H. J. Winters, and R. B. Bhappu. Economic Evaluation of In Situ Extraction of Uranium. Pres. at Am. Nuclear Soc. Meeting, Golden, Colo., Apr. 12-14, 1977, 12 pp.; Available from C. K. Chase, Mountain States Research and Development, P.O. Box 17960, Tucson, Arizona 85731.

49. Chatterji, B. D., A. S. Deshpande, C. V. Sharma, S. C. Kulshrestha, and R. N. Sankran. Results of Some Beneficiation and Lixiviation Tests on Medium-Grade Uranium Ore in Quartzite from Chhinjra, Kulu District, Himachal Pradesh. Proc. of the Indian National Science Academy, V. 36, A, No. 6, 1970.

50. Chemical Week. New Solution Cuts Uranium Mining Costs. V. 29, Dec. 24, 1975, pp. 28-29.

51. Chemical Week. Scowl, Then A Smile for Solution Mining. Feb. 2, 1977, pp. 13-14.

52. Clark, D. A. State-Of-The-Art. Uranium Mining, Milling, and Refining Industry. U.S. Environmental Protection Agency Rept. EPA-660/2-74-038, June 1974, 113 pp.

53. Colchin, M. P., L. Jan Turk, and M. J. Humenick. Sampling of Ground Water Baseline and Monitoring Data for In-Situ Processes. Center for Research in Water Resources Report No. CRWR-157, Tech. Rept. No. EHE 78-01, Univ. Texas at Austin, Austin, Tex., June 1978, 176 pp.

54. Coleman, K. A., and G. W. Stewart. New Mexico's First Uranium In Situ Solution Project. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Tex., Sept. 21-24, 1980, SPE Preprint 9489, 8 pp.

55. Colorado Department of Health. Source Material License Issued to Wyoming Mineral Corporation for a Pilot Scale In Situ Uranium Leaching Operation in Weld County, Colorado. Permit Issued for One Year, October 1976 - October 1977.

56. Conine, W. D. Uranium Solution Mining: A Comparision of New Mexico with South Texas. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Sect., AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 126-128.

57. Cook, L. M. The Uranium District of the Texas Gulf Coastal Plain. Texas Department of Health, Austin, Texas. Apr. 28, 1978, 14 pp.

58. Cooperstein, R. Presentations at Seminar on In Situ Uranium Solution Extraction. Pres. at Seminar on In Situ Uranium Mining for Regulatory Personnel, Corpus Christi, Texas, Mar. 6-9, 1979, 65 pp.

59. Cooperstein, R. Safety Evaluation Report Source Material License W.M.CO., Docket No. 40-8502, Source Material License SUA-1341, issued to Fuel Processing and Fabrication Branch, Division of Fuel Cycle and Material Safety, 50 pp.

60. Cox, C. H., and W. J. Roushey. Recovery of Uranium by In Situ Solution Mining. Mineral Ind. Bull., V. 22, No. 1, January 1979, 12 pp.

61. Crawford, E. Developers Eye Texas Potential for In Situ Uranium Leaching. Eng. and Min. J., V. 176, No. 7, July 1975, pp. 81-82.

62. Daly, L., D. H. Davidson, R. B. Huff, and P. J. Lingane. In-Situ Leaching Materals Consideration. H. K. Van Poolen and Associates.

63. Davidson, D. H. In-Situ Leaching of Nonferrous Metals. Min. Cong. J., V. 66, No. 7, July 1980, pp. 52-54, 57.

64. Davidson, D. H., R. V. Huff, and W. E. Sonstelie. Measurement and Control in Solution Mining of Deep-Lying Deposits of Copper or Uranium. Pres. at Instrument Soc. of America Min. and Met. Ind. Div. Symp., Denver, Colo., Nov. 1-3, 1978, 7 pp.

65. Davis, G. R., and W. M. McKnight, Jr. Facilities for Solution Mining of Uranium Operational and Environmental Aspects. Pres. at Am. Nuclear Society, November 1978, and In Situ Uranium Mining Seminar, March 1979, 10 pp.

66. Davis, G. R., R. E. Miller, and G. G. Swift. In-Situ Leach Mining for Uranium. Proc. Advisory Group Meeting, Internat. Atomic Energy Agency, Washington, D.C., Nov. 24-26, 1975, Panel Proceedings Series, 1976, pp. 193-202.

67. Davis, G. R., and E. L. Reed. Controlling Uranium Solution Mining Operations. Min. Cong. J., V. 64, No. 10, October 1978, pp. 35-38.

68. Davis, L. L. Bureau of Mines Research to Improve Underground Metal/Nonmetal Mining Technology. Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979, Preprint 79-46, 14 pp.

69. Derry, R. The Use of Peroxidants in the Leaching of Metal Sulphides. Pres. at Ann. Meeting of the Met. Soc., AIME, New Orleans, La., Feb. 18-22, 1979, TMS Paper Selection A-79-4, 24 pp.

70. Devries, F. W. Novel Techniques in Lixiviants and Site Restoration. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 12, Pt. 4, 1979, pp. 75-78.

71. Dew, J. N., and W. L. Martin (assigned to Continental Oil Company, Ponca City, Okla., a Corporation of Delaware). In Situ Roasting and Leaching of Uranium Ores. U.S. Pat. 2,954,218, Sept. 27, 1960.

72. Dravo Corporation. Solution Mining. Section 6.6.2 in Analysis of Large Scale Non-Coal Underground Mining Methods, BuMines Contract Report S0122059, January 1974, pp. 455-464.

73. Drever, J. I., and C. R. McKee. The Push-Pull Test: A Method of Evaluating Formation Adsorption Parameters for Predicting the Environmental Effects of In-Situ Coal Gasification and Uranium Recovery. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 87-98.

74. Duncan, D. W., and A. Bruynesteyn. Enhancing Bacterial Activity in a Uranium Mine. Can. Min. and Met. Bull., V. 64, No. 709, May 1971, pp. 32-36.

75. Duncan, D. W., and A. Bruynesteyn. Microbiological Leaching of Uranium. Proc. 1970 Uranium Symp., Socorro, N. Mex., Comp. by R. J. Roman, 1970, pp. 55-61.

76. Durler, D. L., and A. L. Bishop. In-Situ Uranium Leach Mining: Considerations for Monitor Well Systems. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9505, 10 pp.

77. Dutrizac, J. E., and R. J. C. Macdonald. Ferric Ion as a Leaching Medium. Minerals Sci. Eng., V. 6, No. 2, April 1974, pp. 59-100.

78. Duyvesteyn, W. P. C., G. R. Wicker, and R. E. Doane. An Omnivorous Process for Laterite Deposits. To Be Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979.

79. Eargle, D. H. Uranium in Texas. Houston Geol. Soc. Bull., V. 13, No. 2, 1970, pp. 18-27.

80. Eargle, D. H., K. A. Dickinson, and B. O. Davis. South Texas Uranium Deposits. AAPG Bull., V. 59, No. 5, May 1975, pp. 766-779.

81. Eargle, D. H., G. W. Hinds, and A. M. D. Weeks. Uranium Geology and Mines, South Texas. Texas Univ. Bur. Econ. Geol. Guidebook No. 12, Austin, Tex., 1971, 59 pp.

82. Eisenbarth, W. A. Industry View of Regulations on In Situ Mining. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 11-14.

83. Eisenbarth, W. A. Reconcilation: Environmental Issues in In-Situ Mining vs Regulatory Constraints. Pres. at Uranium Resource Tech. Seminar II. Colorado School of Mines, Golden, Colorado, Mar. 12-14, 1979, 7 pp.

84. Engelmann, W. H. (assigned to the United States of America as Represented by the Secretary of the Interior, Washington, D.C.). Foam Injection Leaching Process for Fragmented Ore. U.S. Pat. 4,080,419, Mar. 21, 1978.

85. Engelmann, W. H., and D. R. Kasper. Environmental Regulations for In Situ Uranium Mining: from Exploration to Restoration. Ch. in Proc. of the Am. Assoc. of Petrol. Geol. Ann. Meeting, Houston, Tex., Apr. 1-4, 1979, 21 pp.

86. Engelmann, W. H., P. E. Phillips, D. R. Tweeton, K. W. Loest, and M. T. Nigbor. Restoration of Groundwater Quality Following Pilot-Scale Acidic In Situ Uranium Leaching at Nine-Mile Lake Site Near Casper, Wyoming. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept, 21-24, 1980, SPE Preprint 9494, 24 pp.

87. Engineering and Mining Journal. Agnew Lake Mines; Taking Giant Steps in Solution Mines. V. 179, No. 11, November 1978, pp. 158-161.

88. Engineering and Mining Journal. Bear Creek Gears Up for Commercial Use of Borehole Uranium Mining. V. 180, No. 3, March 1979, pp. 41, 45.

89. Engineering and Mining Journal. Cliffs Readies Uranium Solution Test in Pumpkin Buttes Area. V. 181, No. 1, January 1980, pp. 43, 47.

90. Engineering and Mining Journal. The Cost of Leaching U308 in Stopes and Pumping Solution to the Surface. V. 169, No. 6, June 1968, p. 186.

91. Engineering and Mining Journal. Economics Provide Motive for Growth of Bacteria Leaching. V. 167, No. 6, June 1966, 543 pp.

92. Engineering and Mining Journal. India Studies Possibility of Copper Mining by Nuclear Blasts. V. 171, No. 7, July 1970, 33 pp.

93. Engineering and Mining Journal. In-Situ Leaching Opens New Uranium Reserves in Texas. V. 176, No. 7, July 1975, pp. 73-81.

94. Engineering and Mining Journal. In Situ Uranium Extraction Dominates Texas Meeting. V. 181, No. 12, December 1980, pp. 92-93.

95. Engineering and Mining Journal. In Situ Uranium Leaching Operations Flourish in Southern Texas. V. 178, No. 6, June 1977, pp. 23, 27.

96. Engineering and Mining Journal. Mining In-Situ by Natures Easy Way. V. 168, No. 10, October 1967, pp. 75-80.

97. Engineering and Mining Journal. New Method Suggested for Leaching Uranium Ore In Place. V. 168, No. 5, May 1967, pp. 106-107.; Discussion of U.S. Patent 3,309,140, Leaching of Uranium Ore In Situ, by J. Gardner and M. I. Ritchie.

98. Engineering and Mining Journal. Producers and Newcomers Push Development Plans. V. 179, No. 11, November 1978, pp. 104-106.

99. Engineering and Mining Journal. Solution Mining Opening New Reserves. V. 175, No. 7, July 1974, pp. 62-71.

100. Engineering and Mining Journal. Texas-Uranium Production by In Situ Leaching. V. 176, No. 6, June 1975, p. 304.

101. Engineering and Mining Journal. Uranium Leach Project Snarled in New Mexico's Environmental Rules. V. 178, No. 6, June 1977, P. 33, 36.

102. Engineering and Mining Journal. Uranium Production by In-Situ Leaching. (Texas) June 1975, p. 304.

103. Engineering and Mining Journal. U3O8 Process Avoids Sulphates and Chlorides. V. 180, No. 5, May 1979, pp. 118-119.

104. Erickson, J. W. Underground In Situ Mining-A New Mining Method. Min. Eng., V. 30, No. 11, November 1978, pp. 1532-1534.

105. Erickson, J. W. Underground In Situ : A New Mining Method. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 15-18.

106. Fisher, J. R. Bacterial Leaching of Elliot Lake Uranium Ore. Can. Min. and Met. Bull., V. 59, No. 649, May 1966, pp. 588-592.

107. Fisher, J. R., F. C. Lendrum, and B. G. Macdermid. Laboratory and Underground Studies of Bacterial Leaching of Elliot Lake Ores. Pres. at 95th AIME Ann. Meeting, Feb. 27 - Mar. 3, 1966, New York, 9 pp.

108. Fishman, P. H., and W. H. Huang. Mineralogical Analysis and Uranium Distribution of the Sedimentary-type Uranium Ores. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9502, 12 pp.

109. Fitch, D. C. Exploration Geology Methods in the Grants Mineral Belt. Pres. at Uranium Symposium, Socorro, New Mexico, May 6-8, 1970, 11 pp.

110. Fitch, J. L., and B. G. Hurd (assigned to Mobil Oil Corporation, a corporation of New York). In Situ Leaching Method. U.S. Pat. 3,278,232, Oct. 11, 1966.

111. Fitch, J. L., and B. G. Hurd (assigned to Mobil Oil Corporation, a corporation of New York). Method of Leaching Subsurface Minerals In Situ. U.S. Pat. 3,309,141, Mar. 14, 1967.

112. Frank, J. N. Cost Model for Solution Mining of Uranium. Pres. at the Uranium Industry Seminar, Grand Junction, Colo., Oct. 19-20, 1976, 25 pp.

113. Frank, J. N. In Situ Leaching of Uranium. Pres. at the 1975 Uranium and Thorium Research and Resources Conf., U.S. Geological Survey, Denver, Colo., Dec. 8-10, 1975, 8 pp.

114. Galichon, P. In-Situ Leaching of Uranium Ore. M.S. Thesis, Univ. of Texas, Austin, Texas, December 1976, 83 pp.

115. Galichon, P., R. S. Schechter, A. Cowley, and M. Breland. Chemical Factors in In-Situ Uranium Leach Mining. In Situ, V. 1, No. 2, 1977, pp. 125-146.

116. Galloway, W. E. Depostional and Groundwater Flow Systems in the Exploration for Uranium. Research Collquium, Bureau of Economic Geology, Univ. of Texas, Austin, Tex., 1979, 267 pp.

117. Galloway, W. E. South Texas Uranium Province Geologic Perspective. Guidebook 18, Bureau of Economic Geology, Univ. Texas, Austin, Tex., 1979, 81 pp.

118. Gardner, J., and M. I. Ritchie (assigned to Utah Construction and Mining Company, San Francisco, Calif., a Corporation of Delaware). Leaching of Uranium Ore In Situ. U.S. Pat. 3,309,140, Mar. 14, 1967.

119. Garwacka, K., D. Johnson, M. Walsh, M. Breland, R. S. Schechter, and M. J. Humenick. Investigation of the Fate of Ammonia from In-Situ Uranium Solution Mining. Tech. Report EHE-79-01, Univ. Texas at Austin, Austin, Texas, February 1979, 140 pp.

120. George, D. R., and J. R. Ross. Recovery of Uranium from Uranium Mine Waters and Copper Ore Leaching Solutions, Processing of Low-grade Uranium Ores. Proc. of a Panel Held in Vienna, June 27 - July 1, 1966, Internat. Atomic Energy Agency, Vienna, 1967, pp. 227-234.

121. George, D. R., J. R. Ross, and J. D. Prater. Byproduct Uranium Recovered with New Ion Exchange Techniques. Min. Eng., V. 20, No. 1, January 1968, pp. 73-77.

122. Goddard, J. B., and D. R. Brosnahan. Rate of Consumption of Dissolved Oxygen During Ammonium Carbonate In Situ Leaching of Uranium. Pres. at 109th Annual Meeting, Soc. Min. Eng., AIME, Las Vegas, Nevada, Feb. 24-28, 1980, Preprint 80-42, 18 pp.

123. Goodier, J. T. Wyomings Uranium Industry--Status, Impacts and Trends. Report to Mineral Division, Department of Economic Planning and Development, State of Wyoming. Prepared By Quality Development Associates, Inc., Sept. 30, 1978, 225 pp.

124. Grant, D. C. In-Situ Leaching Studies of Uranium Ores--Phase IV. Final Report, Westinghouse Electric Corp., R and D Center, 1310 Beulah Road, Pittsburgh, PA, BuMines Contract H0262004, November 1978, 497 pp.

125. Grimes, M. E. Prediction of Uranium Extraction in In-Situ Stope Leaching. Proc. Solution Mining Symp., AIME Ann. Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 338-353.

126. Griswold, G. B. Rock Fracturing Techniques for In Place Leaching. Pres. Ann. Meeting of the Soc. of Min. Eng., AIME, Washington D.C., Feb. 16-20, 1969, AIME Preprint 69-AS-74, 4 pp.

127. Guarnera, B. J. Uranium Exploration Activities in the U.S. Min. Eng., V. 30, No. 10, October 1978, pp. 1414-1416.

128. Gubkin, N. V., D. T. Desyatnikov, and I. K. Rudneva. Advantages of Mining Uranium in Inundated Sheet Deposits by Underground Leaching. Atomic Energy, V. 24, No. 6, June 1968, pp. 511-514.

129. Hancock, W. A. Uranium In Situ Leaching: Its Advantages, Practice, Problems, and Computer Simulation. Pres. at 107th Ann. Meeting, AIME, Atlanta, Ga., March 1977, Preprint 77-AS-68, 20 pp.

130. Haque, K. E., B. H. Lucas, and G. M. Ritcey. Hydrochloric Acid Leaching of an Elliot Lake Uranium Ore. Can. Min. and Met. Bull., V. 73, No. 819, July 1980, pp. 141-147.

131. Hard, R. A., and R. L. Ripley (assigned to Union Carbide Corporation, New York, N.Y.). Process for Leaching Base Elements, such as Uranium Ore In Situ. U.S. Pat. 3,708,206, Jan. 2, 1973.

132. Harden, K. C. The Economic Production of Uranium by In Situ Leaching. Fourth Ann. Uranium Seminar, South Texas Min. Sect., SME, AIME, Corpus Christi, Tex., Sept. 14-17, 1980, 8 pp.

133. Hardwick, T. J. In-Situ Acid Leach of Uranium Ore. Gulf Science and Technology Company.

134. Harloff, G. J., and A. C. Riese. Experimantal and Theoretical Study of Uranium In Situ Solution Mining with H2SO4. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9484, 13 pp.

135. Harrison, V. F., W. A. Gow, and M. R. Hughson. Factors Influencing the Application of Bacterial Leaching to a Canadian Uranium Ore. J. Metals, V. 18, No. 11, November 1966, pp. 1189-1194.

136. Harshman, E. N. Genetic Implications of Some Elements Associated with Uranium Deposits, Shirley Basin, Wyoming. U.S. Geol. Survey Prof. Paper 550-C, 1966, pp. C167-C173.

137. Harshman, E. N. Geology and Uranium Deposits, Shirley Basin Area, Wyoming. U.S. Geol. Survey Prof. Paper 745, 1972, 82 pp.

138. Harshman, E. N. Uranium Deposits of Wyoming and South Dakota. Ch. in Ore Deposits of the United States, 1933-1967, ed. by J. D. Ridges. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, V. 1, Pt. 7, Ch. 40, 1968, pp. 815-831.

139. Hartmann, B. E. Solution Mining System. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section IX, 10 pp.

140. Henderson, T. B., Jr. Variations in South Texas Uranium Hosts. Pres. at Uranium In Situ Symp., South Texas Minerals Sect., AIME, Corpus Christi, Tex., Sept. 25-28, 1977, 3 pp.

141. Henderson, W. C., and D. L. Dixson. Hydrometallurgical Recovery of Uranium and Molybdenum from an Acid Carbonate In-Situ Solution by Continuous Counter-Current Ion Exchange. Pres. at 110th Ann. Meeting, Soc. Min. Eng., AIME, Chicago, Ill., Feb. 22-26, 1981.

142. Henrickson, A. V. (assigned to Kerr-McGee Oil Industries, Inc.). Recovery of Uranium Values by Solvent Extraction. U.S. Pat. 3,241,909, Mar. 22, 1966.

143. Higgins, I. R. Update of CHEM-SEPS Continuous Ion Exchange Operation Relations to Uranium Recovery. Pres. at 1978 Uranium Mining Seminar South Texas Minerals Section, Corpus Christi, Tex., September 1978, 8 pp.

144. Hill, A. D., M. P. Walsh, W. M. Breland, I. H. Silberberg, M. J. Humenick, and R. S. Schechter. Restoration of Uranium in Situ Leaching Sites. Pres. at 53rd Ann. Fall Technical Conference and Exhibition of the Soc. of Pet. Eng., AIME, Houston, Texas, Oct. 1-3, 1978, SPE Preprint 7534, 8 pp.

145. Hohne, F. C. Projections of the Impact of Solution Mining on Uranium Production in the United States. Pres. at Uranium Mining Technology Conference, the Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Apr. 25-29, 1977.

146. Howell, E. P., and O. J. Gant, Jr. (assigned to Atlantic Richfield Company, Los Angeles, Calif.). Method for the Production of Minerals. U.S. Pat. 4,032,194, June 28, 1977.

147. Huang, W. H. Geochemical and Sedimentologic Problems of Uranium Deposits of Texas Gulf Coastal Plain. AAPG Bull., V. 62, No. 6, June 1978, pp. 1049-1062.

148. Huang, W. H., and K. Pickett. Factors Controlling In-Situ Leaching of Uranium from Sandstone and Lignite Deposits in South Texas. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section XI, 18 pp.

149. Huff, R. V., and D. H. Davidson. Technology for In Situ Uranium Leaching. Min. Eng., V. 32, No. 2, February 1980, pp. 163-166.

150. Huff, R. V., and H. Davidson. In-Situ Leaching Materials Considerations. Pres. at 54th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Las Vegas, Nev., Sept. 23-26, 1979, SPE Preprint 8320, 6 pp.

151. Humenick, M. J., and D. G. Johnson. Nitrification and In-Situ Uranium Solution Mining. Univ. Texas at Austin, Austin, Tex.

152. Humenick, M. J., R. Turk, and R. S. Schechter. Literature Review and Preliminary Analysis of Inorganic Ammonia Pertinent to South Texas Uranium In-Situ Leach. Center for Research in Water Resources Rept. No. CRWR-155, EHE 78-01, Univ. Texas at Austin, Austin, Tex., 1978. [in press]

153. Hunkin, G. G. Concentration Processes for Uranium In Situ Leach Liquors. Pres. at 105th Ann. Meeting, AIME, Las Vegas, Nev., Feb. 22-26, 1976, Preprint 76-B-77, 7 pp.

154. Hunkin, G. G. Deep Mineral In-Situ Solution Mining. Pres. at 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Tex., Sept. 21-24, 1980, SPE Preprint 9506.

155. Hunkin, G. G. The Environmental Impact of Solution Mining for Uranium. Min. Cong. J., V. 61, No. 10, October 1975, pp. 24-27.

156. Hunkin, G. G. Oral Presentation Uranium In-Situ Solution Mining. The Royal Commission of Inquiry Concerning the Health and Environmental Protection Uranium Mining, 1979, 24 pp.

157. Hunkin, G. G. A Review of In Situ Leaching. Pres. at AIME Ann. Meeting, Soc. of Min. Eng., AIME, New York, N.Y., Feb. 26 - Mar. 4, 1971, AIME Preprint 71-AS-88, 23 pp.

158. Hunkin, G. G. Uranium In-Situ Solution Mining. The Royal Commission of Inquiry Concerning the Health and Environmental Uranium Mining 1979, October 1979, 93 pp.

159. Hurd, B. G., and J. L. Fitch (assigned to Mobil Oil Corporation, a Corporation of New York). In Situ Leaching of Subterranean Deposits. U.S. Pat. 3,278,233, Oct. 11, 1966.

160. Jacoby, C. H. (assigned to Akzona Inc., Asheville, N.c.). In Situ Extraction of Mineral Values from Ore Deposits. U.S. Pat. 3,822,916, July 9, 1974.

161. Jayaram, K. M. V., A. S. Deshpande, and C. V. Sharma. Leaching and Precipitation of Uranium from Quartzite Ores at Chhinjra, Kulu District, Himachal Pradesh. Proc. of the Indian National Science Academy. V. 36, A, No. 5, 1970, pp. 298-305.

162. Johnson, D. Nitrification and In Situ Uranium Leach Mining. Dept. of Civil Eng., University of Texas, Austin, November 1978, 54 pp.

163. Johnson, D. G. Nitrification and In-Situ Uranium Solution Mining. M.S. Thesis, Univ. Texas, Austin, Tex., 1979.

164. Johnson, D., and M. J. Humenick. Nitrification and In-Situ Uranium Solution Mining. Soc. Petrol. Eng. J., V. 20, No. 5, October 1980, pp. 415-422.

165. Johnson, J. M. Recovery of Uranium by Multiple-column Countercurrent Ion Exchange. July 1969, 7 pp.

166. Johnson, P. H. Acid-ferric Sulfate Solutions for Chemical Mining. Min. Eng., V. 17, No. 8, August 1965, pp. 64-68.

167. Johnson, P. H., and R. B. Bhappu. Chemical Mining - A Study of Leaching Agents. New Mexico Bureau of Mines and Mineral Resources, Circ. 99, 1969, 7 pp.

168. Johnson, P. H., and R. B. Bhappu. Chemical Mining - Theoretical and Practical Aspects. Pres. at SME Fall Meeting - Rocky Mountain Minerals Conf., Las Vegas, Nevada, Sept. 6-8, 1967, 20 pp.

169. Kabir, M. I., L. W. Lake, and R. S. Schechter. Evaluation of the One Well Uranium Leaching Test: Restoration. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9486, 11 pp.

170. Kalabin, A. I. Winning of Useful Elements from Minerals by Leaching Underground. Min. Mag. (London), V. 118, No. 2, February 1968, pp. 129-134.

171. Kallus, M. F. Environmental Aspects of Uranium Mining and Milling in South Texas. U.S. Environmental Protection Agency, EPA 906/9-75-004, October 1975, 86 pp.

172. Kasper, D. R. Optimization of Reverse Osmosis Treatment of In Situ Wastewaters. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9492, 5 pp.

173. Kasper, D. R., and W. H. Engelmann. Compliance with Environmental Regulations for In Situ Uranium Mining: from Discovery to Clousure. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section XVII, 36 pp.

174. Kasper, D. R., H. W. Martin, L. D. Munsey, R. B. Bhappu, and C. K. Chase. Environmental Assessment of In Situ Mining. BuMines Open File Report No. 101-80, December 1979, 292 pp.; available for consultation at Twin Cities Research Center, Minneapolis, Minn.; and from National Technical Information Service, Springfield, Va., PB 81-106 783.

175. Kehrman, R. F. Detection of Lixiviant Excursions with Geophysical Resistance Measurements During In Situ Uranium Leaching. BuMines Open File Report 5-81, December 1979, 156 pp.; available for consultation at Twin Cities Research Center, Minneapolis, Minn.; and from National Technical Information Service, Springfield, Va., PB 81-171 324.

176. Kehrman, R. F., A. J. Farstad, and D. R. Tweeton. Use of Resistivity Measurements to Monitor Lixiviant Migration During In-Situ Uranium Leaching. Pres. at 1980 Fall Meeting, Soc. Min. Eng., AIME, Minneapolis, Minn., Oct. 22-24, 1980, SME Preprint 80-338, 10 pp.

177. Kidwell, J. R., and M. J. Humenick. Assessment of Trace Ground Water Contaminants Release from South Texas In-Situ Uranium Solution Mining Sites. Center for Research in Water Resources Report No. CRWR-179, Univ. Texas at Austin, Austin, Tex., January 1981, 111 pp.

178. King, J. W., and S. R. Austin. Some Characteristics of Roll-Type Uranium Deposits at Gas Hills, Wyoming. Min. Eng., V. 18, No. 5, May 1966, pp. 73-80.

179. Koch, L. W. Economics of Uranium Mining and Milling. Pres. at Uranium Resource Tech. Seminar, Colorado School of Mines, Golden, Colorado, Mar. 12-14, 1979, 12 pp.

180. Kolodney, M., and S. C. Hyman (assigned to Nuclear Development Corporation of America, a Corp. of New York). Recovery of Uranium and Vanadium Values from Ores. U.S. Pat. 2,964,380, Dec. 13, 1960.

181. Kurth, D. I., and R. D. Schmidt. Computer Modeling of Five-Spot Well Pattern Fluid Flow During In Situ Uranium Leaching. BuMines RI 8287, 1978, 76 pp.

182. Kurth, D. I., and R. D. Schmidt. Solution Flow Prediction Via Computer Models. Trans. American Nuclear Society, LaGrange Park, Illinois, V. 30, November 1978, pp. 101-102.

183. Lackey, J. A. Environmental Aspects of Uranium Extraction. Amdel Bull. (The Australian Mineral Development Laboratories), No. 19, April 1975, pp. 11-20.

184. Lackey, J. A. Solution Mining (In Situ Leaching) A Literature Survey. Amdel Bull., (The Australian Mineral Development Laboratories), No. 19, April 1975, pp. 40-61.

185. Lang, E. A., and W. R. Archibald. Innovative Systems for the Recovery of Uranium. Pres. at the National Western Min. Conf., Denver, Colo., Feb. 7, 1975, pp. 1-13.; Colorado Mining Assoc., 1975 Mining Yearbook, pp. 114-118.

186. Lang, L. C., and W. B. Morrey. Scientific Blasting for In-Situ Leaching Proves Successful at Agnew Lake Mines. Eng. and Min. J., V. 177, No. 1, January 1976, pp. 100-102.

187. Langen, R. E., and A. L. Kidwell. Geology and Geochemistry of the Highland Uranium Deposit, Converse County, Wyoming. The Mountain Geol., V. 11, No. 2, April 1974, pp. 85-93.

188. Langston, B. G. Ammonium Carbonate Pressure Leaching of Uranium Ores. J. Metals, V. 9, No. 6, June 1957, pp. 752-756.

189. Larson, W. C. Nomograph for Uranium In Situ Leaching. Eng. and Min. J., V. 178, No. 9, September 1977, p. 159.

190. Larson, W. C. Uranium In Situ Leach Mining - A Third Alternative. Pres. at AAPG Ann. Conference, Houston, Texas, Apr. 1-4, 1979, 23 pp.

191. Larson, W. C. Uranium In Situ Leach Mining - Environmental Controls. Pres. at First Internat. Conf. on Uranium Mine Waste Disposal, Vancouver, B.C., Canada, May 19-21, 1980.

192. Larson, W. C. Uranium In Situ Leach Mining in the United States. BuMines IC 8777, 1978, 87 pp.

193. Larson, W. C., and R. J. Morrell (assigned to the United States of America as represented by the Secretary of the Interior, Washington, D.C.). In-Situ Leach Mining Method Using Branched Single Well for Input and Output. U.S. Pat. 4,222,611, Sept. 16, 1980.

194. Larson, W. C., R. J. Morrell, and R. D. Schmidt (assigned to the United States of America as represented by the Secretary of the Interior, Washington, D.C.). Method of In Situ Mining. U.S. Pat. 4,249,777, Feb. 10, 1981.

195. Lawes, B. C. Effect of Sodium Silicate on Leaching Uranium Ores with Hydrogen Peroxide. Pres. at Am. Nuclear Soc. Meeting, Golden, Colo., Apr. 14, 1977, 12 pp.

196. Leaming, G. F. The Economic Impact of the South Texas Uranium Industry. Southwest Economic Info. Center, Marana, Arizona, February 1979, 60 pp.

197. Learmont, R. P. (assigned to United States Steel Corporation, Pittsburgh, Pa.). In Situ Solution Mining Technique. U.S. Pat. 4,082,358, Apr. 4, 1978.

198. Learmont, R. P. (assigned to United States Steel Corporation). Process for Leaching Mineral Values from Underground Formations In Situ. U.S. Pat. 3,860,289, Jan. 14, 1975.

199. Learmont, R. P. (assigned to United States Steel Corp.). Solution Mining of Uranium from an Uranium Ore Deposit, Where Primary Leaching Has Been Conducted Through an Array of Contiguous 5-Spot Leaching Patterns of Production Wells and Injection Wells. U.S. Pat. 4,082,358, Apr. 4, 1978.

200. Letowski, F. Ore Leaching Model with Partial Decomposition of Rocks - 1. Theoretical Predictions. Hydrometallurgy, V. 6., No. 1-2, September 1980, pp. 121-133.

201. Letowski, F., and R. Augustowska. Ore Leaching Model with Partial Decomposition of Rocks - 2. Laboratory Tests. Hydrometallurgy, V. 6, No. 1-2, September 1980, pp. 135-146.

202. Lewis, F. M., and R. B. Bhappu. Evaluating Mining Ventures Via Feasibility Studies. Min. Eng., V. 27, No. 10, October 1975, pp. 48-54.

203. Lewis, F. M., C. K. Chase, and R. B. Bhappu. Economic Evaluation of In Situ Extraction for Copper, Gold, and Uranium. Proc. Joint Meeting of the Mining and Metallurgical Institute of Japan and the American Institute of Mining, Metallurgical, and Petroleum Engineers, Denver, Colo., Sept. 1-3, 1976 (pub. as World Mining and Metals Technology, ed. by A. Weiss), V. 1, 1976, pp. 333-348.

204. Li, T. A., and J. D. Wiebmer. Uranium Mining in the U.S.- Producers Rush to Meet Energy Needs. Min. Eng., V. 30, No. 10, October 1978, pp. 1405-1410.

205. Litz, L. M. In Situ Uranium Mining with Oxygen. Pres. at 109th Annual Meeting, Soc. Min. Eng., AIME, Las Vegas, Nevada, Feb. 24-28, 1980, SME Prepint 80-71, 9 pp.

206. Livingston, C. W. Method of Mining Ores In Situ by Leaching. U.S. Pat. 2,818,240, Dec. 31, 1957.

207. Loest, K. W. Development of an In Situ Operation: Nine Mile Lake. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 75-77.

208. Loo, W. W. Production Optimization of In-Situ Leaching of Uranium by Proper Well Field Design. Pres. at Uranium Mining Technology-Update 78 Conf., Nov. 13-17, 1978, Reno, Nev., 11 pp.

209. Lootens, D. T. Uranium Production Methods and Economic Considerations. Dames and Moore Consulting Co., Park Ridge, Ill., 1976, 11 pp.

210. Macgregor, R. A. The Bacterial Leaching of Uranium. Nuclear Applications, V. 6, January 1969, pp. 68-72.

211. Macgregor, R. A. Recovery of U3O8 by Underground Leaching. Can. Min. and Met. Bull., V. 59, No. 649, May 1966, pp. 583-587.

212. Macgregor, R. A. Uranium Dividends from Bacterial Leaching. Min. Eng., V. 21, No. 3, March 1969, pp. 54-55.

213. Mackay School of Mines, University of Nevada--Reno. In-Place Leaching and Solution Mining. Short Course given at Incline Village, Nev., Nov. 10-14, 1975, 225 pp.

214. Malouf, E. E. Introduction to Dump Leaching Practice. Part I of Second Tutorial Symp. on Extractive Metallurgy, Univ. Utah, Dec. 14-16, 1972, 26 pp.

215. Malouf, E. E. Leaching as a Mining Tool. Internat. Symp. on Hydrometallurgy, Chicago, Ill., Feb. 25-Mar. 1, 1973, Ch. 23, pp. 615-626.

216. Malouf, E. E. The Role of Microorganisms in Chemical Mining. Min. Eng., V. 23, No. 11, November 1971, pp. 43-46.

217. Marrs, L. F. Underground Leaching of Uranium at the Pitch Mine. Pres. American Min. Cong. Convention, Denver, Colo., Sept. 27-30, 1970, 14 PP.; Min. Cong. J., V. 56, No. 11, November 1970, pp. 35-43.

218. Martin, J. W. (assigned to Oil Recovery Corporation, New York, N.Y., a Corporation of New York). Recovery of Uranium by Carbonated Water and Surface Action Agents and Wetting Agents. U.S. Pat. 3,130,960, Apr. 28, 1964.

219. May, H. D. Environmental Considerations of In-Situ Uranium Mining/Milling. Pres. at Seminar on Uranium Solution Mining and Milling for State and Federal Regulatory Personnel, Corpus Christi, Texas, Mar. 6-9, 1979, 17 pp.

220. Mays, W. M. Engineering an In Situ Uranium Well Field. Proc. Third Ann. Uranium Seminar, Wyoming Min. and Metals Sect., AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 69-70.

221. McCreedy, H. H. Bacterial Leaching to be Applied to a New Canadian Uranium Mine. Coordinated Research Committee Meeting of the International Atomic Energy Agency, Coventry, England, Dec. 1976. [in press]

222. McCreedy, H. H., V. F. Harrison, and W. A. Gow. A Proposed Method, Using Bacteria, for the Continuous Leaching of a Uranium Ore. Can. Min. and Met. Bull., V. 62, No. 682, February 1969, pp. 135-140.

223. McKee, C. R. Preliminary Proposal to the Environmental Protection Agency on Controlling Solution Movement and Groundwater Restoration for Uranium Solution Mining. University of Wyoming Through Water Resources Research Institute, January 1977, 9 pp.

224. McKee, C. R., and J. I. Drever. Reservoir Engineering Update--Uranium In Situ Extraction. to be Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979.

225. McKinney, W. A. Solution Mining. Min. Eng., V. 25, No. 2, February 1973, pp. 56-57.

226. McKnight, W. M. Jr., and H. L. Anthony, IV. Well Field Operations. Proc. Third Ann. Uranium Sem., Wyoming Min. and Metals Sect., AIME, Casper, Wyo., Sept. 9-12, 1979, pp. 71-73.

227. Melin, R. E. Description and Origin of Uranium Deposits in Shirley Basin, Wyoming. Econ. Geol., V. 59, 1964, pp. 835-849.

228. Menke, J. R. (assigned to Nuclear Development Corp. of America, a Corp. of New York). Method of Recovering Uranium from Underground Deposit. U.S. Pat. 2,896,930, July 28, 1959.

229. Merritt, R. C. The Extractive Metallurgy of Uranium. Colo. School Mines Research Inst., Prepared Under Contract with U.S. Atomic Energy Commission. Johnson Pub. Co., Boulder, Colo., 1971, 576 pp.

230. Merritt, R. C. The Metallurgy of Uranium Extraction. Pres. at Uranium Mining Technology Conference, The Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Apr. 25-29, 1977, 41 pp.

231. Meyer, A. E. (assigned to Kerr-McGee Oil Industries Inc.). Method of Acid Leaching Uranium Ores. U.S. Pat. 3,250,589, May 10, 1966.

232. Mining Engineering. An Economic Analysis of Open-pit and In Situ Mining. V. 30, No. 10, October 1978, pp. 1420-1422.

233. Mining Engineering. Hydrometallurgy Is Key in Winning U3O8. V. 26, No. 8, August 1974, pp. 26-27.

234. Mining Engineering. Kerr-McGee's Ambrosia Complex: from Mined Rock to Yellowcake. V. 26, No. 8, August 1974, pp. 28-30.

235. Mining Magazine. Development of Argentinian Uranium Deposits. V. 142, No. 1, January 1980, pp. 9-10.

236. Mining Magazine (London). In Situ Leaching - A Review. V. 125, No. 3, September 1971, pp. 213-215.

237. Mining Record (Denver, Colorado). Hydrogen Peroxide Can Maximize Uranium Leaching. V. 90, No. 4, Jan. 24, 1979, p. 8.

238. Mining Record (Denver, Colorado). Solution Mining - Can It Speed Development of Uranium Reserves? V. 87, No. 26, June 23, 1976, pp. 1, 7.

239. Minobras. Uranium Deposits of the Northern U.S. Region. P.O. Box 262, Dana Point, Calif., 92629, 1977, 99 pp.

240. Minobras. Uranium Guidebook for Wyoming. P.O. Box 262, Dana Point, Calif., 92629, 1976, 63 pp.

241. Mrak, V. A. Uranium Deposits in the Eocene Sandstones of the Powder River Basin, Wyoming. Ch. in Ore Deposits of the United States, 1933-1967, ed. by J. D. Ridges. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, V. 1, Pt. 7, Ch. 42, 1968, pp. 838-848.

242. Mutschler, P. H., J. J. Hill, and B. B. Williams. Uranium from the Chattanooga Shale; Some Problems Involved in Development. BuMines IC 8700, 1976, 85 pp.

243. Naden, D., and G. Willey. The Use of Fluid Bed Ion Exchange to Reduce Uranium Recovery Costs. Pres. at the AIME Ann. Meeting, Soc. Min. Eng., AIME, Las Vegas, Neveda, Feb. 22-26, 1976, Preprint 76-B-65, 33 pp.

244. Narayan, K., and R. D. Pick (assigned to Atlantic Richfield Company, Los Angeles, Calif.). Recovery of Uranium from Carbonate Leach Solutions. U.S. Pat. 4,092,399, May 30, 1978.

245. Narayan, K., and P. J. Rand. Environmental Considerations in Uranium Solution Mining. Trans. Soc.of Min. Eng., AIME, V. 262, June 1977, pp. 117-119.

246. Narayan, K., P. J. Rand, and R. B. Hill. Environmental Considerations in Uranium Solution Mining. Pres. at 105th Ann. Meeting, AIME, Las Vegas, Nev., Feb. 22-26, 1976, Preprint 76-AS-70, 12 pp.

247. Neesham, R. Texas Uranium Producers Take a Growing Market Share. Eng. and Min. J., V. 179, No. 11, November 1978, pp. 143-147.

248. New Mexico Department of Health and Environment. Radioactive Material License No. NM-GRA-UL-00 Issued to Michael P. Grace For Pilot Scale In Situ Uranium Leaching Tests, McKinley and Sandoval Counties, New Mexico. Permit Issued Mar. 5, 1976.

249. Nigrini, A. Thermodynamic Calculation of U Loadings and Reaction Paths with Carbonate Lixiviants in Insitu Leaching Systems. to be Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979.

250. Nuclear Regulatory Commission. Ground-Water Elements of In Situ Leach Mining of Uranium. NUREG/CR-0311, 1978, pp. 17-34.

251. Olson, J. J. Bureau of Mines Research in In-Situ Leaching and Borehole (or Slurry) Mining. Pres. at Fall Meeting of Soc. of Min. Eng., AIME, St. Louis, Mo., Oct. 19-21, 1977, Preprint 77-AS-340, 58 pp.

252. Olson, J. J., W. C. Larson, D. R. Tweeton, and Others. Mining Research for Improved In Situ Extraction of Uranium. Pres. at Uranium In Situ Leaching Conf., Sponsored by AAPG, SME, and SPE, Vail, Colo., Aug. 25-27, 1976, BuMines Preprint, 37 pp.

253. Olson, J. J., G. A. Savanick, and D. R. Tweeton. In Situ Mining Technology for Uranium -- A Progress Report on Bureau of Mines Research. Proc. 1978 Energy Technology Conf. and Exhibition, Houston, Texas, Nov. 6-9, 1978 (pub. as Mining Technology for Energy Resources - Advances for the 80's. The American Society of Mechanical Engineers, New York, 1979, pp. 35-46.

254. O'Rourke, J. E., R. J. Essex, and B. K. Ranson. Field Permeability Test Methods with Applications to Solution Mining. Woodward-Clyde Consultants (San Diego, Calif.), Contract No. J0265045. BuMines Open File Rept. 136-77, July 1977, 180 PP.; Available from National Technical Information Service, Springfield, Va., PB 272 452/AS.

255. Ortloff, G. D., C. E. Cooke, Jr., and D. K. Atwood (assigned to Esso Production Research Company). Mineral Recovery. U.S. Pat. 3,574,599, Apr. 13, 1971.

256. Phillips, C. R., and Y. C. Poon. Status and Future Possibilities for the Recovery of Uranium, Thorium, and Rare Earths from Canadian Ores, with Emphasis on the Problem of Radium. Miner. Sci. Eng., V. 12, No. 2, April 1980, pp. 53-72.

257. Phillips, P. Experience with Acid Leaching. Pres. at South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978.

258. Phillips, P. E. A Comparison of Open Pit and In Situ Leach Economics. Pres. at Uranium Mining Technology Conference, The Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Apr. 25-29, 1977, 12 pp.

259. Phillips, P. E. Rocky Mountain Energy's Experiences with In Situ Leaching of Uranium with Acid. Proc. South Texas Uranium Sem., Corpus Christi, Texas, Sept. 10-13, 1978. American Insitute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 9, Pt. 3, 1979, pp. 57-59.

260. Pings, W. B. Bacterial Leaching. Miner. Ind. Bull., V. 2, No. 3, May 1968, 19 pp.

261. Popoff, D. R. Bacterial Leaching Means New Life for Mine. Canadian Nuclear Technology, V. 5, No. 4, July - August 1966, pp. 31-33.

262. Potter, G. M. Solution Mining. Min. Eng., V. 21, No. 1, February 1969, pp. 68-69.

263. Potter, R. W., J. M. Thompson, M. A. Clynne, and V. L. Thurmond. Equilibrium, Kinetic, and Chromatographic Controls of the Solution Composition Obtained During the In Situ Leaching of a Uranium Orebody. Reprint from ACS Symposium Series, No. 93, Nov. 16, 1978, pp. 761-769.

264. Potter, R. W., II. Some Geochemical Parameters Effecting the In-Situ Leaching of Uranium. U.S. Geol. Survey Open-File Report 76-835, 1976, 24 pp.

265. Potter, R. W., II, M. A. Clynne, J. M. Thompson, V. L. Thurmond, R. C. Erd, N. L. Nehring, K. A. Smith, P. J. Lamothe, and J. L. Seeley. Chemical Monitoring of the In-Situ Leaching of a South Texas Uranium Orebody. U.S. Geol. Survey Open File Rept. 79-1144, 54 PP.; Available for Consultation at the U.S. Geol. Survey Open File Reports Services Section, Box 25425, Denver, Colo. 80225.

266. Rabb, D. D. Solution Mining. Min. Eng., V. 24, No. 2, February 1972, pp. 62-64.

267. Rackley, R. I. Concepts and Methods of Uranium Exploration. Wyoming Geo. Assoc. Guidebook of the Twentieth Ann. Field Conf., Casper, Wyoming, 1968, pp. 115-124.

268. Reed, E. L. The Application of Groundwater Hydrology to In Situ Leach Mining. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Insitute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 8, Pt. 3, 1979, pp. 53-55.

269. Reed, V. S. Disposal Well Design for In Situ Uranium Operations. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

270. Rhoades, V. W. (assigned to Cities Service Oil Company, Tulsa, Okla.). Uranium Solution Mining Process. U.S. Pat. 3,713,698, Jan. 30, 1973.

271. Rhoades, V. W. (assigned to Dalco Oil Company; United States Steel Corporation; part interest to each). Uranium Solution Mining Process. U.S. Pat. 3,792,903, Feb. 19, 1974.

272. Rickard, R. S. Chemical Constraints on In-Situ Leaching and Metal Recovery. Proc. Solution Mining Symp., AIME Ann. Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 185-192.

273. Riding, J. R., F. J. Rosswog, T. D. Chatwin, G. Buma, and D. R. Tweeton. Groundwater Restoration for In Situ Solution Mining of Uranium. Pres. at Ann. Meeting, Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979, Preprint 79-127, 24 pp.

274. Ring, R. J. Ferric Sulphate Leaching of Some Australian Uranium Ores. Hydrometallurgy, V. 6, No. 1-2, September 1980, pp. 89-101.

275. Robb, N., V. Opratko, and L. S. Price. Milliken's Two-Stage Sulphuric Acid Leaching Process for Uranium Ores. Can. Min. and Met. Bull., V. 56, No. 614, June 1963, pp. 476-479.

276. Rocky Mountain Energy Company. Nine Mile Lake Environmental Report. Prepared for the U.S. Nuclear Regulatory Commission, January 1979, 194 PP.; Available for Consultation at U.S. NRC Offices in Washington, D.c.

277. Roman, R. J. Solution Mining. Min. Eng., V. 26, No. 2, February 1974, pp. 43-44.

278. Root, T. Enviromental Law Aspects of Extracting and Processing Uranium. Natural Resources Lawyer, 1979, 11(3); pp. 419-454.

279. Root, T. E. Legal Aspects of Mining by the In-Situ Leaching Method. Pres. at 22nd Ann. Rocky Mountain Mineral Law Inst., Sun Valley, Idaho, July 22-24, 1976, 18 pp.

280. Rosenbaum, J. B., and D. R. George. Cost Reductions in Ion Exchange Processing of Uranium Ores. Internat. Atomic Energy Agency, IAEA-SM-135/24, 1971, pp. 297-309.

281. Rosholt, J. N., Jr. Uranium Migration and Geochemistry of Uranium Deposits in Sandstone; Above, At, and Below the Water Table. Part I. Calculation of Apparant Dates of Uranium Migration in Deposits Above and At the Water Table. Econ. Geol., V. 56, 1961, pp. 1392-1403.

282. Rouse, J. V. Environmental Aspects of In Situ Mining and Dump Leaching. Proc. Solution Mining Symp., AIME Ann. Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 3-14.

283. Rouse, J. V. Environmental Considerations of Uranium Mining and Milling. Min. Eng., V. 30, No. 10, October 1978, pp. 1433-1436.

284. Rowswell, M. D. Solution Mining for Uranium Being Pioneered at Agnew Lake. The Northern Miner, V. 63, No. 28, Sept. 22, 1977, pp. C-2, C-5.

285. Rutledge, C. In-Situ Uranium Solution Mining--Environmental and Licensing Regulations. Pres. at AAPG-SEPM Ann. Convention, Houston, Texas, Apr. 1-4, 1979.

286. St. Peter, A. L. In Situ Mining -- A Design for Positive Results. Pres. at 105th Ann. Meeting, AIME, Las Vegas, Nev., Feb. 22-26, 1976, Preprint 76-AS-36, 43 pp.

287. Savanick, G. A. Borehole (Slurry) Mining of Coal and Uraniferous Sandstone. Pres. at 1979 AIME Ann. Meeting, Feb. 18-22, New Orleans, La., SME Preprint 79-53, 11 pp.

288. Savanick, G. A. Borehole (Slurry) Mining of Coal and Uraniferous Sandstone. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 115-125.

289. Savanick, G. A. Water Jet Perforator for Uranium Leaching Wells. Pres. at Uranium Mining Technology Conference, the Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Apr. 25-29, 1977, 24 pp.

290. Savanick, G. A., and W. G. Krawza. Well Perforating Method for Solution Well Mining. U.S. Pat. 4,113,314, Sept. 12, 1978.

291. Schechter, R. S., and P. M. Bommer. Optimization of Uranium Leach Mining. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9488, 13 pp.

292. Schechter, R. S., and P. M. Bommer. Post In-Situ Uranium Leaching Site Restoration - Numerical Analysis. Pres. at 54th Ann. Fall Technical Conf. and Exhibition of Soc. of Petrol. Eng. of AIME, Las Vegas, Nevada, Sept. 23-26, 1979, SPE Preprint 8322, 11 pp.

293. Schecter, R., M. P. Walsh, W. M. Breland, M. J. Humenick, I. H. Silberberg, and A. D. Hill. Restoration of Uranium In Situ Leaching Sites. Pres. at 53rd Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Houston, Texas, Oct. 1-3, 1978, SPE Preprint 7534, 8 pp.

294. Schlitt, W. J., and D. A. Shock. In Situ Uranium Mining and Ground Water Restoration. SME of AIME Proceedings of the New Orleans Symp., Feb. 19, 1979, 137 pp.

295. Schmidt, D., and W. Floter. Urangewinnung Durch Solution Mining - Verfahren (Extraction of Uranium by the Solution Mining Process). Braunkohle, Heft 10, October 1980, pp. 334-339.

296. Schultz. Kosten Des Solution Mining. Diplomarbeit, Ueb, Bonn, W. Germany, 1980.

297. Seidel, D. C. Stored Technology for Possible Use in Uranium Ore Processing. Pres. at IAEA Advisory Group Meeting, Washington D.C., Nov. 24-28, 1975, Paper No. AG/33-7, 17 pp.

298. Shabbir, M., and K. E. Tame. Hydrogen Peroxide Precipitation of Uranium. BuMines RI 7931, 1974, 13 pp.

299. Sharp, W. N., and A. B. Gibbons. Geology and Uranium Deposits of the Southern Part of the Powder River Basin, Wyoming. U.S. Geol. Bull. 1147-D, 1964, 5 Plates (6 Maps).

300. Shock, D. A. Developments in Solution Mining Portend Greater Use for In Situ Leaching. Min. Eng., V. 22, No. 2, February 1970, p. 73.

301. Shock, D. A. The Vail Conference on In Situ Leaching of Uranium. In Situ, V. 1, No. 1, 1977, pp. 103-113.

302. Shock, D. A., and F. R. Conley. Solution Mining-Its Promise and Its Problems. Proc. Solution Mining Symp., AIME Ann. Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 79-97.

303. Shock, D. A., and J. G. Davis. Hydrofracing as a Mining Technique. Pres. at Ann. Meeting, Soc. of Min. Eng., AIME, Washington, D.c., Feb. 16-20, 1969, AIME Preprint 69-AS-63, 25 pp.

304. Showalter, W. E. (assigned to Union Oil Company of California). Process for Recovery of Mineral Values from Underground Formations. U.S. Pat. 4,105,253, Aug. 8, 1978.

305. Shuck, D. L. an Overview of Solution Mining. Pres. at Uranium Resource Tech. Seminar II, Colorado School of Mines, Golden, Colorado, Mar. 12-14, 1979, 7 pp.

306. Sievert, J. A. (assigned to Continental Oil Company, Ponca City, Okla.). In Situ Mining Using Bacteria. U.S. Pat. 3,937,520, Feb. 10, 1976.

307. Sievert, J. A., W. L. Martin, and F. R. Conley. In Situ Leaching of Uranium. Pres. at Soc. of Min. Eng. Fall Meeting, St. Louis, Mo., Oct. 21-23, 1973, 18 pp.

308. Skillings Mining Review. Nuclear Dynamics Test Plant for Uranium Mining. V. 66, No. 22, May 28, 1977, p. 5.

309. Smith, R. B. Geology of South Texas Uranium Deposits. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 6, Pt. 2, 1979, pp. 45-46.

310. Smith, R. B. The Theory of Multiple Oxidation and Reduction of Uranium Deposits in South Texas. Pres. at Uranium In Situ Symp., South Texas Minerals Sect., AIME, Corpus Christi, Tex., Sept. 25-28, 1977, 10 pp.

311. Spence, A. P. (assigned to Atlantic Richfield Co., NM Uranium Inc., and U.S. Steel Corp.). Method for the Recovery of a Mineral. U.S. Pat. 4,082,359, Apr. 4, 1978.

312. Stone and Webster Engineering Corporation, Denver, Colorado. Administrators Guide for Solution Mining of Uranium. Prepared for Western Interstate Energy Board/WINB, formerly the Western Interstate Nuclear Board, Under Contract to the U.S. Environmental Protection Agency, Contract No. 68-01-4490, May 1979, 92 PP.; Available from the National Technical Information Service PB-301 173.

313. Stover, D. E. Evaluating Uranium Deposits for Solution Mining. Pres. at the 55th Ann. Fall Tech. Conf. and Exibition, Soc. Petrol. Eng., AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9504, 6 pp.

314. Stover, D. E. Grade Control for In Situ Uranium Leaching. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

315. Stover, D. E. (assigned to Atlantic Richfield Co.). Method for the Restoration of an Underground Reservoir. U.S. Pat. 4,108,722, Aug. 22, 1978.

316. Sundar, P. S. In-Situ Leaching Simulation Studies of Uranium Ores--Phases I through III. Westinghouse Research and Development Center, 1310 Beulah Road, Pittsburgh, Penn., BuMines Contract No. H0262004, June 1977, 392 pp. Available from National Technical Information Service, Springfield, Va., PB 272 717.

317. Sundar, P. S. In-Situ Leaching Simulation Studies of Uranium Ores. Pres. at 1978 Ann. Meeting, Denver, Colo. Feb. 28 - Mar. 2, 1978, SME Preprint 78-AS-102, 16 pp.

318. Sundin, R. E. Regulations on In Situ Uranium Mines in Wyoming. Proc. Third Ann. Uranium Seminar, Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 3-4.

319. Taylor, W. R. Ground Water Quality Protection in In Situ Uranium Mines. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 1-5; SME Preprint 79-10, 3 pp.

320. Taylor, W. R. Regulation of In Situ Uranium Mining for Purposes of Protecting Groundwater Quality. Pres. at Uranium In Situ Symp., South Texas Minerals Sect., Soc. Petrol. Eng., AIME, Corpus Christi, Tex., Sept. 25-28, 1977, Preprint 7536, 12 pp.

321. Terry, G. A. Environmental Assessment of In-Situ Leaching of Uranium. Pres. at AAPG-SEPM Ann. Convention, Houston, Texas, Apr. 1-4, 1979.

322. Terry, R. C. (assigned to In Situ Technology, Inc., Denver, Colo.). Recovering Uranium from Coal In Situ. U.S. Pat. 4,113,313, Sept. 12, 1978.

323. Texas Department of Water Resources. Permit to Conduct Underground Injection. Longoria Mining Project, Permit No. 02222, 1979, 6 pp.

324. Texas Department of Water Resources. Nondischarge Permit No. 02051 Issued to Union Carbide Corporation for a Full Scale In Situ Uranium Leaching Operation in Duval County, Texas. Permit Issued January 1977.

325. Texas Department of Water Resources. Nondischarge Permit No. 01941 Issued to Mobil Oil Company for a Full Scale In Situ Uranium Leaching Operation in Webb County, Texas. Permit Issued June 1975.

326. Texas Department of Water Resources. Nondischarge Permit No. 01942 Issued to Wyoming Mineral Corporation for a Full Scale In Situ Uranium Leaching Operation in Webb County, Texas. Permit Issued June 1975.

327. Texas Department of Water Resources. Nondischarge Permit No. 01949 Issued to Wyoming Mineral Corporation for a Full Scale In Situ Uranium Leaching Operation in Live Oak County, Texas. Permit Issued August 1975.

328. Texas Department of Water Resources. Nondischarge Permit No. 02050 Issued to Intercontinental Energy Corporation for a Full Scale In Situ Uranium Leaching Operation in Bee County, Texas. Permit Issued January 1975.

329. Texas Department of Water Resources. Nondischarge Permit No. 01890 Issued to Atlantic Richfield Company (operation now U.S. Steel) for a Full Scale In Situ Uranium Leaching Operation in Live Oak County, Texas. Permit Issued January 1975.

330. Texas Department of Water Resources. Nondischarge Permit No. 02025 Issued to U.S. Steel Corporation for a Full Scale In Situ Uranium Leaching Operation in Live Oak County, Texas. Permit Issued August 1976.

331. Texas Department of Water Resources. Nondischarge Permit No. 02130 Issued to U.S. Steel Corporation for a Full Scale In Situ Uranium Leaching Operation in Live Oak County, Texas. Permit Issued December 1977.

332. Texas Uranium Operations - U.S. Steel Corporation. Appliction for In Situ Uranium Mine Production Area Authorization - Pawlik Mine. 1980, 81 pp.

333. Thiede, D. M., and D. W. Walker. South Texas Uranium Leach Drilling and Completion Technology. Pres. at Uranium In Situ Symp., South Texas Minerals Sect., AIME, Corpus Christi, Tex., Sept. 25-28, 1977, 17 pp.

334. Thompson, W. E., W. V. Swarzenski, D. L. Warner, G. E. Rouse, O. F. Carrington, and R. Z. Pyrih. Groundwater Elements of In Situ Leach Mining of Uranium. Geraghty and Miller, Inc. (Tampa, Florida), Prepared for U.S. Nuclear Regulatory Commission Under Contract No. NRC-02-77-187, August 1978, 173 pp.; Available from National Technical Information Service, Springfield, Va., NTIS No. NUREG/CR-0311, $9.00.

335. Tiepel, E. In-Situ Mining of Uranium, Groundwater Restoration Methods and Field Test Data. Pres. at South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978.

336. Timmons, T. Pilot Testing In-Situ Leach in Texas and New Mexico. Pres. at South Texas Urainium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978.

337. Toth, G. W. Cost Estimating Technique for Uranium Solution Mining Projects. Pres. at Northwest Min. Assoc. 83rd Ann. Convention, Spokane, Washington, Dec. 2, 1977, 38 PP.; Available from NUS Corp., 4 Research Place, Rockville, Maryland 20850.

338. Toth, G. W. A Cost Model for Uranium Solution Mining. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section V, 42 pp.

339. Traut, D. E., I. L. Nichols, and D. C. Seidel. Design Criteria for Uranium Ion Exchange in a Fluidized System. Trans. Soc. of Min. Eng., AIME, V. 260, March 1976, pp. 24-28.

340. Traut, D. E., I. L. Nichols, and D. C. Seidel. Design Requirements for Uranium Ion Exchange from Acidic Solutions in a Fluidized System. BuMines RI 8282, 1978, 29 pp.

341. Traut, D. E., I. L. Nichols, and D. C. Seidel. Design Requirements for Uranium Ion Exchange from Ammonium Bicarbonate Solutions in a Fluidized System. BuMines RI 8280, 1978, 27 pp.

342. Trussell, P. C., D. W. Duncan, and C. C. Walden. Biological Mining. Can. Min. J., V. 85, No. 3, March 1964, pp. 46-49.

343. Tuovinen, O. H. Microbiological Aspects in the Leaching of Uranium by Thiobacillus Ferrooxidans. Atomic Energy Review, V. 10, No. 2, 1972, pp. 251-258.

344. Turosak, G. Igniting Coal Vein Seen as Way to Get Uranium. Bismark Tribune, Aug. 1, 1980.

345. Tweeton, D. R. (assigned to the United States of America as represented by the Secretary of the Interior, Washington, D.C.). Impedence Measuring Method of and Apparatus for Detecting Escaping Leach Solution. U.S. Pat. 4,253,063, Feb. 24, 1981.

346. Tweeton, D. R., G. R. Anderson, J. K. Ahlness, O. M. Peterson, and W. H. Engelmann. Geochemical Changes During In Situ Uranium Leaching with Acid. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 23-51; SME Preprint 79-43, 27 pp.

347. Tweeton, D. R., G. R. Anderson, and W. H. Engelmann. Bureau of Mines Research in Injection Well Construction and Environmental Aspects of In Situ Uranium Leaching. Pres. at 1978 AIME Ann. Meeting, Denver, Colo., Feb. 26-Mar. 2, 1978, Preprint 78-AS-111, 8 pp.

348. Tweeton, D. R., and K. Connor. Well Construction Information for In Situ Uranium Leaching. BuMines IC 8769, 1978, 19 pp.

349. Tweeton, D. R., and K. A. Peterson. Selection of Lixiviants for In Situ Uranium Leaching. BuMines IC 8851, 1981.

350. Tweeton, D. R., T. R. Guilinger, W. M. Breland, and R. Schecter. The Advantages of Conditioning an Orebody with a Chloride Solution Before In Situ Uranium Leaching with a Carbonate Solution. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9490, 4 pp.

351. U.S. Energy Research and Development Administration. National Uranium Resource Evaluation Preliminary Report. Grand Junction Office, Grand Junction, Colo., Rept. GJO-111(76), June 1976, 132 pp.

352. U.S. Energy Research and Development Administration. Statistical Data of the Uranium Industry. Grand Junction Office, Grand Junction, Colo., Rept. GJO-100(76), April 1976, 87 pp.

353. U.S. Energy Research and Development Administration. Statistical Data of the Uranium Industry. Grand Junction Office, Grand Junction, Colo., Rept. No. GJO-100(77), Jan. 1, 1977, 107 pp.

354. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Campbell County, Wyoming. Docket No. 40-8200, Source Material License No. SUA-1199, Issued to Cleveland Cliffs Iron Company, May 1974.

355. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Johnson County, Wyoming. Docket No. 40-8511, Source Material License No. SUA-1273, Issued to Cotter Corporation (formerly operated by Uranerz, U.S.A.), June 1976.

356. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Highland Uranium Operations, Converse County, Wyoming. Docket No. 40-8064, Source Material License No. SUA-1064, Issued to Humble Oil and Refining Company (now Exxon Company, U.S.A.), November 1970.

357. U.S. Nuclear Regulatory Commission. Application to Conduct a Full Scale In Situ Uranium Leach Mining Operation, Highland Uranium Operation, Converse County, Wyoming. Docket No. 40-8102, as Amendment to Source Material License SUA-1139, Issued to Exxon Company, U.S.A., August 1977.

358. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Shirley Basin, Wyoming. Docket No. 40-8586, Submitted by Kerr McGee Nuclear Corporation, November 1976.

359. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Sweetwater County, Wyoming. Docket No. 40-8348, Source Material License No. SUA-1223, Issued to Minerals Exploration Company, December 1974.

360. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Crook County, Wyoming. Docket No. 40-8663, Submitted by Nuclear Dynamics, November 1977.

361. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Converse and Natrona Counties, Wyoming. Docket No. 40-8380, Source Material License SUA-1228, Issued to Rocky Mountain Energy Corporation, February 1975.

362. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Sweetwater County, Wyoming. Docket No. 40-8636, Submitted by Wold Nuclear Company, June 1977.

363. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Johnson County, Wyoming. Docket No. 40-8304, Source Material License No. SUA-1204, Issued to Wyoming Mineral Corporation, Submitted July 1974.

364. U.S. Nuclear Regulatory Commission. Application to Conduct a Full Scale In Situ Uranium Leach Mining Operation, Johnson County, Wyoming. Docket No. 40-8502, submitted by Wyoming Mineral Corporation, September 1977.

365. Uranium Resources Inc. Application and Technical Report, Benavides In Situ Uranium Leach Project. 1979, 162 pp.

366. Uranium Resources Inc. Application and Technical Report, Longoria In Situ Leach Project. 1978, 175 pp.

367. Wadsworth, M. E., J. Milbourne, and S. Y. Han. A Kinetic Study of the Carbonate Leaching of Uranium Ore with Hydrogen Peroxide and Oxygen. To be Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979.

368. Wallace, R. E. Aspects of In Situ Solution Mining of Uranium. Pres. at Ann. Meeting of the Arizona Conf. of AIME, Dec. 3-4, 1978, 6 pp.

369. Walsh, M. P., W. M. Breland, R. S. Schechter, and J. M. Humenick. Multicomponent Ion Exchange at In Situ Uranium Solution Mining Sites. Tech. Report EHE-79-06, Univ. Texas, Austin, Tex., 1979, 103 pp.

370. Walsh, M. P., R. S. Schechter, and M. J. Humenick. Cation Exchange Processes in the Chromatographic Movement of Ammonium: Application to Restoration of Uranium In Situ Leaching Sites. Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979, SME Preprint 79-73.

371. Walsh, M. P., R. S. Schechter, and M. J. Humenick. The Displacement and Migration of Ammonium Ions from Uranium In Situ Leaching Sites. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 99-111; SME Preprint 79-73, 12 pp.

372. Walsh, M. P., R. S. Schechter, M. J. Humenick, A. D. Hill, and I. H. Silverberg. A Model for Predicting the Restoration of and Ammonium Migration from In Situ Mine Sites. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 4, Pt. 1, 1979, pp. 29-38.

373. Ward, M. H. Engineering for In Situ Leaching. Min. Cong. J., V. 59, No. 1, January 1973, pp. 21-27.

374. Westinghouse Electric Corp. Solution Mining of Uranium. Report 5923, 3 PP.; Available from Westinghouse Electric Corp., Nuclear Fuel Division, Box 355, Pittsburgh, Pa. 15230.

375. Westinghouse Electric Corp. Uranium Solution Mining. 1975, 16 PP.; Available from Westinghouse Electric Corp., Nuclear Fuel Division, Box 355, Pittsburgh, Pa. 15230.

376. Westinghouse Research Laboratories. Correlation of Rock Structure with Uranium Reserves. Tech. Report 5M792, November 1975, 4 PP.; Available from Westinghouse Electric Corp., Nuclear Fuel Division, Box 355, Pittsburgh, Pa. 15230.

377. Westinghouse Electric Corporation. Detection of Lixiviant Excursions with Geophysical Resistance Measurements During In Situ Uranium Leaching. BuMines Open File Rept. 5-81, 1981, 156 pp.; available for cousultation at Twin Cities Research Center, Minneapolis, Minn.; and from National Technical Information Service, PB 81 171 324.

378. White, G., Jr. Uranium: Continued Price Stability Seen for 1979, as Supply and Demand Stay in Balance. Eng. and Min. J., V. 180, No. 3, March 1979, pp. 145-147.

379. White, L. In Situ Leaching Opens New Uranium Reserves in Texas. Eng. and Min. J., V. 176, No. 7, July 1975, pp. 73-80.

380. White, L. Wyoming Uranium Miners Set Sights on Higher Production. Eng. and Min. J., V. 152, No. 12, December 1975, pp. 61-71.

381. Whiting, D. L. Hydrology of Dump Leaching and In Situ Solution Mining. Pres. at SME-AIME Fall Meeting, St. Louis, Mo., Oct. 19-21, 1977, Preprint 77-AS-336, 37 pp.

382. Whittington, D., and W. R. Taylor. Regulations and Restoration of In Situ Uranium Mines in Texas. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 2, Pt. 1, 1979, pp. 7-10.

383. Williams, R. L., P. Smith, and P. Osborne. The Environment, EPA, and the In Situ Mining of Uranium. Proc. Third Ann. Uranium Seminar, Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 5-10.

384. Winkley, D. C. The Effect of Uranium Leach Conditions on the Kinetics of Hydrogen Peroxide Reactions. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section X, 14 pp.

385. Winters, H. J., C. K. Chase, and R. B. Bhappu. Technical Notes Economic Evaluation for In Situ Extraction of Uranium. Pres. at 104th AIME Ann. Meeting, New York, Feb. 16-20, 1975, 5 pp.

386. Wood, S. Characterization of the Uranium Occurence in Pre- and Post-Leach Ore Samples from Sandstone Deposits in Texas & Wyoming. Pres. at the 53rd Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Houston, Texas, Oct. 1-3, 1978, SPE Preprint 7537, 8 pp.

387. Wood, S. Characteriization of the Uranium Occurance in Pre- and Post-Leach Ore Samples from Sandstone Deposits in Texas and Wyoming. In Situ Oil Coal Shale Miner, V. 4, No. 2, 1980, pp. 111-127.

388. Woolery, R. G. Processing Marginal Uranium Reserves. Pres. at Uranium Resource Tech. Seminar II, Colorado School of Mines, Golden, Colorado, Mar. 12-14, 1979, 10 pp.

389. Woolery, R. G., D. J. Hansen, J. A. Weber, and S. Ramachandran. Heap Leaching of Uranium -- A Case History. Pres. at 107th Ann. Meeting, AIME, Atlanta, Ga., Mar. 6-10, 1977, Preprint 77-AS-93, 20 pp.

390. Woolery, R. G., and S. Ramachandran. An Alkaline Heap Leach Evaluation. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 14, Pt. 4, 1979, pp. 87-90.

391. Wyoming Mineral Corp. Uranium Solution Mining. 1976, 12 PP.; Available from Wyoming Mineral Corp., 3900 S. Wadsworth Blvd., Lakewood, Colo. 80235.

392. Wyrick, R. Solution Mining in Old Stopes. Pres. at Uranium Min. Technol. Conf., the Mackay School of Mines, Univ. Nevada-Reno, Reno, Nevada, Apr. 25-29, 1977, 16 pp.

393. Yan, T. Y. Calcite Control in In-Situ Uranium Leaching Process. J. Petrol. Tech., V. 32, No. 11, November 1980, pp. 2068-2074.

394. Yan, T. A Method for Removing Ammonium Ions from Subterranean Formation After In Situ Uranium Leaching. Pres. at the 55th Ann. Fall Tech. Conf. and Exibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9491, 7 pp.

1. ADAMS, J. A., AND J. E. ODDO. GEOLOGICAL TRADE-OFFS IN URANIUM SOLUTION MINING. PRES. AT AAPG-SEPM ANN. CONVENTION, HOUSTON, TEXAS, APR. 1-4, 1979.

2. ADLER, H. H. CONCEPTS OF GENESIS OF SANDSTONE-TYPE URANIUM ORE DEPOSITS. ECON. GEOL., V. 58, NO. 6, 1963, PP. 839-851.

3. AMELL, A. R., AND D. LANGMUIR. FACTORS INFLUENCING THE SOLUTION RATE OF URANIUM DIOXIDE UNDER CONDITIONS APPLICABLE TO IN SITU LEACHING. FINAL REPT. OF BUMINES CONTRACT NO. H0272019, NOV. 20, 1978, 124 PP.; AVAILABLE FOR CONSULTATION AT TWIN CITIES MINING RESEARCH CENTER, TWIN CITIES, MINNESOTA.

4. ANDERSON, J. S., AND M. I. RICHIE. SOLUTION MINING OF URANIUM. MIN. CONG. J., V. 54, NO. 1, JANUARY 1968, PP. 20-23, 26.

5. ANNAMALAI, V., AND F. X. MCGARVEY. OPERATING EXPERIENCE IN THE RECOVERY OF URANIUM AT THE PAWNEE AND ZAMZOW SITES. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9507, 14 PP.

6. BAKHUROV, V. G., S. G. VECHERKIN, AND I. K. LUTSENKO. PODZEMNOE VYSMCHELACIVANIE URANOVYKH RUD (UNDERGROUND LEACHING OF URANIUM ORES). ATOMIZDAT, MOSCOW, 1969, 151 PP.

7. BALLARD, J. K. SOLUTION MINING. MIN. ENG., V. 23, NO. 2, FEBRUARY 1971, P. 109.

8. BARNES, F. Q. URANIUM--WHERE ARE THE RESERVES. MIN. CONG. J., V. 62, NO. 2, FEBRUARY 1976, PP. 28-33.

9. BECHERKIN, S. G., V. G. BAKHUROV, AND I. K. LUTSENKO. UNDERGROUND LEACHING OF URANIUM FROM LOW-GRADE IN-SITU ORES. SOVIET ATOMIC ENERGY, V. 21, NO. 2, FEBRUARY 1968, PP. 128-133.

10. BERG, D. NEW URANIUM RECOVERY TECHNIQUES. PRES. AT ATOMIC IND. FORUM INTERNAT. CONF. ON URANIUM, GENEVA, SEPT. 13-16, 1976, 13 PP.

11. BHAPPU, R. B. ECONOMIC EVALUATION OF IN PLACE LEACHING AND SOLUTION MINING SITUATIONS. PRES. AT A SHORT COURSE IN IN-PLACE LEACHING AND SOLUTION MINING, THE MACKAY SCHOOL OF MINES, UNIV. NEVADA--RENO, RENO, NEV., NOV. 10-14, 1975, 22 PP.

12. BHAPPU, R. B. IN SITU EXTRACTION AND LEACHING TECHNOLOGY. PRES. AT INTER-REGIONAL SEMINAR ON THE ECONOMICS OF MINERAL ENGINEERING, ANKARA, TURKEY, APR. 5-16, 1976, 39 PP.

13. BHAPPU, R. B. IN SITU MINING TECHNOLOGY - PRACTICAL AND ECONOMIC ASPECTS. PRES. AT THE TURKISH MINING INSTITUTE, ANKARA, TURKEY, APR. 5-16, 1976, 29 PP.

14. BOMMER, P. M. A STREAMLINE-CONCENTRATION BALANCE MODEL FOR IN-SITU URANIUM LEACHING AND SITE RESTORATION. PH.D. DISSERTATION, UNIVERSITY OF TEXAS AT AUSTIN, AUSTIN, TEXAS, AUGUST 1978.

15. BOMMER, P. M., AND R. S. SCHECHTER. MATHEMATICAL MODELING OF IN-SITU URANIUM LEACHING. PROC. OF NEW ORLEANS SYMP. OF SOC. MIN. ENG., AIME, NEW ORLEANS, LA., FEB. 18-22, 1979 (PUB. AS IN SITU URANIUM MINING AND GROUND WATER RESTORATION, ED. BY W. J. SCHLITT AND D. A. SHOCK), PP. 54-66; SME PREPRINT 79-28, 13 PP.

16. BOMMER, P. M., AND R. S. SCHECHTER. MATHEMATICAL MODELING OF IN-SITU URANIUM LEACHING. SOC. OF PETROL. ENG. J., V. 19, NO. 7, DECEMBER 1979, PP. 393-400.

17. BORKERT, J. J. JR. EVALUATION OF A URANIUM IN-SITU LEACHING PROJECT. PLANNING AND ANALYSIS DIV., U.S. ENERGY RES. AND DEV. ADMIN., GRAND JUNCTION, CO., FEBRUARY 1975, 47 PP.

18. BORKERT, J. J., AND C. E. GERITY. AN ECONOMIC ANALYSIS OF OPEN-PIT AND IN SITU MINING. MIN. ENG., V. 30, NO. 10, OCTOBER 1978, PP. 1420-1422.

19. BORKERT, J. J., AND C. E GERITY. THE ECONOMICS OF IN SITU MINING VERSUS OPEN PIT MINING. PROC. SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978. AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC., NEW YORK, CH. 18, PT. 5, 1979, PP. 107-112.

20. BOSSLER, J. F., AND R. F. JANKE. ION EXCHANGE RESIN EVALUATION IN URANIUM RECOVERY. PROC. SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978. AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC., NEW YORK, CH. 13, PT. 4, 1979, PP. 79-86.

21. BOYCE, T. D. THE RELATIONSHIP BETWEEN ION EXCHANGE RESIN PROPERTIES AND URANIUM RECOVERY IN FLUIDIZED BED COLUMNS. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9508, 8 PP.

22. BRIERLEY, C. L. BIOGENIC EXTRACTION OF URANIUM FROM ORES OF THE GRANTS REGION. PROC. INTERNAT. SYMP. ON METALLURGICAL APPLICATIONS OF BACTERIAL LEACHING AND ACADEMIC PRESS, INC., NEW YORK, 1977, PP. 345-363.

23. BRIERLEY, C. L. MICROBIOLOGY AND URANIUM MINING: PRACTICES AND PROBLEMS. PROC. THIRD ANN. URANIUM SEM., WYOMING MIN. AND METALS SECT., AIME, CASPER, WYO., SEPT. 9-12, 1979, PP. 129-133.

24. BRIERLEY, C. L., J. A. BRIERLEY, P. R. NORRIS, AND D. P. KELLY. METAL-TOLERANT MICROORGANISMS OF HOT, ACID ENVIRONMENTS. TECH. SERIES PUB., NO. 14, SOC. FOR APPLIED BACTERIOLOGY, IN PRESS.

25. BROWN, M. R. KERR GETS FIRST SALES CONTRACT FOR URANIUM FOR AGNEW LAKE MINE PRODUCTION. THE NORTHERN MINER, V. 62, NO. 18, JULY 15, 1976, P. 1.

26. BUMA, G. GEOCHEMICAL ARGUMENTS FOR NATURAL STABILIZATION FOLLOWING IN-SITU LEACHING OF URANIUM. PROC. OF NEW ORLEANS SYMP. OF SOC. MIN. ENG.. AIME. NEW ORLEANS. LA.. FEB. 18-22. 1979 (PUB. AS IN SITU URANIUM MINING AND GROUND WATER RESTORATION, ED. BY W. J. SCHLITT AND D. A. SHCOK), PP. 113-124.

27. BUMA, G. PROPERTY EVALUATION PROCEDURES FOR IN-SITU LEACHING OF URANIUM. ROCKY MT. GEOCHEMICAL CORP.. APR. 29, 1977, 20 PP.; AVAILABLE FROM P.O. BOX 337, MIDVALE, UTAH 84047.

28. BUMA, G. URANIUM SOLUTION MINING STATE OF THE ART. PRES. AT ENERGY TECHNOLOGY CONF. AND EXHIBIT. PETROL. DIV. OF SOC. MECH. ENG.. AIME, HOUSTON, TEX.. SEPT. 18-22, 1977, PREPRINT 77-PET-47. 11 PP.

29. BUNKER, C. M.. AND J. A. MACKALLON. GEOLOGY OF THE OXIDIZED URANIUM ORE DEPOSITS OF THE TORDILLA HILL-DEWEESVILLE AREA. KARNES COUNTY, TEXAS: A STUDY OF A DISTRICT BEFORE MINING. U.S. GEOL. SURVEY PAPER NO. 465. 1973. 37 PP.

30. CARLSON, R. H.. R. D. NORRIS. AND R. SCHELLINGER. THE ROLE OF OXIDIZING AGENT IN THE CHEMISTRY OF IN SITU URANIUM LEACHING. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION. SPE. AIME, DALLAS, TEXAS. SEPT. 21-24, 1980, SPE PREPRINT 9483. 16 PP.

31. CARNAHAN, T. G. (RENO METALLURGY RESEARCH CENTER). IN SITU LEACHING OF URANIUM. PRES. AT THE IN-PLACE LEACHING AND SOLUTION MINING SHORT COURSE, INCLINE VILLAGE, NEVADA. NOV. 10-14, 1975. 18 PP.

32. CARNINE, G. T.. AND L. R. DARBEE (ASSIGNED TO FMC CORPORATION, NEW YORK, N.Y.. A CORP. OF DEL.). STABILIZATION OF HYDROGEN PEROXIDE. U.S. PAT. 3,383.174, MAY 14. 1968.

33. CARPENTER, R. H.. AND R. B. BHAPPU. HYDROMETALLURGY AND LOW GRADE ORE POTENTIAL. PRES. AT 107TH ANN. MEETING. AIME, ATLANTA, GA.. MAR. 6-10, 1977.

34. CHAMBERLAIN, P. G. EVALUATING ORE BODIES FOR LEACHING WITH PERMEABILITY MEASUREMENTS. PROC. OF NEW ORLEANS SYMP. OF SOC. MIN. ENG.. AIME, NEW ORLEANS, LA.. FEB. 18-22. 1979 (PUB. AS IN SITU URANIUM MINING AND GROUND WATER RESTORATION, ED. BY W. J. SCHLITT AND D. A. SHOCK), PP. 7-22; PREPRINT 79-27. 14 PP.

35. CHAMBERLAIN, P. G. FIELD PERMEABILITY METHODS FOR IN-PLACE LEACHING. MIN. CONG. J.. V. 64, NO. 9, SEPTEMBER 1978, PP. 22-25.

36. CHAPMAN, WOOD, AND GRISWOLD. INC. GEOLOGIC MAP OF GRANTS URANIUM REGION. NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES, CIRC. 31, 1977. 3 PP.

37. CHARLEY, W. R. ECONOMIC CONSIDERATIONS OF SOLUTION MINING. PRES. AT URANIUM RESOURCE/TECH. SEMINAR II, COLORADO SCHOOL OF MINES, GOLDEN, COLORADO, MAR. 12-14, 1979, 13 PP.

38. CHASE, C. K., H. J. WINTERS, AND R. B. BHAPPU. ECONOMIC EVALUATION OF IN SITU EXTRACTION OF URANIUM. PRES. AT AM. NUCLEAR SOC. MEETING, GOLDEN, COLO., APR. 12-14, 1977, 12 PP.; AVAILABLE FROM C. K. CHASE, MOUNTAIN STATES RESEARCH AND DEVELOPMENT, P.O. BOX 17960, TUCSON, ARIZONA 85731.

39. CHATTERJI, B. D., A. S. DESHPANDE, C. V. SHARMA, S. C. KULSHRESTHA, AND R. N. SANKRAN. RESULTS OF SOME BENEFICIATION AND LIXIVIATION TESTS ON MEDIUM-GRADE URANIUM ORE IN QUARTZITE FROM CHHINJPA, KULU DISTRICT, HIMACHAL PRADESH. PROC. OF THE INDIAN NATIONAL SCIENCE ACADEMY, V. 36, A, NO. 6, 1970.

40. CHEMICAL WEEK. NEW SOLUTION CUTS URANIUM MINING COSTS. V. 29, DEC. 24, 1975, PP. 28-29.

41. CHEMICAL WEEK. SCOWL, THEN A SMILE FOR SOLUTION MINING. FEB. 2, 1977, PP. 13-14.

42. CLARK, D. A. STATE-OF-THE-ART. URANIUM MINING, MILLING, AND REFINING INDUSTRY. U.S. ENVIRONMENTAL PROTECTION AGENCY REPT. EPA-660/2-74-038, JUNE 1974, 113 PP.

43. COLEMAN, K. A., AND G. W. STEWART. NEW MEXICO'S FIRST URANIUM IN SITU SOLUTION PROJECT. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9489, 8 PP.

44. COLORADO DEPARTMENT OF HEALTH. SOURCE MATERIAL LICENSE ISSUED TO WYOMING MINERAL CORPORATION FOR A PILOT SCALE IN SITU URANIUM LEACHING OPERATION IN WELD COUNTY, COLORADO. PERMIT ISSUED FOR ONE YEAR, OCTOBER 1976 - OCTOBER 1977.

45. CONINE, W. D. URANIUM SOLUTION MINING: A COMPARISION OF NEW MEXICO WITH SOUTH TEXAS. PROC. THIRD ANN. URANIUM SEMINAR WYOMING MIN. AND METALS SECTION OF AIME, CASPER, WYOMING, SEPT. 9-12, 1979, PP. 126-128.

46. COOK, L. M. THE URANIUM DISTRICT OF THE TEXAS GULF COASTAL PLAIN. TEXAS DEPARTMENT OF HEALTH, AUSTIN, TEXAS. APR. 28, 1978, 14 PP.

47. COOPERSTEIN, R. PRESENTATIONS AT SEMINAR ON IN SITU URANIUM SOLUTION EXTRACTION. PRES. AT SEMINAR ON IN SITU URANIUM MINING FOR REGULATORY PERSONNEL, CORPUS CHRISTI, TEXAS, MAR. 6-9, 1979, 65 PP.

48. COOPERSTEIN, R. SAFETY EVALUATION REPORT SOURCE MATERIAL LICENSE W.M.CO., DOCKET NO. 40-8502, SOURCE MATERIAL LICENSE SUA-1341, ISSUED TO FUEL PROCESSING AND FABRICATION BRANCH, DIVISION OF FUEL CYCLE AND MATERIAL SAFETY, 50 PP.

49. COX, C. H., AND W. J. ROUSHEY. RECOVERY OF URANIUM BY IN SITU SOLUTION MINING. MINERAL IND. BULL., V. 22, NO. 1, JANUARY 1979, 12 PP.

50. CRAWFORD, E. DEVELOPERS EYE TEXAS POTENTIAL FOR IN SITU URANIUM LEACHING. ENG. AND MIN. J., V. 176, NO. 7, JULY 1975, PP. 81-82.

51. DAVIDSON, D. H. IN-SITU LEACHING OF NONFERROUS METALS. MIN. CONG. J., V. 66, NO. 7, JULY 1980, PP. 52-54, 57.

52. DAVIDSON, D. H., R. V. HUFF, AND W. E. SONSTELIE. MEASUREMENT AND CONTROL IN SOLUTION MINING OF DEEP-LYING DEPOSITS OF COPPER OR URANIUM. PRES. AT INSTRUMENT SOC. OF AMERICA MIN. AND MET. IND. DIV. SYMP., DENVER, COLO., NOV. 1-3, 1978, 7 PP.

53. DAVIS, G. R., AND W. M. MCKNIGHT, JR. FACILITIES FOR SOLUTION MINING OF URANIUM OPERATIONAL AND ENVIRONMENTAL ASPECTS. PRES. AT AM. NUCLEAR SOCIETY, NOVEMBER 1978, AND IN SITU URANIUM MINING SEMINAR, MARCH 1979, 10 PP.

54. DAVIS, G. R., R. E. MILLER, AND G. G. SWIFT. IN-SITU LEACH MINING FOR URANIUM. PROC. ADVISORY GROUP MEETING, INTERNAT. ATOMIC ENERGY AGENCY, WASHINGTON, D.C., NOV. 24-26, 1975, PANEL PROCEEDINGS SERIES, 1976, PP. 193-202.

55. DAVIS, G. R., AND E. L. REED. CONTROLLING URANIUM SOLUTION MINING OPERATIONS. MIN. CONG. J., V. 64, NO. 10, OCTOBER 1978, PP. 35-38.

56. DERRY, R. THE USE OF PEROXIDANTS IN THE LEACHING OF METAL SULPHIDES. PRES. AT ANN. MEETING OF THE MET. SOC., AIME, NEW ORLEANS, LA., FEB. 18-22, 1979, TMS PAPER SELECTION A-79-4, 24 PP.

57. DEVRIES, F. W. NOVEL TECHNIQUES IN LIXIVIANTS AND SITE RESTORATION. PROC. SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978. AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC., NEW YORK, CH. 12, PT. 4, 1979, PP. 75-78.

58. DEW, J. N., AND W. L. MARTIN (ASSIGNED TO CONTINENTAL OIL COMPANY, PONCA CITY, OKLA., A CORPORATION OF DELAWARE). IN SITU ROASTING AND LEACHING OF URANIUM ORES. U.S. PAT. 2,954,218, SEPT. 27, 1960.

59. DRAVO CORPORATION. SOLUTION MINING. SECTION 6.6.2 IN ANALYSIS OF LARGE SCALE NON-COAL UNDERGROUND MINING METHODS, BUMINES CONTRACT REPORT S0122059, JANUARY 1974, PP. 455-464.

60. DREVER, J. I., AND C. R. MCKEE. THE PUSH-PULL TEST: A METHOD OF EVALUATING FORMATION ADSORPTION PARAMETERS FOR PREDICTING THE ENVIRONMENTAL EFFECTS OF IN-SITU COAL GASIFICATION AND URANIUM RECOVERY. PROC. OF NEW ORLEANS SYMP. OF SOC. MIN. ENG., AIME, NEW ORLEANS, LA., FEB. 18-22, 1979 (PUB. AS IN SITU URANIUM MINING AND GROUND WATER RESTORATION, ED. BY W. J. SCHLITT AND D. A. SHOCK), PP. 87-98.

61. DUNCAN, D. W., AND A. BRUYNESTEYN. ENHANCING BACTERIAL ACTIVITY IN A URANIUM MINE. CAN. MIN. AND MET. BULL., V. 64, NO. 709, MAY 1971, PP. 32-36.

62. DUNCAN, D. W., AND A. BRUYNESTEYN. MICROBIOLOGICAL LEACHING OF URANIUM. PROC. 1970 URANIUM SYMP., SOCORRO, N. MEX., COMP. BY R. J. ROMAN, 1970, PP. 55-61.

63. DURLER, D. L., AND A. L. BISHOP. IN-SITU URANIUM LEACH MINING: CONSIDERATIONS FOR MONITOR WELL SYSTEMS. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9505, 10 PP.

64. DUTRIZAC, J. E., AND R. J. C. MACDONALD. FERRIC ION AS A LEACHING MEDIUM. MINERALS SCI. ENG., V. 6, NO. 2, APRIL 1974, PP. 59-100.

65. DUYVESTEYN, W. P. C., G. R. WICKER, AND R. E. DOANE. AN OMNIVOROUS PROCESS FOR LATERITE DEPOSITS. TO BE PRES. AT AIME ANN. MEETING, NEW ORLEANS, LA., FEB. 18-22, 1979.

66. EARGLE, D. H. URANIUM IN TEXAS. HOUSTON GEOL. SOC. BULL., V. 13, NO. 2, 1970, PP. 18-27.

67. EARGLE, D. H., K. A. DICKINSON, AND B. O. DAVIS. SOUTH TEXAS URANIUM DEPOSITS. AAPG BULL., V. 59, NO. 5, MAY 1975, PP. 766-779.

68. EARGLE, D. H., G. W. HINDS, AND A. M. D. WEEKS. URANIUM GEOLOGY AND MINES, SOUTH TEXAS. TEXAS UNIV. BUR. ECON. GEOL. GUIDEBOOK NO. 12, AUSTIN, TEX., 1971, 59 PP.

69. EISENBARTH, W. A. INDUSTRY VIEW OF REGULATIONS ON IN SITU MINING. PROC. THIRD ANN. URANIUM SEMINAR WYOMING MIN. AND METALS SECTION OF AIME, CASPER, WYOMING, SEPT. 9-12, 1979, PP. 11-14.

70. EISENBARTH, W. A. RECONCILATION: ENVIRONMENTAL ISSUES IN IN-SITU MINING VS REGULATORY CONSTRAINTS. PRES. AT URANIUM RESOURCE TECH. SEMINAR II. COLORADO SCHOOL OF MINES, GOLDEN, COLORADO, MAR. 12-14, 1979, 7 PP.

71. ENGELMANN, W. H. (ASSIGNED TO THE UNITED STATES OF AMERICA AS REPRESENTED BY THE SECRETARY OF THE INTERIOR, WASHINGTON, D.C.). FOAM INJECTION LEACHING PROCESS FOR FRAGMENTED ORE. U.S. PAT. 4,080,419, MAR. 21, 1978.

72. ENGELMANN, W. H., AND D. R. KASPER. ENVIRONMENTAL REGULATIONS FOR IN SITU URANIUM MINING: FROM EXPLORATION TO RESTORATION. CH. IN PROC. OF THE AM. ASSOC. OF PETROL. GEOL. ANN. MEETING, HOUSTON, TEX., APR. 1-4, 1979, 21 PP.

73. ENGELMANN, W. H., P. E. PHILLIPS, D. R. TWEETON, K. W. LOEST, AND M. T. NIGBOR. RESTORATION OF GROUNDWATER QUALITY FOLLOWING PILOT-SCALE ACIDIC IN SITU URANIUMLEACHING AT NINE-MILE LAKE SITE NEAR CASPER, WYOMING. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9494, 24 PP.

74. ENGINEERING AND MINING JOURNAL. AGNEW LAKE MINES; TAKING GIANT STEPS IN SOLUTION MINES. V. 179, NO. 11, NOVEMBER 1978, PP. 158-161.

75. ENGINEERING AND MINING JOURNAL. BEAR CREEK GEARS UP FOR COMMERCIAL USE OF BOREHOLE URANIUM MINING. ENG. AND MIN. J., V. 180, NO. 3, MARCH 1979, PP. 41 AND 45.

76. ENGINEERING AND MINING JOURNAL. CLIFFS READIES URANIUM SOLUTION TEST IN PUMPKIN BUTTES AREA. V. 181, NO. 1, JANUARY 1980, PP. 43, 47.

77. ENGINEERING AND MINING JOURNAL. THE COST OF LEACHING U308 IN STOPES AND PUMPING SOLUTION TO THE SURFACE. V. 169, NO. 6, JUNE 1968, P. 186.

78. ENGINEERING AND MINING JOURNAL. ECONOMICS PROVIDE MOTIVE FOR GROWTH OF BACTERIA LEACHING. V. 167, NO. 6, JUNE 1966, 543 PP.

79. ENGINEERING AND MINING JOURNAL. INDIA STUDIES POSSIBILITY OF COPPER MINING BY NUCLEAR BLASTS. V. 171, NO. 7, JULY 1970, 33 PP.

80. ENGINEERING AND MINING JOURNAL. IN-SITU LEACHING OPENS NEW URANIUM RESERVES IN TEXAS. V. 176, NO. 7, JULY 1975, PP. 73-81.

81. ENGINEERING AND MINING JOURNAL. IN SITU URANIUM LEACHING OPERATIONS FLOURISH IN SOUTHERN TEXAS. V. 178, NO. 6, JUNE 1977, PP. 23, 27.

82. ENGINEERING AND MINING JOURNAL. MINING IN-SITU BY NATURES EASY WAY. V. 168, NO. 10, OCTOBER 1967, PP. 75-80.

83. ENGINEERING AND MINING JOURNAL. NEW METHOD SUGGESTED FOR LEACHING URANIUM ORE IN PLACE. V. 168, NO. 5, MAY 1967, PP. 106-107.; DISCUSSION OF U.S. PATENT 3,309,140, LEACHING OF URANIUM ORE IN SITU, BY J. GARDNER AND M. I. RITCHIE.

84. ENGINEERING AND MINING JOURNAL. PRODUCERS AND NEWCOMERS PUSH DEVELOPMENT PLANS. V. 179, NO. 11, NOVEMBER 1978, PP. 104-106.

85. ENGINEERING AND MINING JOURNAL. SOLUTION MINING OPENING NEW RESERVES. V. 175, NO. 7, JULY 1974, PP. 62-71.

86. ENGINEERING AND MINING JOURNAL. TEXAS-URANIUM PRODUCTION BY IN SITU LEACHING. V. 176, NO. 6, JUNE 1975, P. 304.

87. ENGINEERING AND MINING JOURNAL. URANIUM LEACH PROJECT SNARLED IN NEW MEXICOS ENVIRONMENTAL RULES. V. 178, NO. 6, JUNE 1977, P. 33, 36.

88. ENGINEERING AND MINING JOURNAL. URANIUM PRODUCTION BY IN-SITU LEACHING. (TEXAS) JUNE 1975, P. 304.

89. ENGINEERING AND MINING JOURNAL. U3O8 PROCESS AVOIDS SULPHATES AND CHLORIDES. V. 180, NO. 5, MAY 1979, PP. 118-119.

90. ENGINEERING AND MINING JOURNAL. IN SITU URANIUM EXTRACTION DOMINATES TEXAS MEETING. V. 181, NO. 12, DECEMBER 1980, PP. 92-93.

91. ERICKSON, J. W. UNDERGROUND IN SITU MINING-A NEW MINING METHOD. MIN. ENG., V. 30, NO. 11, NOVEMBER 1978, PP. 1532-1534.

92. ERICKSON, J. W. UNDERGROUND IN SITU : A NEW MINING METHOD. PROC. THIRD ANN. URANIUM SEMINAR WYOMING MIN. AND METALS SECTION OF AIME, CASPER, WYOMING, SEPT. 9-12, 1979, PP. 15-18.

93. FISHER, J. R. BACTERIAL LEACHING OF ELLIOT LAKE URANIUM ORE. CAN. MIN. AND MET. BULL., V. 59, NO. 649, MAY 1966, PP. 588-592.

94. FISHER, J. R., F. C. LENDRUM, AND R. G. MACDERMID. LABORATORY AND UNDERGROUND STUDIES OF BACTERIAL LEACHING OF ELLIOT LAKE ORES. PRES. AT 95TH AIME ANN. MEETING, FEB. 27 - MAR. 3, 1966, NEW YORK, 9 PP.

95. FISHMAN, P. H., AND W. H. HUANG. MINERALOGICAL ANALYSIS AND URANIUM DISTRIBUTION OF THE SEDIMENTARY-TYPE URANIUM ORES. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9502, 12 PP.

96. FITCH, D. C. EXPLORATION GEOLOGY METHODS IN THE GRANTS MINERAL BELT. PRES. AT URANIUM SYMPOSIUM, SOCORRO, NEW MEXICO, MAY 6-8, 1970, 11 PP.

97. FITCH, J. L., AND B. G. HURD (ASSIGNED TO MOBIL OIL CORPORATION, A CORPORATION OF NEW YORK). IN SITU LEACHING METHOD. U.S. PAT. 3,278,232, OCT. 11, 1966.

98. FITCH, J. L., AND B. G. HURD (ASSIGNED TO MOBIL OIL CORPORATION, A CORPORATION OF NEW YORK). METHOD OF LEACHING SUBSURFACE MINERALS IN SITU. U.S. PAT. 3,309,141, MAR. 14, 1967.

99. FRANK, J. N. COST MODEL FOR SOLUTION MINING OF URANIUM. PRES. AT THE URANIUM INDUSTRY SEMINAR, GRAND JUNCTION, COLO., OCT. 19-20, 1976, 25 PP.

100. FRANK, J. N. IN SITU LEACHING OF URANIUM. PRES. AT THE 1975 URANIUM AND THORIUM RESEARCH AND RESOURCES CONF., U.S. GEOLOGICAL SURVEY, DENVER, COLO., DEC. 8-10, 1975, 8 PP.

101. GALICHON, P. IN-SITU LEACHING OF URANIUM ORE. M.S. THESIS, UNIV. OF TEXAS, AUSTIN, TEXAS, DECEMBER 1976, 83 PP.

102. GALICHON, P., R. S. SCHECHTER, A. COWLEY, AND M. BRELAND. CHEMICAL FACTORS IN IN-SITU URANIUM LEACH MINING. IN SITU, V. 1, NO. 2, 1977, PP. 125-146.

103. GALLOWAY, W. E. DEPOSTIONAL AND GROUNDWATER FLOW SYSTEMS IN THE EXPLORATION FOR URANIUM. RESEARCH COLLOQUIUM, BUREAU OF ECONOMIC GEOLOGY, UNIV. OF TEXAS, AUSTIN, TEX., 1979, 267 PP.

104. GALLOWAY, W. E. SOUTH TEXAS URANIUM PROVINCE GEOLOGIC PERSPECTIVE. GUIDEBOOK 18, BUREAU OF ECONOMIC GEOLOGY, UNIV. TEXAS, AUSTIN, TEX., 1979, 81 PP.

105. GARDNER, J., AND M. I. RITCHIE (ASSIGNED TO UTAH CONSTRUCTION AND MINING COMPANY, SAN FRANCISCO, CALIF., A CORPORATION OF DELAWARE). LEACHING OF URANIUM ORE IN SITU. U.S. PAT. 3,309,140, MAR. 14, 1967.

106. GARWACKA, K., D. JOHNSON, M. WALSH, M. BRELAND, R. SCHECHTER, AND M. HUMENICK. INVESTIGATION OF THE FATE OF AMMONIA FROM IN-SITU URANIUM SOLUTION MINING. TECH. REPORT EHE-79-01, THE UNIV. OF TEXAS AT AUSTIN, AUSTIN, TEXAS, FEBRUARY 1979, 140 PP.

107. GEORGE, D. R., AND J. R. ROSS. RECOVERY OF URANIUM FROM URANIUM MINE WATERS AND COPPER ORE LEACHING SOLUTIONS, PROCESSING OF LOW-GRADE URANIUM ORES. PROC. OF A PANEL HELD IN VIENNA, JUNE 27 - JULY 1, 1966, INTERNAT. ATOMIC ENERGY AGENCY, VIENNA, 1967, PP. 227-234.

108. GEORGE, D. R., J. R. ROSS, AND J. D. PRATER. BYPRODUCT URANIUM RECOVERED WITH NEW ION EXCHANGE TECHNIQUES. MIN. ENG., V. 20, NO. 1, JANUARY 1968, PP. 73-77.

109. GODDARD, J. B., AND D. P. BROSNAHAN. RATE OF CONSUMPTION OF DISSOLVED OXYGEN DURING AMMONIUM CARBONATE IN SITU LEACHING OF URANIUM. PRES. AT 109TH ANNUAL MEETING, SOC. MIN. ENG., AIME, LAS VEGAS, NEVADA, FEB. 24-28, 1980.

110. GOODIER, J. T. WYOMINGS URANIUM INDUSTRY--STATUS, IMPACTS AND TRENDS. REPORT TO; MINERAL DIVISION, DEPARTMENT OF ECONOMIC PLANNING AND DEVELOPMENT, STATE OF WYOMING. PREPARED BY; QUALITY DEVELOPMENT ASSOCIATES, INC., SEPT. 30, 1978, 225 PP.

111. GRANT, D. C. IN-SITU LEACHING STUDIES OF URANIUM ORES--PHASE IV. FINAL REPORT, WESTINGHOUSE ELECTRIC CORP., R AND D CENTER, 1310 BEULAH ROAD, PITTSBURGH, P.A., BUMINES CONTRACT H0262004, NOVEMBER 1978, 497 PP.

112. GRIMES, M. E. PREDICTION OF URANIUM EXTRACTION IN IN-SITU STOPE LEACHING. PROC. SOLUTION MINING SYMP., AIME ANN. MEETING, DALLAS, TEXAS, FEB. 25-27, 1974, PP. 338-353.

113. GRISWOLD, G. B. ROCK FRACTURING TECHNIQUES FOR IN PLACE LEACHING. PRES. ANN. MEETING OF THE SOC. OF MIN. ENG., AIME, WASHINGTON D.C., FEB. 16-20, 1969, AIME PREPRINT 69-AS-74, 4 PP.

114. GUARNERA, B. J. URANIUM EXPLORATION ACTIVITIES IN THE U.S. MIN. ENG., V. 30, NO. 10, OCTOBER 1978, PP. 1414-1416.

115. GUBKIN, N. V., D. T. DESYATNIKOV, AND I. K. RUDNEVA. ADVANTAGES OF MINING URANIUM IN INUNDATED SHEET DEPOSITS BY UNDERGROUND LEACHING. ATOMIC ENERGY, V. 24, NO. 6, JUNE 1968, PP. 511-514.

116. GUILINGER, T., M. BRELAND, M. MCGARRY, D. MAGID, AND R. S. SCHECHTER. ENVIRONMENTALLY ATTRACTIVE LEACHANTS FOR IN SITU URANIUM MINING. DEPT. OF CHEM. ENG., DEPT. OF PETROL. ENG., UNIVERSITY OF TEXAS AT AUSTIN. BUMINES CONTRACT NO. H0282016, APR. 10, 1979, 113 PP.

117. HANCOCK, W. A. URANIUM IN SITU LEACHING: ITS ADVANTAGES, PRACTICE, PROBLEMS, AND COMPUTER SIMULATION. PRES. AT 107TH ANN. MEETING, AIME, ATLANTA, GA., MARCH 1977, PREPRINT 77-AS-68, 20 PP.

118. HARD, R. A., AND R. L. RIPLEY (ASSIGNED TO UNION CARBIDE CORPORATION, NEW YORK, N.Y.). PROCESS FOR LEACHING BASE ELEMENTS, SUCH AS URANIUM ORE IN SITU. U.S. PAT. 3,708,206, JAN. 2, 1973.

119. HARDEN, K. C. THE ECONOMIC PRODUCTION OF URANIUM BY IN SITU LEACHING. FOURTH ANN. URANIUM SEMINAR, SOUTH TEXAS MIN. SECT., SME, AIME, CORPUS CHRISTI, TEX., SEPT. 14-17, 1980, 8 PP.

120. HARLOFF, G. J., AND A. C. RIESE. EXPERIMANTAL AND THEORETICAL STUDY OF URANIUM IN SITU SOLUTION MINING WITH H2SO4. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9484, 13 PP.

121. HARRISON, V. F., W. A. GOW, AND M. R. HUGHSON. FACTORS INFLUENCING THE APPLICATION OF BACTERIAL LEACHING TO A CANADIAN URANIUM ORE. J. METALS, V. 18, NO. 11, NOVEMBER 1966, PP. 1189-1194.

122. HARSHMAN, E. N. GENETIC IMPLICATIONS OF SOME ELEMENTS ASSOCIATED WITH URANIUM DEPOSITS, SHIRLEY BASIN, WYOMING. U.S. GEOL. SURVEY PROF. PAPER 550-C, 1966, PP. C167-C173.

123. HARSHMAN, E. N. GEOLOGY AND URANIUM DEPOSITS, SHIRLEY BASIN AREA, WYOMING. U.S. GEOL. SURVEY PROF. PAPER 745, 1972, 82 PP.

124. HARSHMAN, E. N. URANIUM DEPOSITS OF WYOMING AND SOUTH DAKOTA. CH. IN ORE DEPOSITS OF THE UNITED STATES, 1933-1967, ED. BY J. D. RIDGES. AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, NEW YORK, V. 1, PT. 7, CH. 40, 1968, PP. 815-831.

125. HARTMANN, B. E. SOLUTION MINING SYSTEM. PROC. UPDATE ON URANIUM MINING TECHNOL. CONF., RENO, NEVADA, NOV. 13-17, 1978 (PUB. AS URANIUM MINING TECHNOLOGY, ED. BY Y. S. KIM), SECTION IX, 10 PP.

126. HENDERSON, T. B., JR. VARIATIONS IN SOUTH TEXAS URANIUM HOSTS. PRES. AT URANIUM IN SITU SYMP., SOUTH TEXAS MINERALS SECT., AIME, CORPUS CHRISTI, TEX., SEPT. 25-28, 1977, 3 PP.

127. HENRICKSON, A. V. (ASSIGNED TO KERR-MCGEE OIL INDUSTRIES, INC.). RECOVERY OF URANIUM VALUES BY SOLVENT EXTRACTION. U.S. PAT. 3,241,909, MAR. 22, 1966.

128. HIGGINS, I. R. UPDATE OF CHEM-SEPS CONTINUOUS ION EXCHANGE OPERATION RELATIONS TO URANIUM RECOVERY. PRES. AT 1978 URANIUM MINING SEMINAR SOUTH TEXAS MINERALS SECTION, CORPUS CHRISTI, TEX., SEPTEMBER 1978, 8 PP.

129. HILL, A. D., M. P. WALSH, W. M. BRELAND, I. H. SILBERBERG, M. J. HUMENICK, AND R. S. SCHECHTER. RESTORATION OF URANIUM IN SITU LEACHING SITES. PRES. AT 53RD ANN. FALL TECHNICAL CONFERENCE AND EXHIBITION OF THE SOC. OF PET. ENG., AIME, HOUSTON, TEXAS, OCT. 1-3, 1978, SPE PREPRINT 7534, 8 PP.

130. HOHNE, F. C. PROJECTIONS OF THE IMPACT OF SOLUTION MINING ON URANIUM PRODUCTION IN THE UNITED STATES. PRES. AT URANIUM MINING TECHNOLOGY CONFERENCE, THE MACKAY SCHOOL OF MINES, UNIV. NEVADA--RENO, RENO, NEV., APR. 25-29, 1977.

131. HOWELL, E. P., AND O. J. GANT, JR. (ASSIGNED TO ATLANTIC RICHFIELD COMPANY, LOS ANGELES, CALIF.). METHOD FOR THE PRODUCTION OF MINERALS. U.S. PAT. 4,032,194, JUNE 28, 1977.

132. HUANG, W. H. GEOCHEMICAL AND SEDIMENTOLOGIC PROBLEMS OF URANIUM DEPOSITS OF TEXAS GULF COASTAL PLAIN. AAPG BULL., V. 62, NO. 6, JUNE 1978, PP. 1049-1062.

133. HUANG, W. H., AND K. PICKETT. FACTORS CONTROLLING IN-SITU LEACHING OF URANIUM FROM SANDSTONE AND LIGNITE DEPOSITS IN SOUTH TEXAS. PROC. UPDATE ON URANIUM MINING TECHNOL. CONF., RENO, NEVADA, NOV. 13-17, 1978 (PUB. AS URANIUM MINING TECHNOLOGY, ED. BY Y. S. KIM), SECTION XI, 18 PP.

134. HUFF, R. V., AND D. H. DAVIDSON. TECHNOLOGY FOR IN SITU URANIUM LEACHING. MIN. ENG., V. 32, NO. 2, FEBRUARY 1980, PP. 163-166.

135. HUFF, R. V., AND H. DAVIDSON. IN-SITU LEACHING MATERIALS CONSIDERATIONS. PRES. AT 54TH ANN. FALL TECHNICAL CONFERENCE AND EXHIBITION, SOC. PETROL. ENG., AIME, LAS VEGAS, NEVADA, SEPT. 23-26, 1979, SPE PREPRINT 8320, 6 PP.

136. HUNKIN, G. G. CONCENTRATION PROCESSES FOR URANIUM IN SITU LEACH LIQUORS. PRES. AT 105TH ANN. MEETING, AIME, LAS VEGAS, NEV., FEB. 22-26, 1976, PREPRINT 76-B-77, 7 PP.

137. HUNKIN, G. G. THE ENVIRONMENTAL IMPACT OF SOLUTION MINING FOR URANIUM. MIN. CONG. J., V. 61, NO. 10, OCTOBER 1975, PP. 24-27.

138. HUNKIN, G. G. A REVIEW OF IN SITU LEACHING. PRES. AT AIME ANN. MEETING, SOC. OF MIN. ENG., AIME, NEW YORK, N.Y., FEB. 26 - MAR. 4, 1971, AIME PREPRINT 71-AS-88, 23 PP.

139. HUNKIN, G. G. ORAL PRESENTATION URANIUM IN-SITU SOLUTION MINING. THE ROYAL COMMISSION OF INQUIRY CONCERNING THE HEALTH AND ENVIRONMENTAL PROTECTION URANIUM MINING, 1979, 24 PP.

140. HUNKIN, G. G. URANIUM IN-SITU SOLUTION MINING. THE ROYAL COMMISSION OF INQUIRY CONCERNING THE HEALTH AND ENVIRONMENTAL URANIUM MINING 1979, OCTOBER 1979, 93 PP.

141. HURD, B. G., AND J. L. FITCH (ASSIGNED TO MOBIL OIL CORPORATION, A CORPORATION OF NEW YORK). IN SITU LEACHING OF SUBTERRANEAN DEPOSITS. U.S. PAT. 3,278,233, OCT. 11, 1966.

142. JACOBY, C. H. (ASSIGNED TO AKZONA INC., ASHEVILLE, N.C.). IN SITU EXTRACTION OF MINERAL VALUES FROM ORE DEPOSITS. U.S. PAT. 3,822,916, JULY 9, 1974.

143. JAYARAM, K. M. V., A. S. DESHPANDE, AND C. V. SHARMA. LEACHING AND PRECIPITATION OF URANIUM FROM QUARTZITE ORES AT CHHINJRA, KULU DISTRICT, HIMACHAL PRADESH. PROC. OF THE INDIAN NATIONAL SCIENCE ACADEMY. V. 36, A, NO. 5, 1970, PP. 298-305.

144. JOHNSON, D. NITRIFICATION AND IN SITU URANIUM LEACH MINING. DEPT. OF CIVIL ENG., UNIVERSITY OF TEXAS, AUSTIN, NOVEMBER 1978, 54 PP.

145. JOHNSON, D., AND M. J. HUMENICK. NITRIFICATION AND IN-SITU URANIUM SOLUTION MINING. SOC. PETROL. ENG. J., V. 20, NO. 5, OCTOBER 1980, PP. 415-422.

146. JOHNSON, J. M. RECOVERY OF URANIUM BY MULTIPLE-COLUMN COUNTERCURRENT ION EXCHANGE. JULY 1969, 7 PP.

147. JOHNSON, P. H. ACID-FERRIC SULFATE SOLUTIONS FOR CHEMICAL MINING. MIN. ENG., V. 17, NO. 8, AUGUST 1965, PP. 64-68.

148. JOHNSON, P. H., AND R. B. BHAPPU. CHEMICAL MINING - A STUDY OF LEACHING AGENTS. NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES, CIRC. 99, 1969, 7 PP.

149. JOHNSON, P. H., AND R. B. BHAPPU. CHEMICAL MINING - THEORETICAL AND PRACTICAL ASPECTS. PRES. AT SME FALL MEETING - ROCKY MOUNTAIN MINERALS CONF., LAS VEGAS, NEVADA, SEPT. 6-8, 1967, 20 PP.

150. KABIR, M. I., L. W. LAKE, AND R. S. SCHECHTER. EVALUATION OF THE ONE WELL URANIUM LEACHING TEST: RESTORATION. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9486, 11 PP.

151. KALARIN, A. I. WINNING OF USEFUL ELEMENTS FROM MINERALS BY LEACHING UNDERGROUND. MIN. MAG. (LONDON). V. 118, NO. 2, FEBRUARY 1968. PP. 129-134.

152. KALLUS, M. F. ENVIRONMENTAL ASPECTS OF URANIUM MINING AND MILLING IN SOUTH TEXAS. U.S. ENVIRONMENTAL PROTECTION AGENCY, EPA 906/9-75-004. OCTOBER 1975. 86 PP.

153. KASPER, D. R. OPTIMIZATION OF REVERSE OSMOSIS TREATMENT OF IN SITU WASTEWATERS. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION. SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9492, 5 PP.

154. KASPER, D. R., AND W. H. ENGELMANN. COMPLIANCE WITH ENVIRONMENTAL REGULATIONS FOR IN SITU URANIUM MINING: FROM DISCOVERY TO CLOUSURE. PROC. UPDATE ON URANIUM MINING TECHNOL. CONF., RENO. NEVADA, NOV. 13-17, 1978 (PUB. AS URANIUM MINING TECHNOLOGY, ED. BY Y. S. KIM), SECTION XVII, 36 PP.

155. KEHRMAN, R. F., A. J. FARSTAD, AND D. R. TWEETON. USE OF RESISTIVITY MEASUREMENTS TO MONITOR LIXIVIANT MIGRATION DURING IN-SITU URANIUM LEACHING. 10 PP.

156. KING, J. W., AND S. R. AUSTIN. SOME CHARACTERISTICS OF ROLL-TYPE URANIUM DEPOSITS AT GAS HILLS, WYOMING. MIN. ENG., V. 18, NO. 5, MAY 1966, PP. 73-80.

157. KOCH, L. W. ECONOMICS OF URANIUM MINING AND MILLING. PRES. AT URANIUM RESOURCE TECH. SEMINAR, COLORADO SCHOOL OF MINES, GOLDEN, COLORADO, MAR. 12-14, 1979, 12 PP.

158. KOLODNEY, M., AND S. C. HYMAN (ASSIGNED TO NUCLEAR DEVELOPMENT CORPORATION OF AMERICA, A CORP. OF NEW YORK). RECOVERY OF URANIUM AND VANADIUM VALUES FROM ORES. U.S. PAT. 2,964,380. DEC. 13, 1960.

159. KURTH, D. I., AND R. D. SCHMIDT. COMPUTER MODELING OF FIVE-SPOT WELL PATTERN FLUID FLOW DURING IN SITU URANIUM LEACHING. BUMINES RI 8287, 1978, 76 PP.

160. LACKEY, J. A. ENVIRONMENTAL ASPECTS OF URANIUM EXTRACTION. AMDEL BULL. (THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES), NO. 19, APRIL 1975, PP. 11-20.

161. LACKEY, J. A. SOLUTION MINING (IN SITU LEACHING) A LITERATURE SURVEY. AMDEL BULL., (THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES), NO. 19. APRIL 1975. PP. 40-61.

162. LANG, E. A., AND W. R. ARCHIBALD. INNOVATIVE SYSTEMS FOR THE RECOVERY OF URANIUM. PRES. AT THE NATIONAL WESTERN MIN. CONF., DENVER, COLO., FEB. 7, 1975, PP. 1-13.: COLORADO MINING ASSOC., 1975 MINING YEARBOOK. PP. 114-118.

163. LANG, L. C., AND W. B. MORREY. SCIENTIFIC BLASTING FOR IN-SITU LEACHING PROVES SUCCESSFUL AT AGNEW LAKE MINES. ENG. AND MIN. J., V. 177, NO. 1, JANUARY 1976. PP. 100-102.

164. LANGEN, R. E., AND A. L. KIDWELL. GEOLOGY AND GEOCHEMISTRY OF THE HIGHLAND URANIUM DEPOSIT, CONVERSE COUNTY, WYOMING. THE MOUNTAIN GEOL., V. 11, NO. 2, APRIL 1974, PP. 85-93.

165. LANGSTON, B. G. AMMONIUM CARBONATE PRESSURE LEACHING OF URANIUM ORES. J. METALS, V. 9, NO. 6, JUNE 1957, PP. 752-756.

166. LARSON, W. C. NOMOGRAPH FOR URANIUM IN SITU LEACHING. ENG. AND MIN. J., V. 178, NO. 9, SEPTEMBER 1977, P. 159.

167. LARSON, W. C. URANIUM IN SITU LEACH MINING - A THIRD ALTERNATIVE. PRES. AT AAPG ANN. CONFERENCE, HOUSTON, TEXAS, APR. 1-4, 1979, 23 PP.

168. LARSON, W. C. URANIUM IN SITU LEACH MINING IN THE UNITED STATES. BUMINES IC 8777, 1978, 87 PP.

169. LAWES, B. C. EFFECT OF SODIUM SILICATE ON LEACHING URANIUM ORES WITH HYDROGEN PEROXIDE. PRES. AT AM. NUCLEAR SOC. MEETING, GOLDEN, COLO., APR. 14, 1977, 12 PP.

170. LEAMING, G. F. THE ECONOMIC IMPACT OF THE SOUTH TEXAS URANIUM INDUSTRY. SOUTHWEST ECONOMIC INFO. CENTER, MARANA, ARIZONA, FEBRUARY 1979, 60 PP.

171. LEARMONT, R. P. (ASSIGNED TO UNITED STATES STEEL CORPORATION, PITTSBURGH, PA.). IN SITU SOLUTION MINING TECHNIQUE. U.S. PAT. 4,082,358, APR. 4, 1978.

172. LEARMONT, R. P. (ASSIGNED TO UNITED STATES STEEL CORPORATION). PROCESS FOR LEACHING MINERAL VALUES FROM UNDERGROUND FORMATIONS IN SITU. U.S. PAT. 3,860,289, JAN. 14, 1975.

173. LEWIS, F. M., AND R. B. BHAPPU. EVALUATING MINING VENTURES VIA FEASIBILITY STUDIES. MIN. ENG., V. 27, NO. 10, OCTOBER 1975, PP. 48-54.

174. LEWIS, F. M., C. K. CHASE, AND R. B. BHAPPU. ECONOMIC EVALUATION OF IN SITU EXTRACTION FOR COPPER, GOLD, AND URANIUM. PROC. JOINT MEETING OF THE MINING AND METALLURGICAL INSTITUTE OF JAPAN AND THE AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, DENVER, COLO., SEPT. 1-3, 1976 (PUB. AS WORLD MINING AND METALS TECHNOLOGY, ED. BY A. WEISS), V. 1, 1976, PP. 333-348.

175. LI, T. A., AND J. D. WIERMER. URANIUM MINING IN THE U.S.- PRODUCERS RUSH TO MEET ENERGY NEEDS. MIN. ENG., V. 30, NO. 10, OCTOBER 1978, PP. 1405-1410.

176. LITZ, L. M. IN SITU URANIUM MINING WITH OXYGEN. PRES. AT 109TH ANNUAL MEETING,SOC. MIN. ENG., AIME, LAS VEGAS, NEVADA, FEB. 24-28, 1980.

177. LIVINGSTON, C. W. METHOD OF MINING ORES IN SITU BY LEACHING. U.S. PAT. 2,818,240, DEC. 31, 1957.

178. LOEST, K. W. DEVELOPMENT OF AN IN SITU OPERATION: NINE MILE LAKE. PROC. THIRD ANN. URANIUM SEMINAR WYOMING MIN. AND METALS SECTION OF AIME. CASPER, WYOMING, SEPT. 9-12, 1979, PP. 75-77.

179. LOO, W. W. PRODUCTION OPTIMIZATION OF IN-SITU LEACHING OF URANIUM BY PROPER WELL FIELD DESIGN. PRES. AT URANIUM MINING TECHNOLOGY-UPDATE 78 CONF., NOV. 13-17, 1978, RENO, NEV., 11 PP.

180. LOOTENS, D. T. URANIUM PRODUCTION METHODS AND ECONOMIC CONSIDERATIONS. DAMES AND MOORE CONSULTING CO., PARK RIDGE. ILL., 1976, 11 PP.

181. MACGREGOR, R. A. THE BACTERIAL LEACHING OF URANIUM. NUCLEAR APPLICATIONS, V. 6, JANUARY 1969, PP. 68-72.

182. MACGREGOR, R. A. RECOVERY OF U308 BY UNDERGROUND LEACHING. CAN. MIN. AND MET. BULL., V. 59, NO. 649, MAY 1966, PP. 583-587.

183. MACGREGOR, R. A. URANIUM DIVIDENDS FROM BACTERIAL LEACHING. MIN. ENG., V. 21, NO. 3, MARCH 1969, PP. 54-55.

184. MACKAY SCHOOL OF MINES, UNIVERSITY OF NEVADA--RENO. IN-PLACE LEACHING AND SOLUTION MINING. SHORT COURSE GIVEN AT INCLINE VILLAGE, NEV., NOV. 10-14, 1975, 225 PP.

185. MALOUF, E. E. INTRODUCTION TO DUMP LEACHING PRACTICE. PART I OF SECOND TUTORIAL SYMP. ON EXTRACTIVE METALLURGY, UNIV. UTAH, DEC. 14-16, 1972, 26 PP.

186. MALOUF, E. E. LEACHING AS A MINING TOOL. INTERNAT. SYMP. ON HYDROMETALLURGY. CHICAGO, ILL., FEB. 25-MAR. 1, 1973, CH. 23, PP. 615-626.

187. MALOUF, E. E. THE ROLE OF MICROORGANISMS IN CHEMICAL MINING. MIN. ENG., V. 23, NO. 11, NOVEMBER 1971, PP. 43-46.

188. MARRS, L. F. UNDERGROUND LEACHING OF URANIUM AT THE PITCH MINE. PRES. AMERICAN MIN. CONG. CONVENTION, DENVER, COLO., SEPT. 27-30, 1970, 14 PP.; MIN. CONG. J., V. 56, NO. 11, NOVEMBER 1970, PP. 35-43.

189. MARTIN, J. W. (ASSIGNED TO OIL RECOVERY CORPORATION, NEW YORK, N.Y., A CORPORATION OF NEW YORK). RECOVERY OF URANIUM BY CARBONATED WATER AND SURFACE ACTION AGENTS AND WETTING AGENTS. U.S. PAT. 3,130,960, APR. 28, 1964.

190. MAY, H. D. ENVIRONMENTAL CONSIDERATIONS OF IN-SITU URANIUM MINING/MILLING. PRES. AT SEMINAR ON URANIUM SOLUTION MINING AND MILLING FOR STATE AND FEDERAL REGULATORY PERSONNEL, CORPUS CHRISTI, TEXAS, MAR. 6-9, 1979, 17 PP.

191. MAYS, W. M. ENGINEERING AN IN SITU URANIUM WELL FIELD. THIRD ANN. URANIUM SEM., WYOMING MIN. AND METALS SECT., AIME, CASPER, WYO., SEPT. 9-12, 1979, PP. 69-70.

192. MCCREEDY, H. H., V. F. HARRISON, AND W. A. GOW. A PROPOSED METHOD, USING BACTERIA, FOR THE CONTINUOUS LEACHING OF A URANIUM ORE. CAN. MIN. AND MET. BULL., V. 62, NO. 682, FEBRUARY 1969, PP. 135-140.

193. MCKEE, C. R. PRELIMINARY PROPOSAL TO THE ENVIRONMENTAL PROTECTION AGENCY ON CONTROLLING SOLUTION MOVEMENT AND GROUNDWATER RESTORATION FOR URANIUM SOLUTION MINING. UNIVERSITY OF WYOMING THROUGH WATER RESOURCES RESEARCH INSTITUTE, JANUARY 1977. 9 PP.

194. MCKEE, C. R., AND J. I. DREVER. RESERVOIR ENGINEERING UPDATE--URANIUM IN SITU EXTRACTION. TO BE PRES. AT AIME ANN. MEETING, NEW ORLEANS, LA., FEB. 18-22, 1979.

195. MCKINNEY, W. A. SOLUTION MINING. MIN. ENG., V. 25, NO. 2, FEBRUARY 1973, PP. 56-57.

196. MC KNIGHT, W. M. JR., AND H. L. ANTHONY, IV. WELL FIELD OPERATIONS. PROC. THIRD ANN. URANIUM SEM., WYOMING MIN. AND METALS SECT., AIME, CASPER, WYO., SEPT. 9-12, 1979, PP. 71-73.

197. MELIN, R. E. DESCRIPTION AND ORIGIN OF URANIUM DEPOSITS IN SHIRLEY BASIN, WYOMING. ECON. GEOL., V. 59, 1964, PP. 835-849.

198. MENKE, J. R. (ASSIGNED TO NUCLEAR DEVELOPMENT CORP. OF AMERICA, A CORP. OF NEW YORK). METHOD OF RECOVERING URANIUM FROM UNDERGROUND DEPOSIT. U.S. PAT. 2,896,930, JULY 28, 1959.

199. MERRITT, R. C. THE EXTRACTIVE METALLURGY OF URANIUM. COLO. SCHOOL MINES RESEARCH INST., PREPARED UNDER CONTRACT WITH U.S. ATOMIC ENERGY COMMISSION. JOHNSON PUB. CO., BOULDER, COLO., 1971. 576 PP.

200. MERRITT, R. C. THE METALLURGY OF URANIUM EXTRACTION. PRES. AT URANIUM MINING TECHNOLOGY CONFERENCE, THE MACKAY SCHOOL OF MINES, UNIV. NEVADA--RENO, RENO, NEV., APR. 25-29, 1977, 41 PP.

201. MEYER, A. E. (ASSIGNED TO KERR-MCGEE OIL INDUSTRIES INC.). METHOD OF ACID LEACHING URANIUM ORES. U.S. PAT. 3,250,589, MAY 10, 1966.

202. MINING ENGINEERING. AN ECONOMIC ANALYSIS OF OPEN-PIT AND IN SITU MINING. V. 30, NO. 10, OCTOBER 1978, PP. 1420-1422.

203. MINING ENGINEERING. HYDROMETALLURGY IS KEY IN WINNING U3O8. V. 26, NO. 8, AUGUST 1974, PP. 26-27.

204. MINING ENGINEERING. KERR-MCGEES AMBROSIA COMPLEX: FROM MINED ROCK TO YELLOWCAKE. V. 26, NO. 8, AUGUST 1974, PP. 28-30.

205. MINING MAGAZINE (LONDON). IN SITU LEACHING - A REVIEW. V. 125, NO. 3, SEPTEMBER 1971, PP. 213-215.

206. MINING RECORD (DENVER, COLORADO). HYDROGEN PEROXIDE CAN MAXIMIZE URANIUM LEACHING. V. 90, NO. 4, JAN. 24, 1979, P. 8.

207. MINING RECORD (DENVER, COLORADO). SOLUTION MINING - CAN IT SPEED DEVELOPMENT OF URANIUM RESERVES. V. 87, NO. 26, JUNE 23, 1976, PP. 1, 7.

208. MINING MAGAZINE. DEVELOPMENT OF ARGENTINIAN URANIUM DEPOSITS. V. 142, NO. 1, JANUARY 1980, PP. 9-10.

209. MINOBRAS. URANIUM DEPOSITS OF THE NORTHERN U.S. REGION. P.O. BOX 262, DANA POINT, CALIF., 92629, 1977, 99 PP.

210. MINOBRAS. URANIUM GUIDEBOOK FOR WYOMING. P.O. BOX 262, DANA POINT, CALIF., 92629, 1976, 63 PP.

211. MRAK, V. A. URANIUM DEPOSITS IN THE EOCENE SANDSTONES OF THE POWDER RIVER BASIN, WYOMING. CH. IN ORE DEPOSITS OF THE UNITED STATES, 1933-1967, ED. BY J. D. RIDGES. AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, NEW YORK, V. 1, PT. 7, CH. 42, 1968, PP. 838-848.

212. MUTSCHLER, P. H., J. J. HILL, AND B. B. WILLIAMS. URANIUM FROM THE CHATTANOOGA SHALE; SOME PROBLEMS INVOLVED IN DEVELOPMENT. BUMINES IC 8700, 1976, 85 PP.

213. NADEN, D., AND G. WILLEY. THE USE OF FLUID BED ION EXCHANGE TO REDUCE URANIUM RECOVERY COSTS. PRES. AT THE AIME ANN. MEETING, SOC. MIN. ENG., AIME, LAS VEGAS, NEVEDA, FEB. 22-26, 1976, PREPRINT 76-B-65, 33 PP.

214. NARAYAN, K., AND R. D. PICK (ASSIGNED TO ATLANTIC RICHFIELD COMPANY, LOS ANGELES, CALIF.). RECOVERY OF URANIUM FROM CARBONATE LEACH SOLUTIONS. U.S. PAT. 4,092,399, MAY 30, 1978.

215. NARAYAN, K., AND P. J. RAND. ENVIRONMENTAL CONSIDERATIONS IN URANIUM SOLUTION MINING. TRANS. SOC. OF MIN. ENG., AIME, V. 262, JUNE 1977, PP. 117-119.

216. NARAYAN, K., P. J. RAND, AND R. B. HILL. ENVIRONMENTAL CONSIDERATIONS IN URANIUM SOLUTION MINING. PRES. AT 105TH ANN. MEETING, AIME, LAS VEGAS, NEV., FEB. 22-26, 1976, PREPRINT 76-AS-70, 12 PP.

217. NEESHAM, R. TEXAS URANIUM PRODUCERS TAKE A GROWING MARKET SHARE. ENG. AND MIN. J., V. 179, NO. 11, NOVEMBER 1978, PP. 143-147.

218. NEW MEXICO DEPARTMENT OF HEALTH AND ENVIRONMENT. RADIOACTIVE MATERIAL LICENSE NO. NM-GRA-UL-00 ISSUED TO MICHAEL P. GRACE FOR PILOT SCALE IN SITU URANIUM LEACHING TESTS, MCKINLEY AND SANDOVAL COUNTIES, NEW MEXICO. PERMIT ISSUED MAR. 5, 1976.

219. NIGRINI, A. THERMODYNAMIC CALCULATION OF U LOADINGS AND REACTION PATHS WITH CARBONATE LIXIVIANTS IN INSITU LEACHING SYSTEMS. TO BE PRES. AT AIME ANN. MEETING, NEW ORLEANS, LA., FEB. 18-22, 1979.

220. NUCLEAR REGULATORY COMMISSION. GROUND-WATER ELEMENTS OF IN SITU LEACH MINING OF URANIUM. NUREG/CR-0311, 1978, PP. 17-34.

221. OLSON, J. J. BUREAU OF MINES RESEARCH IN IN-SITU LEACHING AND BOREHOLE (OR SLURRY) MINING. PRES. AT FALL MEETING OF SOC. OF MIN. ENG., AIME, ST. LOUIS, MO., OCT. 19-21, 1977, PREPRINT 77-AS-340, 58 PP.

222. OLSON, J. J., W. C. LARSON, D. R. TWEETON, AND OTHERS. MINING RESEARCH FOR IMPROVED IN SITU EXTRACTION OF URANIUM. PRES. AT URANIUM IN SITU LEACHING CONF., SPONSORED BY AAPG, SME, AND SPE, VAIL, COLO., AUG. 25-27, 1976, BUMINES PREPRINT, 37 PP.

223. OLSON, J. J., G. A. SAVANICK, AND D. R. TWEETON. IN SITU MINING TECHNOLOGY FOR URANIUM -- A PROGRESS REPORT ON BUREAU OF MINES RESEARCH. PROC. 1978 ENERGY TECHNOLOGY CONF. AND EXHIBITION, HOUSTON, TEXAS, NOV. 6-9, 1978 (PUB. AS MINING TECHNOLOGY FOR ENERGY RESOURCES - ADVANCES FOR THE 80S. THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, NEW YORK, 1979, PP. 35-46.

224. OROURKE, J. E., R. J. ESSEX, AND B. K. RANSON. FIELD PERMEABILITY TEST METHODS WITH APPLICATIONS TO SOLUTION MINING. WOODWARD-CLYDE CONSULTANTS (SAN DIEGO, CALIF.), CONTRACT NO. J0265045. BUMINES OPEN FILE REPT. 136-77, JULY 1977, 180 PP.; AVAILABLE FROM NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VA., PB 272 452/AS.

225. ORTLOFF, G. D., C. E. COOKE, JR., AND D. K. ATWOOD (ASSIGNED TO ESSO PRODUCTION RESEARCH COMPANY). MINERAL RECOVERY. U.S. PAT. 3,574.599, APR. 13, 1971.

226. PHILLIPS, P. EXPERIENCE WITH ACID LEACHING. PRES. AT SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978.

227. PHILLIPS, P. E. A COMPARISON OF OPEN PIT AND IN SITU LEACH ECONOMICS. PRES. AT URANIUM MINING TECHNOLOGY CONFERENCE, THE MACKAY SCHOOL OF MINES, UNIV. NEVADA--RENO, RENO, NEV., APR. 25-29, 1977, 12 PP.

228. PHILLIPS, P. E. ROCKY MOUNTAIN ENERGY'S EXPERIENCES WITH IN SITU LEACHING OF URANIUM WITH ACID. PROC. SOUTH TEXAS URANIUM SEM., CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978. AMERICAN INSITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC., NEW YORK, CH. 9, PT. 3, 1979, PP. 57-59.

229. PINGS, W. B. BACTERIAL LEACHING. MINER. IND. BULL., V. 2, NO. 3, MAY 1968, 19 PP.

230. POPOFF, D. R. BACTERIAL LEACHING MEANS NEW LIFE FOR MINE. CANADIAN NUCLEAR TECHNOLOGY, V. 5, NO. 4, JULY - AUGUST 1966, PP. 31-33.

231. POTTER, G. M. SOLUTION MINING. MIN. ENG., V. 21, NO. 1, FEBRUARY 1969, PP. 68-69.

232. POTTER, R. W., J. M. THOMPSON, M. A. CLYNNE, AND V. L. THURMOND. EQUILIBRIUM, KINETIC, AND CHROMATOGRAPHIC CONTROLS OF THE SOLUTION COMPOSITION OBTAINED DURING THE IN SITU LEACHING OF A URANIUM OREBODY. REPRINT FROM ACS SYMPOSIUM SERIES, NO. 93, NOV. 16, 1978, PP. 761-769.

233. POTTER, R. W., II. SOME GEOCHEMICAL PARAMETERS EFFECTING THE IN-SITU LEACHING OF URANIUM. U.S. GEOL. SURVEY OPEN-FILE REPORT 76-835, 1976, 24 PP.

234. POTTER, R. W., II, M. A. CLYNNE, J. M. THOMPSON, V. L. THURMOND, R. C. ERD, N. L. NEHRING, K. A. SMITH, P. J. LAMOTHE, AND J. L. SEELEY. CHEMICAL MONITORING OF THE IN-SITU LEACHING OF A SOUTH TEXAS URANIUM OREBODY. U.S. GEOL. SURVEY OPEN FILE REPT. 79-1144, 54 PP.; AVAILABLE FOR CONSULTATION AT THE U.S. GEOL. SURVEY OPEN FILE REPORTS SERVICES SECTION, BOX 25425, DENVER, COLO. 80225.

235. RABB, D. D. SOLUTION MINING. MIN. ENG., V. 24, NO. 2, FEBRUARY 1972, PP. 62-64.

236. RACKLEY, R. I. CONCEPTS AND METHODS OF URANIUM EXPLORATION. WYOMING GEO. ASSOC. GUIDEBOOK OF THE TWENTIETH ANN. FIELD CONF., CASPER, WYOMING, 1968, PP. 115-124.

237. REED, E. L. THE APPLICATION OF GROUNDWATER HYDROLOGY TO IN SITU LEACH MINING. PROC. SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978. AMERICAN INSITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC., NEW YORK, CH. 8, PT. 3, 1979, PP. 53-55.

238. RESOURCE ENGINEERING & DEVELOPMENT, INC. ANALYSIS OF GROUNDWATER CRITERIA AND RECENT RESTORATION ATTEMPTS AFTER IN SITU URANIUM LEACHING. V. 1, BUMINES CONTRACT NO. J0295019, FINAL DRAFT, OCTOBER 1980, 132 PP.

239. RHOADES, V. W. (ASSIGNED TO CITIES SERVICE OIL COMPANY, TULSA, OKLA.). URANIUM SOLUTION MINING PROCESS. U.S. PAT. 3,713,698, JAN. 30, 1973.

240. RHOADES, V. W. (ASSIGNED TO DALCO OIL COMPANY; UNITED STATES STEEL CORPORATION; PART INTEREST TO EACH). URANIUM SOLUTION MINING PROCESS. U.S. PAT. 3,792,903, FEB. 19, 1974.

241. RICKARD, R. S. CHEMICAL CONSTRAINTS ON IN-SITU LEACHING AND METAL RECOVERY. PROC. SOLUTION MINING SYMP., AIME ANN. MEETING, DALLAS, TEXAS, FEB. 25-27, 1974, PP. 185-192.

242. RIDING, J. R., F. J. ROSSWOG, T. D. CHATWIN, G. BUMA, AND D. R. TWEETON. GROUNDWATER RESTORATION FOR IN SITU SOLUTION MINING OF URANIUM. PRES. AT ANN. MEETING, SOC. MIN. ENG., AIME, NEW ORLEANS, LA., FEB. 18-22, 1979, PREPRINT 79-127, 24 PP.

243. ROBB, N., V. OPRATKO, AND L. S. PRICE. MILLIKENS TWO-STAGE SULPHURIC ACID LEACHING PROCESS FOR URANIUM ORES. CAN. MIN. AND MET. BULL., V. 56, NO. 614, JUNE 1963, PP. 476-479.

244. ROCKY MOUNTAIN ENERGY COMPANY. NINE MILE LAKE ENVIRONMENTAL REPORT. PREPARED FOR THE U.S. NUCLEAR REGULATORY COMMISSION, JANUARY 1979, 194 PP.; AVAILABLE FOR CONSULTATION AT U.S. NRC OFFICES IN WASHINGTON, D.C.

245. ROMAN, R. J. SOLUTION MINING. MIN. ENG., V. 26, NO. 2, FEBRUARY 1974, PP. 43-44.

246. ROOT, T. ENVIROMENTAL LAW ASPECTS OF EXTRACTING AND PROCESSING URANIUM. NATURAL RESOURCES LAWYER, 1979, 11(3); PP. 419-454.

247. ROOT, T. E. LEGAL ASPECTS OF MINING BY THE IN-SITU LEACHING METHOD. PRES. AT 22ND ANN. ROCKY MOUNTAIN MINERAL LAW INST., SUN VALLEY, IDAHO, JULY 22-24, 1976, 18 PP.

248. ROSENBAUM, J. B., AND D. R. GEORGE. COST REDUCTIONS IN ION EXCHANGE PROCESSING OF URANIUM ORES. INTERNAT. ATOMIC ENERGY AGENCY, IAEA-SM-135/24, 1971, PP. 297-309.

249. ROSHOLT, J. N., JR. URANIUM MIGRATION AND GEOCHEMISTRY OF URANIUM DEPOSITS IN SANDSTONE: ABOVE, AT, AND BELOW THE WATER TABLE. PART I. CALCULATION OF APPARANT DATES OF URANIUM MIGRATION IN DEPOSITS ABOVE AND AT THE WATER TABLE. ECON. GEOL., V. 56, 1961, PP. 1392-1403.

250. ROUSE, J. V. ENVIRONMENTAL ASPECTS OF IN SITU MINING AND DUMP LEACHING. PROC. SOLUTION MINING SYMP., AIME ANN. MEETING, DALLAS, TEXAS, FEB. 25-27, 1974, PP. 3-14.

251. ROUSE, J. V. ENVIRONMENTAL CONSIDERATIONS OF URANIUM MINING AND MILLING. MIN. ENG., V. 30, NO. 10, OCTOBER 1978, PP. 1433-1436.

252. ROWSWELL, M. D. SOLUTION MINING FOR URANIUM BEING PIONEERED AT AGNEW LAKE. THE NORTHERN MINER, V. 63, NO. 28, SEPT. 22, 1977, PP. C-2, C-5.

253. RUTLEDGE, C. IN-SITU URANIUM SOLUTION MINING--ENVIRONMENTAL AND LICENSING REGULATIONS. PRES. AT AAPG-SEPM ANN. CONVENTION, HOUSTON, TEXAS, APR. 1-4, 1979.

254. ST. PETER, A. L. IN SITU MINING -- A DESIGN FOR POSITIVE RESULTS. PRES. AT 105TH ANN. MEETING, AIME, LAS VEGAS, NEV., FEB. 22-26, 1976, PREPRINT 76-AS-36, 43 PP.

255. SAVANICK, G. A. BOREHOLE (SLURRY) MINING OF COAL AND URANIFEROUS SANDSTONE. PRES. AT 1979 AIME ANN. MEETING, FEB. 18-22, NEW ORLEANS, LA., SME PREPRINT 79-53, 11 PP.

256. SAVANICK, G. A. BOREHOLE(SLURRY) MINING OF COAL AND URANIFEROUS SANDSTONE. PROC. THIRD ANN. URANIUM SEMINAR WYOMING MIN. AND METALS SECTION OF AIME, CASPER, WYOMING, SEPT. 9-12, 1979, PP. 115-125.

257. SAVANICK, G. A. WATER JET PERFORATOR FOR URANIUM LEACHING WELLS. PRES. AT URANIUM MINING TECHNOLOGY CONFERENCE, THE MACKAY SCHOOL OF MINES, UNIV. NEVADA--RENO, RENO, NEV., APR. 25-29, 1977, 24 PP.

258. SAVANICK, G. A., AND W. G. KRAWZA. WELL PERFORATING METHOD FOR SOLUTION WELL MINING. U.S. PAT. 4,113,314, SEPT. 12, 1978.

259. SCHECHTER, R. S., AND P. M. BOMMER. POST IN-SITU URANIUM LEACHING SITE RESTORATION - NUMERICAL ANALYSIS. PRES. AT 54TH ANN. FALL TECHNICAL CONF. AND EXHIBITION OF SOC. OF PETROL. ENG. OF AIME, LAS VEGAS, NEVADA, SEPT. 23-26, 1979, SPE PREPRINT 8322, 11 PP.

260. SCHECHTER, R. S., AND P. M. BOMMER. OPTIMIZATION OF URANIUM LEACH MINING. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9488, 13 PP.

261. SCHECTER, R., M. P. WALSH, W. M. BRELAND, M. J. HUMENICK, I. H. SILBERBERG, AND A. D. HILL. RESTORATION OF URANIUM IN SITU LEACHING SITES. PRES. AT 53RD ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, HOUSTON, TEXAS, OCT. 1-3, 1978, SPE PREPRINT 7534, 8 PP.

262. SCHLITT, W. J., AND D. A. SHOCK. IN SITU URANIUM MINING AND GROUND WATER RESTORATION. SME OF AIME PROCEEDINGS OF THE NEW ORLEANS SYMP., FEB. 19, 1979, 137 PP.

263. SCHMIDT, D., AND W. FLOTER. URANGEWINNUNG DURCH SOLUTION MINING - VERFAHREN (EXTRACTION OF URANIUM BY THE SOLUTION MINING PROCESS). BRAUNKOHLE, HEFT 10, OCTOBER 1980, PP. 334-339.

264. SCHULTZ. KOSTEN DES SOLUTION MINING. DIPLOMARBEIT, UEB, BONN, W. GERMANY, 1980.

265. SEIDEL, D. C. STORED TECHNOLOGY FOR POSSIBLE USE IN URANIUM ORE PROCESSING. PRES. AT IAEA ADVISORY GROUP MEETING, WASHINGTON D.C., NOV. 24-28, 1975, PAPER NO. AG/33-7, 17 PP.

266. SHABBIR, M., AND K. E. TAME. HYDROGEN PEROXIDE PRECIPITATION OF URANIUM. BUMINES RI 7931, 1974, 13 PP.

267. SHARP, W. N., AND A. B. GIBBONS. GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN PART OF THE POWDER RIVER BASIN, WYOMING. U.S. GEOL. BULL. 1147-D, 1964, 5 PLATES (6 MAPS).

268. SHOCK, D. A. DEVELOPMENTS IN SOLUTION MINING PORTEND GREATER USE FOR IN SITU LEACHING. MIN. ENG., V. 22, NO. 2, FEBRUARY 1970, P. 73.

269. SHOCK, D. A. THE VAIL CONFERENCE ON IN SITU LEACHING OF URANIUM. IN SITU, V. 1, NO. 1, 1977, PP. 103-113.

270. SHOCK, D. A., AND F. R. CONLEY. SOLUTION MINING-ITS PROMISE AND ITS PROBLEMS. PROC. SOLUTION MINING SYMP., AIME ANN. MEETING, DALLAS, TEXAS, FEB. 25-27, 1974, PP. 79-97.

271. SHOCK, D. A., AND J. G. DAVIS. HYDROFRACING AS A MINING TECHNIQUE. PRES. AT ANN. MEETING, SOC. OF MIN. ENG., AIME, WASHINGTON, D.C., FEB. 16-20, 1969, AIME PREPRINT 69-AS-63, 25 PP.

272. SHOWALTER, W. E. (ASSIGNED TO UNION OIL COMPANY OF CALIFORNIA). PROCESS FOR RECOVERY OF MINERAL VALUES FROM UNDERGROUND FORMATIONS. U.S. PAT. 4,105,253, AUG. 8, 1978.

273. SHUCK, D. L. AN OVERVIEW OF SOLUTION MINING. PRES. AT URANIUM RESOURCE TECH. SEMINAR II, COLORADO SCHOOL OF MINES, GOLDEN, COLORADO, MAR. 12-14, 1979, 7 PP.

274. SIEVERT, J. A. (ASSIGNED TO CONTINENTAL OIL COMPANY, PONCA CITY, OKLA.). IN SITU MINING USING BACTERIA. U.S. PAT. 3,937,520, FEB. 10, 1976.

275. SIEVERT, J. A., W. L. MARTIN, AND F. R. CONLEY. IN SITU LEACHING OF URANIUM. PRES. AT SOC. OF MIN. ENG. FALL MEETING, ST. LOUIS, MO., OCT. 21-23, 1973, 18 PP.

276. SKILLINGS MINING REVIEW. NUCLEAR DYNAMICS TEST PLANT FOR URANIUM MINING. V. 66, NO. 22, MAY 28, 1977, P. 5.

277. SMITH, R. B. GEOLOGY OF SOUTH TEXAS URANIUM DEPOSITS. PROC. SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978. AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC., NEW YORK, CH. 6, PT. 2, 1979, PP. 45-46.

278. SMITH, R. B. THE THEORY OF MULTIPLE OXIDATION AND REDUCTION OF URANIUM DEPOSITS IN SOUTH TEXAS. PRES. AT URANIUM IN SITU SYMP., SOUTH TEXAS MINERALS SECT., AIME, CORPUS CHRISTI, TEX., SEPT. 25-28, 1977, 10 PP.

279. SPENCE, A. P. (ASSIGNED TO ATLANTIC RICHFIELD CO., NM URANIUM INC., AND U.S. STEEL CORP.). METHOD FOR THE RECOVERY OF A MINERAL. U.S. PAT. 4,082,359, APR. 4, 1978.

280. STONE AND WEBSTER ENGINEERING CORPORATION, DENVER, COLORADO. ADMINISTRATORS GUIDE FOR SOLUTION MINING OF URANIUM. PREPARED FOR WESTERN INTERSTATE ENERGY BOARD/WINB, FORMERLY THE WESTERN INTERSTATE NUCLEAR BOARD, UNDER CONTRACT TO THE U.S. ENVIRONMENTAL PROTECTION AGENCY, CONTRACT NO. 68-01-4490, MAY 1979, 92 PP.; AVAILABLE FROM THE NATIONAL TECHNICAL INFORMATION SERVICE PB-301 173.

281. STOVER, D. E. (ASSIGNED TO ATLANTIC RICHFIELD CO.). METHOD FOR THE RESTORATION OF AN UNDERGROUND RESERVOIR. U.S. PAT. 4,108,722, AUG. 22, 1978.

282. STOVER, D. E. EVALUATING URANIUM DEPOSITS FOR SOLUTION MINING. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9504. 6 PP.

283. SUNDAR, P. S. IN-SITU LEACHING SIMULATION STUDIES OF URANIUM ORES--PHASES I THROUGH III. WESTINGHOUSE RESEARCH AND DEVELOPMENT CENTER, 1310 BEULAH ROAD, PITTSBURGH, PENN., BUMINES CONTRACT NO. H0262004, JUNE 1977, 392 PP. AVAILABLE FROM NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VA., PB 272 717.

284. SUNDAR, P. S. IN-SITU LEACHING SIMULATION STUDIES OF URANIUM ORES. PRES. AT 1978 ANN. MEETING, DENVER, COLO. FEB. 28 - MAR. 2, 1978, SME PREPRINT 78-AS-102, 16 PP.

285. SUNDIN, R. E. REGULATIONS ON IN SITU URANIUM MINES IN WYOMING. PROC. THIRD ANN. URANIUM SEMINAR, WYOMING MIN. AND METALS SECTION OF AIME, CASPER, WYOMING, SEPT. 9-12, 1979, PP. 3-4.

286. TAYLOR, W. P. GROUND WATER QUALITY PROTECTION IN IN SITU URANIUM MINES. PROC. OF NEW ORLEANS SYMP. OF SOC. MIN. ENG., AIME, NEW ORLEANS, LA., FEB. 18-22, 1979 (PUB. AS IN SITU URANIUM MINING AND GROUND WATER RESTORATION, ED. BY W. J. SCHLITT AND D. A. SHOCK), PP. 1-5; SME PREPRINT 79-10, 3 PP.

287. TAYLOR, W. P. REGULATION OF IN SITU URANIUM MINING FOR PURPOSES OF PROTECTING GROUNDWATER QUALITY. PRES. AT URANIUM IN SITU SYMP., SOUTH TEXAS MINERALS SECT., SOC. PETROL. ENG., AIME, CORPUS CHRISTI, TEX., SEPT. 25-28, 1977, PREPRINT 7536, 12 PP.

288. TERRY, G. A. ENVIRONMENTAL ASSESSMENT OF IN-SITU LEACHING OF URANIUM. PRES. AT AAPG-SEMP ANN. CONVENTION, HOUSTON, TEXAS, APR. 1-4, 1979.

289. TERRY, R. C. (ASSIGNED TO IN SITU TECHNOLOGY, INC., DENVER, COLO.). RECOVERING URANIUM FROM COAL IN SITU. U.S. PAT. 4,113,313, SEPT. 12, 1978.

290. TEXAS DEPARTMENT OF WATER RESOURCES. PERMIT TO CONDUCT UNDERGROUND INJECTION. LONGORIA MINING PROJECT, PERMIT NO. 02222, 1979, 6 PP.

291. TEXAS DEPARTMENT OF WATER RESOURCES. NONDISCHARGE PERMIT NO. 02051 ISSUED TO UNION CARBIDE CORPORATION FOR A FULL SCALE IN SITU URANIUM LEACHING OPERATION IN DUVAL COUNTY, TEXAS. PERMIT ISSUED JANUARY 1977.

292. TEXAS DEPARTMENT OF WATER RESOURCES. NONDISCHARGE PERMIT NO. 01941 ISSUED TO MOBIL OIL COMPANY FOR A FULL SCALE IN SITU URANIUM LEACHING OPERATION IN WEBB COUNTY, TEXAS. PERMIT ISSUED JUNE 1975.

293. TEXAS DEPARTMENT OF WATER RESOURCES. NONDISCHARGE PERMIT NO. 01942 ISSUED TO WYOMING MINERAL CORPORATION FOR A FULL SCALE IN SITU URANIUM LEACHING OPERATION IN WEBB COUNTY, TEXAS. PERMIT ISSUED JUNE 1975.

294. TEXAS DEPARTMENT OF WATER RESOURCES. NONDISCHARGE PERMIT NO. 01949 ISSUED TO WYOMING MINERAL CORPORATION FOR A FULL SCALE IN SITU URANIUM LEACHING OPERATION IN LIVE OAK COUNTY, TEXAS. PERMIT ISSUED AUGUST 1975.

295. TEXAS DEPARTMENT OF WATER RESOURCES. NONDISCHARGE PERMIT NO. 02050 ISSUED TO INTERCONTINENTAL ENERGY CORPORATION FOR A FULL SCALE IN SITU URANIUM LEACHING OPERATION IN BEE COUNTY, TEXAS. PERMIT ISSUED JANUARY 1975.

296. TEXAS DEPARTMENT OF WATER RESOURCES. NONDISCHARGE PERMIT NO. 01890 ISSUED TO ATLANTIC RICHFIELD COMPANY (OPERATION NOW U.S. STEEL) FOR A FULL SCALE IN SITU URANIUM LEACHING OPERATION IN LIVE OAK COUNTY, TEXAS. PERMIT ISSUED JANUARY 1975.

297. TEXAS DEPARTMENT OF WATER RESOURCES. NONDISCHARGE PERMIT NO. 02025 ISSUED TO U.S. STEEL CORPORATION FOR A FULL SCALE IN SITU URANIUM LEACHING OPERATION IN LIVE OAK COUNTY, TEXAS. PERMIT ISSUED AUGUST 1976.

298. TEXAS DEPARTMENT OF WATER RESOURCES. NONDISCHARGE PERMIT NO. 02130 ISSUED TO U.S. STEEL CORPORATION FOR A FULL SCALE IN SITU URANIUM LEACHING OPERATION IN LIVE OAK COUNTY, TEXAS. PERMIT ISSUED DECEMBER 1977.

299. TEXAS URANIUM OPERATIONS - U.S. STEEL CORPORATION. APPLICTION FOR IN SITU URANIUM MINE PRODUCTION AREA AUTHORIZATION - PAWLIK MINE. 1980, 81 PP.

300. THIEDE, D. M., AND D. W. WALKER. SOUTH TEXAS URANIUM LEACH DRILLING AND COMPLETION TECHNOLOGY. PRES. AT URANIUM IN SITU SYMP., SOUTH TEXAS MINERALS SECT., AIME, CORPUS CHRISTI, TEX., SEPT. 25-28, 1977, 17 PP.

301. THOMPSON, W. E., W. V. SWARZENSKI, D. L. WARNER, G. E. ROUSE, O. F. CARRINGTON, AND R. Z. PYRIH. GROUNDWATER ELEMENTS OF IN SITU LEACH MINING OF URANIUM. GERAGHTY AND MILLER, INC. (TAMPA, FLORIDA), PREPARED FOR U.S. NUCLEAR REGULATORY COMMISSION UNDER CONTRACT NO. NRC-02-77-187, AUGUST 1978, 173 PP.; AVAILABLE FROM NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VA., NTIS NO. NUREG/CR-0311, $9.00.

302. TIEPEL, E. IN-SITU MINING OF URANIUM, GROUNDWATER RESTORATION METHODS AND FIELD TEST DATA. PRES. AT SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978.

303. TIMMONS, T. PILOT TESTING IN-SITU LEACH IN TEXAS AND NEW MEXICO. PRES. AT SOUTH TEXAS URAINIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978.

304. TOTH, G. W. COST ESTIMATING TECHNIQUE FOR URANIUM SOLUTION MINING PROJECTS. PRES. AT NORTHWEST MIN. ASSOC. 83RD ANN. CONVENTION, SPOKANE, WASHINGTON, DEC. 2, 1977, 38 PP.; AVAILABLE FROM NUS CORP., 4 RESEARCH PLACE, ROCKVILLE, MARYLAND 20850.

305. TOTH, G. W. A COST MODEL FOR URANIUM SOLUTION MINING. PROC. UPDATE ON URANIUM MINING TECHNOL. CONF., RENO, NEVADA, NOV. 13-17, 1978 (PUB. AS URANIUM MINING TECHNOLOGY, ED. BY Y. S. KIM), SECTION V, 42 PP.

306. TRAUT, D. E., I. L. NICHOLS, AND D. C. SEIDEL. DESIGN CRITERIA FOR URANIUM ION EXCHANGE IN A FLUIDIZED SYSTEM. TRANS. SOC. OF MIN. ENG., AIME, V. 260, MARCH 1976, PP. 24-28.

307. TRAUT, D. E., I. L. NICHOLS, AND D. C. SEIDEL. DESIGN REQUIREMENTS FOR URANIUM ION EXCHANGE FROM ACIDIC SOLUTIONS IN A FLUIDIZED SYSTEM. BUMINES RI 8282, 1978, 29 PP.

308. TRAUT, D. E., I. L. NICHOLS, AND D. C. SEIDEL. DESIGN REQUIREMENTS FOR URANIUM ION EXCHANGE FROM AMMONIUM BICARBONATE SOLUTIONS IN A FLUIDIZED SYSTEM. BUMINES RI 8280, 1978, 27 PP.

309. TRUSSELL, P. C., D. W. DUNCAN, AND C. C. WALDEN. BIOLOGICAL MINING. CAN. MIN. J., V. 85, NO. 3, MARCH 1964, PP. 46-49.

310. TUOVINEN, O. H. MICROBIOLOGICAL ASPECTS IN THE LEACHING OF URANIUM BY THIOBACILLUS FERROOXIDANS. ATOMIC ENERGY REVIEW, V. 10, NO. 2, 1972, PP. 251-258.

311. TWEETON, D. R., G. R. ANDERSON, J. K. AHLNESS, O. M. PETERSON, AND W. H. ENGELMANN. GEOCHEMICAL CHANGES DURING IN SITU URANIUM LEACHING WITH ACID. PROC. OF NEW ORLEANS SYMP. OF SOC. MIN. ENG., AIME, NEW ORLEANS, LA., FEB. 18-22, 1979 (PUB. AS IN SITU URANIUM MINING AND GROUND WATER RESTORATION, ED. BY W. J. SCHLITT AND D. A. SHOCK), PP. 23-51; SME PREPRINT 79-43, 27 PP.

312. TWEETON, D. R., G. R. ANDERSON, AND W. H. ENGELMANN. BUREAU OF MINES RESEARCH IN INJECTION WELL CONSTRUCTION AND ENVIRONMENTAL ASPECTS OF IN SITU URANIUM LEACHING. PRES. AT 1978 AIME ANN. MEETING, DENVER, COLO., FEB. 26-MAR. 2, 1978, PREPRINT 78-AS-111, 8 PP.

313. TWEETON, D. R., AND K. CONNOR. WELL CONSTRUCTION INFORMATION FOR IN SITU URANIUM LEACHING. BUMINES IC 8769, 1978, 19 PP.

314. TWEETON, D. R., AND K. A. PETERSON. SELECTION OF LIXIVIANTS FOR IN SITU URANIUM LEACHING. BUMINES IC.

315. TWEETON, D. R., T. R. GUILINGER, W. M. BRELAND, AND R. SCHECTER. THE ADVANTAGES OF CONDITIONING AN OREBODY WITH A CHLORIDE SOLUTION BEFORE IN SITU URANIUM LEACHING WITH A CARBONATE SOLUTION. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9490, 4 PP.

316. U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION. NATIONAL URANIUM RESOURCE EVALUATION PRELIMINARY REPORT. GRAND JUNCTION OFFICE, GRAND JUNCTION, COLO., REPT. GJO-111(76), JUNE 1976, 132 PP.

317. U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION. STATISTICAL DATA OF THE URANIUM INDUSTRY. GRAND JUNCTION OFFICE, GRAND JUNCTION, COLO., REPT. GJO-100(76), APRIL 1976, 87 PP.

318. U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION. STATISTICAL DATA OF THE URANIUM INDUSTRY. GRAND JUNCTION OFFICE, GRAND JUNCTION, COLO., REPT. NO. GJO-100(77), JAN. 1, 1977, 107 PP.

319. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT PILOT SCALE IN SITU URANIUM LEACH MINING TESTS, CAMPBELL COUNTY, WYOMING. DOCKET NO. 40-8200, SOURCE MATERIAL LICENSE NO. SUA-1199, ISSUED TO CLEVELAND CLIFFS IRON COMPANY, MAY 1974.

320. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT PILOT SCALE IN SITU URANIUM LEACH MINING TESTS, JOHNSON COUNTY, WYOMING. DOCKET NO. 40-8511, SOURCE MATERIAL LICENSE NO. SUA-1273, ISSUED TO COTTER CORPORATION (FORMERLY OPERATED BY URANERZ, U.S.A.), JUNE 1976.

321. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT PILOT SCALE IN SITU URANIUM LEACH MINING TESTS, HIGHLAND URANIUM OPERATIONS, CONVERSE COUNTY, WYOMING. DOCKET NO. 40-8064, SOURCE MATERIAL LICENSE NO. SUA-1064, ISSUED TO HUMBLE OIL AND REFINING COMPANY (NOW EXXON COMPANY, U.S.A.), NOVEMBER 1970.

322. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT A FULL SCALE IN SITU URANIUM LEACH MINING OPERATION, HIGHLAND URANIUM OPERATION, CONVERSE COUNTY, WYOMING. DOCKET NO. 40-8102, AS AMENDMENT TO SOURCE MATERIAL LICENSE SUA-1139, ISSUED TO EXXON COMPANY, U.S.A., AUGUST 1977.

323. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT PILOT SCALE IN SITU URANIUM LEACH MINING TESTS, SHIRLEY BASIN, WYOMING. DOCKET NO. 40-8586, SUBMITTED BY KERR MCGEE NUCLEAR CORPORATION, NOVEMBER 1976.

324. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT PILOT SCALE IN SITU URANIUM LEACH MINING TESTS, SWEETWATER COUNTY, WYOMING. DOCKET NO. 40-8348, SOURCE MATERIAL LICENSE NO. SUA-1223, ISSUED TO MINERALS EXPLORATION COMPANY, DECEMBER 1974.

325. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT PILOT SCALE IN SITU URANIUM LEACH MINING TESTS, CROOK COUNTY, WYOMING. DOCKET NO. 40-8663, SUBMITTED BY NUCLEAR DYNAMICS, NOVEMBER 1977.

326. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT PILOT SCALE IN SITU URANIUM LEACH MINING TESTS. CONVERSE AND NATRONA COUNTIES. WYOMING. DOCKET NO. 40-8380, SOURCE MATERIAL LICENSE SUA-1228, ISSUED TO ROCKY MOUNTAIN ENERGY CORPORATION, FEBRUARY 1975.

327. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT PILOT SCALE IN SITU URANIUM LEACH MINING TESTS, SWEETWATER COUNTY, WYOMING. DOCKET NO. 40-8636, SUBMITTED BY WOLD NUCLEAR COMPANY, JUNE 1977.

328. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT PILOT SCALE IN SITU URANIUM LEACH MINING TESTS, JOHNSON COUNTY, WYOMING. DOCKET NO. 40-8304, SOURCE MATERIAL LICENSE NO. SUA-1204, ISSUED TO WYOMING MINERAL CORPORATION, SUBMITTED JULY 1974.

329. U.S. NUCLEAR REGULATORY COMMISSION. APPLICATION TO CONDUCT A FULL SCALE IN SITU URANIUM LEACH MINING OPERATION, JOHNSON COUNTY, WYOMING. DOCKET NO. 40-8502, SUBMITTED BY WYOMING MINERAL CORPORATION, SEPTEMBER 1977.

330. URANIUM RESOURCES INC. APPLICATION AND TECHNICAL REPORT. BENAVIDES IN SITU URANIUM LEACH PROJECT. 1979, 162 PP.

331. URANIUM RESOURCES INC. APPLICATION AND TECHNICAL REPORT. LONGORIA IN SITU LEACH PROJECT. 1978. 175 PP.

332. WADSWORTH, M. E., J. MILBOURNE, AND S. Y. HAN. A KINETIC STUDY OF THE CARBONATE LEACHING OF URANIUM ORE WITH HYDROGEN PEROXIDE AND OXYGEN. TO BE PRES. AT AIME ANN. MEETING, NEW ORLEANS, LA., FEB. 18-22, 1979.

333. WALLACE, R. E. ASPECTS OF IN SITU SOLUTION MINING OF URANIUM. PRES. AT ANN. MEETING OF THE ARIZONA CONF. OF AIME, DEC. 3-4, 1978, 6 PP.

334. WALSH, M. P., W. M. BRELAND, R. S. SCHECHTER, AND J. M. HUMENICK. MULTICOMPONENT ION EXCHANGE AT IN SITU URANIUM SOLUTION MINING SITES. TECH. REPORT EHF-79-06, UNIV. TEXAS, AUSTIN, TEX., 1979, 103 PP.

335. WALSH, M. P., R. S. SCHECHTER, AND M. J. HUMENICK. CATION EXCHANGE PROCESSES IN THE CHROMATOGRAPHIC MOVEMENT OF AMMONIUM: APPLICATION TO RESTORATION OF URANIUM IN SITU LEACHING SITES. PRES. AT AIME ANN. MEETING, NEW ORLEANS, LA., FEB. 18-22, 1979, SME PREPRINT 79-73.

336. WALSH, M. P., R. S. SCHECHTER, AND M. J. HUMENICK. THE DISPLACEMENT AND MIGRATION OF AMMONIUM IONS FROM URANIUM IN SITU LEACHING SITES. PROC. OF NEW ORLEANS SYMP. OF SOC. MIN. ENG., AIME, NEW ORLEANS, LA., FEB. 18-22, 1979 (PUB. AS IN SITU URANIUM MINING AND GROUND WATER RESTORATION, ED. BY W. J. SCHLITT AND D. A. SHOCK), PP. 99-111; SME PREPRINT 79-73. 12 PP.

337. WALSH, M. P., R. S. SCHECHTER, M. J. HUMENICK, A. D. HILL, AND I. H. SILVERBERG. A MODEL FOR PREDICTING THE RESTORATION OF AND AMMONIUM MIGRATION FROM IN SITU MINE SITES. PROC. SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978. AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC., NEW YORK, CH. 4, PT. 1, 1979, PP. 29-38.

338. WARD, M. H. ENGINEERING FOR IN SITU LEACHING. MIN. CONG. J., V. 59, NO. 1, JANUARY 1973, PP. 21-27.

339. WESTINGHOUSE ELECTRIC CORP. SOLUTION MINING OF URANIUM. REPORT 5923, 3 PP.; AVAILABLE FROM WESTINGHOUSE ELECTRIC CORP., NUCLEAR FUEL DIVISION, BOX 355, PITTSBURGH, PA. 15230.

340. WESTINGHOUSE ELECTRIC CORP. URANIUM SOLUTION MINING. 1975, 16 PP.; AVAILABLE FROM WESTINGHOUSE ELECTRIC CORP., NUCLEAR FUEL DIVISION, BOX 355, PITTSBURGH, PA. 15230.

341. WESTINGHOUSE RESEARCH LABORATORIES. CORRELATION OF ROCK STRUCTURE WITH URANIUM RESERVES. TECH. REPORT 5M792, NOVEMBER 1975, 4 PP.; AVAILABLE FROM WESTINGHOUSE ELECTRIC CORP., NUCLEAR FUEL DIVISION, BOX 355, PITTSBURGH, PA. 15230.

342. WESTINGHOUSE ELECTRIC CORPORATION. DETECTION OF LIXIVIANT EXCURSIONS WITH GEOPHYSICAL RESISTANCE MEASUREMENTS DURING IN SITU URANIUM LEACHING. BUMINES CONTRACT NO. J0188080, FINAL REPORT, DECEMBER 1979, 156 PP.

343. WHITE, G., JR. URANIUM: CONTINUED PRICE STABILITY SEEN FOR 1979, AS SUPPLY AND DEMAND STAY IN BALANCE. ENG. AND MIN. J., V. 180, NO. 3, MARCH 1979, PP. 145-147.

344. WHITE, L. IN SITU LEACHING OPENS NEW URANIUM RESERVES IN TEXAS. ENG. AND MIN. J., V. 176, NO. 7, JULY 1975, PP. 73-80.

345. WHITE, L. WYOMING URANIUM MINERS SET SIGHTS ON HIGHER PRODUCTION. ENG. AND MIN. J., V. 152, NO. 12, DECEMBER 1975, PP. 61-71.

346. WHITING, D. L. HYDROLOGY OF DUMP LEACHING AND IN SITU SOLUTION MINING. PRES. AT SME-AIME FALL MEETING, ST. LOUIS, MO., OCT. 19-21, 1977, PREPRINT 77-AS-336, 37 PP.

347. WHITTINGTON, D., AND W. R. TAYLOR. REGULATIONS AND RESTORATION OF IN SITU URANIUM MINES IN TEXAS. PROC. SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978. AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC., NEW YORK, CH. 2, PT. 1, 1979, PP. 7-10.

348. WILLIAMS, R. L., P. SMITH, AND P. OSBORNE. THE ENVIRONMENT, EPA, AND THE IN SITU MINING OF URANIUM. PROC. THIRD ANN. URANIUM SEMINAR, WYOMING MIN. AND METALS SECTION OF AIME, CASPER, WYOMING, SEPT. 9-12, 1979, PP. 5-10.

349. WINKLEY, D. C. THE EFFECT OF URANIUM LEACH CONDITIONS ON THE KINETICS OF HYDROGEN PEROXIDE REACTIONS. PROC. UPDATE ON URANIUM MINING TECHNOL. CONF., RENO, NEVADA, NOV. 13-17, 1978 (PUB. AS URANIUM MINING TECHNOLOGY, ED. BY Y. S. KIM), SECTION X, 14 PP.

350. WINTERS, H. J., C. K. CHASE, AND R. B. BHAPPU. TECHNICAL NOTES ECONOMIC EVALUATION FOR IN SITU EXTRACTION OF URANIUM. PRES. AT 104TH AIME ANN. MEETING, NEW YORK, FEB. 16-20, 1975, 5 PP.

351. WOOD, S. CHARACTERIZATION OF THE URANIUM OCCURENCE IN PRE- AND POST-LEACH ORE SAMPLES FROM SANDSTONE DEPOSITS IN TEXAS & WYOMING. PRES. AT THE 53RD ANN. FALL TECH. CONF. AND EXHIBITION, SPE, AIME, HOUSTON, TEXAS, OCT. 1-3, 1978, SPE PREPRINT 7537, 8 PP.

352. WOOLERY, R. G. PROCESSING MARGINAL URANIUM RESERVES. PRES. AT URANIUM RESOURCE TECH. SEMINAR II, COLORADO SCHOOL OF MINES, GOLDEN, COLORADO, MAR. 12-14, 1979, 10 PP.

353. WOOLERY, R. G., D. J. HANSEN, J. A. WEBER, AND S. RAMACHANDRAN. HEAP LEACHING OF URANIUM -- A CASE HISTORY. PRES. AT 107TH ANN. MEETING, AIME, ATLANTA, GA., MAR. 6-10, 1977, PREPRINT 77-AS-93, 20 PP.

354. WOOLERY, R. G., AND S. RAMACHANDRAN. AN ALKALINE HEAP LEACH EVALUATION. PROC. SOUTH TEXAS URANIUM SEMINAR, CORPUS CHRISTI, TEXAS, SEPT. 10-13, 1978. AMERICAN INSTITUTE OF MINING, METALLURGICAL, AND PETROLEUM ENGINEERS, INC., NEW YORK, CH. 14, PT. 4, 1979, PP. 87-90.

355. WYOMING MINERAL CORP. URANIUM SOLUTION MINING. 1976, 12 PP.: AVAILABLE FROM WYOMING MINERAL CORP., 3900 S. WADSWORTH BLVD., LAKEWOOD, COLO. 80235.

356. WYRICK, R. SOLUTION MINING IN OLD STOPES. PRES. AT URANIUM MIN. TECHNOL. CONF., THE MACKAY SCHOOL OF MINES, UNIV. NEVADA-RENO, RENO, NEVADA, APR. 25-29, 1977, 16 PP.

357. YAN, T. A METHOD FOR REMOVING AMMONIUM IONS FROM SUBTERRANEAN FORMATION AFTER IN SITU URANIUM LEACHING. PRES. AT THE 55TH ANN. FALL TECH. CONF. AND EXIBITION, SPE, AIME, DALLAS, TEXAS, SEPT. 21-24, 1980, SPE PREPRINT 9491, 7 PP.

U.S. BUREAU OF MINES
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1. Adams, J. A., and J. E. Oddo. Geological Trade-offs in Uranium Solution Mining. Pres. at AAPG-SEPM Ann. Convention, Houston, Texas, Apr. 1-4, 1979.

2. Adler, H. H. Concepts of Genesis of Sandstone-type Uranium Ore Deposits. Econ. Geol., V. 58, No. 6, 1963, pp. 839-851.

3. Alvarez, J. J. The Elution and Precipitation Systems at URI's In Situ Solution Mining Plants. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

4. Amell, A. R., and D. Langmuir. Factors Influencing the Solution Rate of Uranium Dioxide under Conditions Applicable to In Situ Leaching. Final Rept. of Bumines Contract No. H0272019, Nov. 20, 1978, 124 PP.; Available for Consultation at Twin Cities Mining Research Center, Twin Cities, Minnesota.

5. Anderson, J. S., and M. I. Richie. Solution Mining of Uranium. Min. Cong. J., V. 54, No. 1, January 1968, pp. 20-23, 26.

6. Annamalai, V., and F. X. Mcgarvey. Operating Experience in the Recovery of Uranium at the Pawnee and Zamzow Sites. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Tex., Sept. 21-24, 1980, SPE Preprint 9507, 14 pp.

7. Bakhurov, V. G., S. G. Vecherkin, and I. K. Lutsenko. Podzemnoe Vysmchelacivanie Uranovykh Rud (Underground Leaching of Uranium Ores). Atomizdat, Moscow, 1969, 151 pp.

8. Ballard, J. K. Solution Mining. Min. Eng., V. 23, No. 2, February 1971, p. 109.

9. Barnes, F. Q. Uranium--Where are the Reserves? Min. Cong. J., V. 62, No. 2, February 1976, pp. 28-33.

10. Becherkin, S. G., V. G. Bakhurov, and I. K. Lutsenko. Underground Leaching of Uranium from Low-grade In-Situ Ores. Soviet Atomic Energy, V. 21, No. 2, February 1968, pp. 128-133.

11. Berg, D. New Uranium Recovery Techniques. Pres. at Atomic Ind. Forum Internat. Conf. On Uranium, Geneva, Sept. 13-16, 1976, 13 pp.

12. Bhappu, R. B. Economic Evaluation of In Place Leaching and Solution Mining Situations. Pres. at a Short Course in In-Place Leaching and Solution Mining, the Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Nov. 10-14, 1975, 22 pp.

13. Bhappu, R. B. In Situ Extraction and Leaching Technology. Pres. at Inter-Regional Seminar on the Economics of Mineral Engineering, Ankara, Turkey, Apr. 5-16, 1976, 39 pp.

14. Bhappu, R. B. In Situ Mining Technology - Practical and Economic Aspects. Pres. at the Turkish Mining Institute, Ankara, Turkey, Apr. 5-16, 1976, 29 pp.

15. Bishop, A. L. Non-Production Zone Excursion: Detection and Correction. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

16. Bommer, P. M. A Streamline-Concentration Balance Model for In-Situ Uranium Leaching and Site Restoration. Ph.d. Dissertation, University of Texas at Austin, Austin, Texas, August 1978.

17. Bommer, P. M., and R. S. Schechter. Mathematical Modeling of In-Situ Uranium Leaching. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 54-66; SME Preprint 79-28, 13 pp.

18. Bommer, P. M., and R. S. Schechter. Mathematical Modeling of In-Situ Uranium Leaching. Soc. Petrol. Eng. J., V. 19, No. 7, December 1979, pp. 393-400.

19. Bommer, P. M., and R. S. Schechter. Post In-Situ Uranium Leaching Site Restoration-Numerical Analysis. Univ. Texas, Austin, Tex. [in press]

20. Borkert, J. J., Jr. Evaluation of a Uranium In-Situ Leaching Project. Planning and Analysis Div., U.S. Energy Res. and Dev. Admin., Grand Junction, Co., February 1975, 47 pp.

21. Borkert, J. J., and C. E. Gerity. An Economic Analysis of Open-Pit and In Situ Mining. Min. Eng., V. 30, No. 10, October 1978, pp. 1420-1422.

22. Borkert, J. J., and C. E. Gerity. The Economics of In Situ Mining Versus Open Pit Mining. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 18, Pt. 5, 1979, pp. 107-112.

23. Bossler, J. F., and R. F. Janke. Ion Exchange Resin Evaluation in Uranium Recovery. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 13, Pt. 4, 1979, pp. 79-86.

24. Boyce, T. D. The Relationship Between Ion Exchange Resin Properties and Uranium Recovery in Fluidized Bed Columns. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9508, 8 pp.

25. Brierley, C. L. Biogenic Extraction of Uranium from Ores of the Grants Region. Proc. Internat. Symp. on Metallurgical Applications of Bacterial Leaching and Academic Press, Inc., New York, 1977, pp. 345-363.

26. Brierley, C. L. Microbiology and Uranium Mining: Practices and Problems. Proc. Third Ann. Uranium Sem., Wyoming Min. and Metals Sect., AIME, Casper, Wyo., Sept. 9-12, 1979, pp. 129-133.

27. Brierley, C. L., J. A. Brierley, P. R. Norris, and D. P. Kelly. Metal-Tolerant Microorganisms of Hot, Acid Environments. Tech. Series Pub., No. 14, Soc. for Applied Bacteriology, [in Press].

28. Brown, M. R. Kerr Gets First Sales Contract for Uranium for Agnew Lake Mine Production. The Northern Miner, V. 62, No. 18, July 15, 1976, p. 1.

29. Buma, G. Geochemical Arguments for Natural Stabilization Following In-Situ Leaching of Uranium. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shcok), pp. 113-124.

30. Buma, G. Property Evaluation Procedures for In-Situ Leaching of Uranium. Rocky Mt. Geochemical Corp., Apr. 29, 1977, 20 pp.; Available from P.O. Box 337, Midvale, Utah 84047.

31. Buma, G. Uranium Solution Mining State of the Art. Pres. at Energy Technology Conf. and Exhibit, Petrol. Div. of Soc. Mech. Eng., AIME, Houston, Tex., Sept. 18-22, 1977, Preprint 77-PET-47, 11 pp.

32. Bunker, C. M., and J. A. Mackallon. Geology of the Oxidized Uranium Ore Deposits of the Tordilla Hill-Deweesville Area, Karnes County, Texas: A Study of a District Before Mining. U.S. Geol. Survey Paper No. 465, 1973, 37 pp.

33. Carlson, R. H. The Effect of Uranium Leach Conditions on the Kinetics of Hydrogen Peroxide Reactions. Pres. at South Texas Uranium Symp., Corpus Christi, Tex., Sept. 25-28, 1977. [in press]

34. Carlson, R. H. New Techniques for Measuring Oxidant Effectiveness in In Situ Uranium Leaching. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

35. Carlson, R. H., R. D. Norris, and R. Schellinger. Oxidant Effectiveness in In Situ Uranium Leaching. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

36. Carlson, R. H., R. D. Norris, and R. Schellinger. The Role of Oxidizing Agent in the Chemistry of In Situ Uranium Leaching. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Tex., Sept. 21-24, 1980, SPE Preprint 9483, 16 pp.

37. Carnahan, T. G. (Reno Metallurgy Research Center). In Situ Leaching of Uranium. Pres. at the In-Place Leaching and Solution Mining Short Course, Incline Village, Nevada, Nov. 10-14, 1975, 18 pp.

38. Carnine, G. T., and L. R. Darbee (assigned to FMC Corporation, New York, N.Y., a corp. of Del.). Stabilization of Hydrogen Peroxide. U.S. Pat. 3,383,174, May 14, 1968.

39. Carpenter, R. H., and R. B. Bhappu. Hydrometallurgy and Low Grade Ore Potential. Pres. at 107th Ann. Meeting, AIME, Atlanta, Ga., Mar. 6-10, 1977.

40. Chamberlain, P. G. Evaluating Ore Bodies for Leaching with Permeability Measurements. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 7-22; Preprint 79-27, 14 pp.

41. Chamberlain, P. G. Field Permeability Methods for In-Place Leaching. Min. Cong. J., V. 64, No. 9, September 1978, pp. 22-25.

42. Chapman, Wood, and Griswold, Inc. Geologic Map of Grants Uranium Region. New Mexico Bureau of Mines and Mineral Resources, Circ. 31, 1977, 3 pp.

43. Charley, W. R. Economic Considerations of Solution Mining. Pres. at Uranium Resource/Tech. Seminar II, Colorado School of Mines, Golden, Colo., Mar. 12-14, 1979, 13 pp.

44. Chase, C. K., H. J. Winters, and R. B. Bhappu. Economic Evaluation of In Situ Extraction of Uranium. Pres. at Am. Nuclear Soc. Meeting, Golden, Colo., Apr. 12-14, 1977, 12 PP.; Available from C. K. Chase, Mountain States Research and Development, P.O. Box 17960, Tucson, Arizona 85731.

45. Chatterji, B. D., A. S. Deshpande, C. V. Sharma, S. C. Kulshrestha, and R. N. Sankran. Results of Some Beneficiation and Lixiviation Tests on Medium-Grade Uranium Ore in Quartzite from Chhinjra, Kulu District, Himachal Pradesh. Proc. of the Indian National Science Academy, V. 36, A, No. 6, 1970.

46. Chemical Week. New Solution Cuts Uranium Mining Costs. V. 29, Dec. 24, 1975, pp. 28-29.

47. Chemical Week. Scowl, Then A Smile for Solution Mining. Feb. 2, 1977, pp. 13-14.

48. Clark, D. A. State-Of-The-Art. Uranium Mining, Milling, and Refining Industry. U.S. Environmental Protection Agency Rept. EPA-660/2-74-038, June 1974, 113 pp.

49. Coleman, K. A., and G. W. Stewart. New Mexico's First Uranium In Situ Solution Project. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Tex., Sept. 21-24, 1980, SPE Preprint 9489, 8 pp.

50. Colorado Department of Health. Source Material License Issued to Wyoming Mineral Corporation for a Pilot Scale In Situ Uranium Leaching Operation in Weld County, Colorado. Permit Issued for One Year, October 1976 - October 1977.

51. Conine, W. D. Uranium Solution Mining: A Comparision of New Mexico with South Texas. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Sect., AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 126-128.

52. Cook, L. M. The Uranium District of the Texas Gulf Coastal Plain. Texas Department of Health, Austin, Texas. Apr. 28, 1978, 14 pp.

53. Cooperstein, R. Presentations at Seminar on In Situ Uranium Solution Extraction. Pres. at Seminar on In Situ Uranium Mining for Regulatory Personnel, Corpus Christi, Texas, Mar. 6-9, 1979, 65 pp.

54. Cooperstein, R. Safety Evaluation Report Source Material License W.M.CO., Docket No. 40-8502, Source Material License SUA-1341, issued to Fuel Processing and Fabrication Branch, Division of Fuel Cycle and Material Safety, 50 pp.

55. Cox, C. H., and W. J. Roushey. Recovery of Uranium by In Situ Solution Mining. Mineral Ind. Bull., V. 22, No. 1, January 1979, 12 pp.

56. Crawford, E. Developers Eye Texas Potential for In Situ Uranium Leaching. Eng. and Min. J., V. 176, No. 7, July 1975, pp. 81-82.

57. Davidson, D. H. In-Situ Leaching of Nonferrous Metals. Min. Cong. J., V. 66, No. 7, July 1980, pp. 52-54, 57.

58. Davidson, D. H., R. V. Huff, and W. E. Sonstelie. Measurement and Control in Solution Mining of Deep-Lying Deposits of Copper or Uranium. Pres. at Instrument Soc. of America Min. and Met. Ind. Div. Symp., Denver, Colo., Nov. 1-3, 1978, 7 pp.

59. Davis, G. R., and W. M. McKnight, Jr. Facilities for Solution Mining of Uranium Operational and Environmental Aspects. Pres. at Am. Nuclear Society, November 1978, and In Situ Uranium Mining Seminar, March 1979, 10 pp.

60. Davis, G. R., R. E. Miller, and G. G. Swift. In-Situ Leach Mining for Uranium. Proc. Advisory Group Meeting, Internat. Atomic Energy Agency, Washington, D.C., Nov. 24-26, 1975, Panel Proceedings Series, 1976, pp. 193-202.

61. Davis, G. R., and E. L. Reed. Controlling Uranium Solution Mining Operations. Min. Cong. J., V. 64, No. 10, October 1978, pp. 35-38.

62. Derry, R. The Use of Peroxidants in the Leaching of Metal Sulphides. Pres. at Ann. Meeting of the Met. Soc., AIME, New Orleans, La., Feb. 18-22, 1979, TMS Paper Selection A-79-4, 24 pp.

63. Devries, F. W. Novel Techniques in Lixiviants and Site Restoration. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 12, Pt. 4, 1979, pp. 75-78.

64. Dew, J. N., and W. L. Martin (assigned to Continental Oil Company, Ponca City, Okla., a Corporation of Delaware). In Situ Roasting and Leaching of Uranium Ores. U.S. Pat. 2,954,218, Sept. 27, 1960.

65. Dravo Corporation. Solution Mining. Section 6.6.2 in Analysis of Large Scale Non-Coal Underground Mining Methods, BuMines Contract Report S0122059, January 1974, pp. 455-464.

66. Drever, J. I., and C. R. McKee. The Push-Pull Test: A Method of Evaluating Formation Adsorption Parameters for Predicting the Environmental Effects of In-Situ Coal Gasification and Uranium Recovery. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 87-98.

67. Duncan, D. W., and A. Bruynesteyn. Enhancing Bacterial Activity in a Uranium Mine. Can. Min. and Met. Bull., V. 64, No. 709, May 1971, pp. 32-36.

68. Duncan, D. W., and A. Bruynesteyn. Microbiological Leaching of Uranium. Proc. 1970 Uranium Symp., Socorro, N. Mex., Comp. by R. J. Roman, 1970, pp. 55-61.

69. Durler, D. L., and A. L. Bishop. In-Situ Uranium Leach Mining: Considerations for Monitor Well Systems. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9505, 10 pp.

70. Dutrizac, J. E., and R. J. C. Macdonald. Ferric Ion as a Leaching Medium. Minerals Sci. Eng., V. 6, No. 2, April 1974, pp. 59-100.

71. Duyvesteyn, W. P. C., G. R. Wicker, and R. E. Doane. An Omnivorous Process for Laterite Deposits. To Be Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979.

72. Eargle, D. H. Uranium in Texas. Houston Geol. Soc. Bull., V. 13, No. 2, 1970, pp. 18-27.

73. Eargle, D. H., K. A. Dickinson, and B. O. Davis. South Texas Uranium Deposits. AAPG Bull., V. 59, No. 5, May 1975, pp. 766-779.

74. Eargle, D. H., G. W. Hinds, and A. M. D. Weeks. Uranium Geology and Mines, South Texas. Texas Univ. Bur. Econ. Geol. Guidebook No. 12, Austin, Tex., 1971, 59 pp.

75. Eisenbarth, W. A. Industry View of Regulations on In Situ Mining. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 11-14.

76. Eisenbarth, W. A. Reconcilation: Environmental Issues in In-Situ Mining vs Regulatory Constraints. Pres. at Uranium Resource Tech. Seminar II. Colorado School of Mines, Golden, Colorado, Mar. 12-14, 1979, 7 pp.

77. Engelmann, W. H. (assigned to the United States of America as Represented by the Secretary of the Interior, Washington, D.C.). Foam Injection Leaching Process for Fragmented Ore. U.S. Pat. 4,080,419, Mar. 21, 1978.

78. Engelmann, W. H., and D. R. Kasper. Environmental Regulations for In Situ Uranium Mining: from Exploration to Restoration. Ch. in Proc. of the Am. Assoc. of Petrol. Geol. Ann. Meeting, Houston, Tex., Apr. 1-4, 1979, 21 pp.

79. Engelmann, W. H., P. E. Phillips, D. R. Tweeton, K. W. Loest, and M. T. Nigbor. Restoration of Groundwater Quality Following Pilot-Scale Acidic In Situ Uranium Leaching at Nine-Mile Lake Site Near Casper, Wyoming. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9494, 24 pp.

80. Engineering and Mining Journal. Agnew Lake Mines; Taking Giant Steps in Solution Mines. V. 179, No. 11, November 1978, pp. 158-161.

81. Engineering and Mining Journal. Bear Creek Gears Up for Commercial Use of Borehole Uranium Mining. V. 180, No. 3, March 1979, pp. 41, 45.

82. Engineering and Mining Journal. Cliffs Readies Uranium Solution Test in Pumpkin Buttes Area. V. 181, No. 1, January 1980, pp. 43, 47.

83. Engineering and Mining Journal. The Cost of Leaching U3O8 in Stopes and Pumping Solution to the Surface. V. 169, No. 6, June 1968, p. 186.

84. Engineering and Mining Journal. Economics Provide Motive for Growth of Bacteria Leaching. V. 167, No. 6, June 1966, 543 pp.

85. Engineering and Mining Journal. India Studies Possibility of Copper Mining by Nuclear Blasts. V. 171, No. 7, July 1970, 33 pp.

86. Engineering and Mining Journal. In-Situ Leaching Opens New Uranium Reserves in Texas. V. 176, No. 7, July 1975, pp. 73-81.

87. Engineering and Mining Journal. In Situ Uranium Extraction Dominates Texas Meeting. V. 181, No. 12, December 1980, pp. 92-93.

88. Engineering and Mining Journal. In Situ Uranium Leaching Operations Flourish in Southern Texas. V. 178, No. 6, June 1977, pp. 23, 27.

89. Engineering and Mining Journal. Mining In-Situ by Natures Easy Way. V. 168, No. 10, October 1967, pp. 75-80.

90. Engineering and Mining Journal. New Method Suggested for Leaching Uranium Ore In Place. V. 168, No. 5, May 1967, pp. 106-107.; Discussion of U.S. Patent 3,309,140, Leaching of Uranium Ore In Situ, by J. Gardner and M. I. Ritchie.

91. Engineering and Mining Journal. Producers and Newcomers Push Development Plans. V. 179, No. 11, November 1978, pp. 104-106.

92. Engineering and Mining Journal. Solution Mining Opening New Reserves. V. 175, No. 7, July 1974, pp. 62-71.

93. Engineering and Mining Journal. Texas-Uranium Production by In Situ Leaching. V. 176, No. 6, June 1975, p. 304.

94. Engineering and Mining Journal. Uranium Leach Project Snarled in New Mexico's Environmental Rules. V. 178, No. 6, June 1977, P. 33, 36.

95. Engineering and Mining Journal. Uranium Production by In-Situ Leaching. (Texas) June 1975, p. 304.

96. Engineering and Mining Journal. U308 Process Avoids Sulphates and Chlorides. V. 180, No. 5, May 1979, pp. 118-119.

97. Erickson, J. W. Underground In Situ Mining-A New Mining Method. Min. Eng., V. 30, No. 11, November 1978, pp. 1532-1534.

98. Erickson, J. W. Underground In Situ : A New Mining Method. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 15-18.

99. Fisher, J. R. Bacterial Leaching of Elliot Lake Uranium Ore. Can. Min. and Met. Bull., V. 59, No. 649, May 1966, pp. 588-592.

100. Fisher, J. R., F. C. Lendrum, and B. G. Macdermid. Laboratory and Underground Studies of Bacterial Leaching of Elliot Lake Ores. Pres. at 95th AIME Ann. Meeting, Feb. 27 - Mar. 3, 1966, New York, 9 pp.

101. Fishman, P. H., and W. H. Huang. Mineralogical Analysis and Uranium Distribution of the Sedimentary-type Uranium Ores. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9502, 12 pp.

102. Fitch, D. C. Exploration Geology Methods in the Grants Mineral Belt. Pres. at Uranium Symposium, Socorro, New Mexico, May 6-8, 1970, 11 pp.

103. Fitch, J. L., and B. G. Hurd (assigned to Mobil Oil Corporation, a corporation of New York). In Situ Leaching Method. U.S. Pat. 3,278,232, Oct. 11, 1966.

104. Fitch, J. L., and B. G. Hurd (assigned to Mobil Oil Corporation, a corporation of New York). Method of Leaching Subsurface Minerals In Situ. U.S. Pat. 3,309,141, Mar. 14, 1967.

105. Frank, J. N. Cost Model for Solution Mining of Uranium. Pres. at the Uranium Industry Seminar, Grand Junction, Colo., Oct. 19-20, 1976, 25 pp.

106. Frank, J. N. In Situ Leaching of Uranium. Pres. at the 1975 Uranium and Thorium Research and Resources Conf., U.S. Geological Survey, Denver, Colo., Dec. 8-10, 1975, 8 pp.

107. Galichon, P. In-Situ Leaching of Uranium Ore. M.S. Thesis, Univ. of Texas, Austin, Texas, December 1976, 83 pp.

108. Galichon, P., R. S. Schechter, A. Cowley, and M. Breland. Chemical Factors in In-Situ Uranium Leach Mining. In Situ, V. 1, No. 2, 1977, pp. 125-146.

109. Galloway, W. E. Depostional and Groundwater Flow Systems in the Exploration for Uranium. Research Callquium, Bureau of Economic Geology, Univ. of Texas, Austin, Tex., 1979, 267 pp.

110. Galloway, W. E. South Texas Uranium Province Geologic Perspective. Guidebook 18, Bureau of Economic Geology, Univ. Texas, Austin, Tex., 1979, 81 pp.

111. Gardner, J., and M. I. Ritchie (assigned to Utah Construction and Mining Company, San Francisco, Calif., a Corporation of Delaware). Leaching of Uranium Ore In Situ. U.S. Pat. 3,309,140, Mar. 14, 1967.

112. Garwacka, K., D. Johnson, M. Walsh, M. Breland, R. Schechter, and M. Humenick. Investigation of the Fate of Ammonia from In-Situ Uranium Solution Mining. Tech. Report EHE-79-01, the Univ. of Texas at Austin, Austin, Texas, February 1979, 140 pp.

113. George, D. R., and J. R. Ross. Recovery of Uranium from Uranium Mine Waters and Copper Ore Leaching Solutions, Processing of Low-grade Uranium Ores. Proc. of a Panel Held in Vienna, June 27 - July 1, 1966, Internat. Atomic Energy Agency, Vienna, 1967, pp. 227-234.

114. George, D. R., J. R. Ross, and J. D. Prater. Byproduct Uranium Recovered with New Ion Exchange Techniques. Min. Eng., V. 20, No. 1, January 1968, pp. 73-77.

115. Goddard, J. B., and D. R. Brosnahan. Rate of Consumption of Dissolved Oxygen During Ammonium Carbonate In Situ Leaching of Uranium. Pres. at 109th Annual Meeting, Soc. Min. Eng., AIME, Las Vegas, Nevada, Feb. 24-28, 1980.

116. Goodier, J. T. Wyomings Uranium Industry--Status, Impacts and Trends. Report to Mineral Division, Department of Economic Planning and Development, State of Wyoming. Prepared By Quality Development Associates, Inc., Sept. 30, 1978, 225 pp.

117. Grant, D. C. In-Situ Leaching Studies of Uranium Ores--Phase IV. Final Report, Westinghouse Electric Corp., R and D Center, 1310 Beulah Road, Pittsburgh, PA, BuMines Contract H0262004, November 1978, 497 pp.

118. Grimes, M. E. Prediction of Uranium Extraction in In-Situ Stope Leaching. Proc. Solution Mining Symp., AIME Ann. Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 338-353.

119. Griswold, G. B. Rock Fracturing Techniques for In Place Leaching. Pres. Ann. Meeting of the Soc. of Min. Eng., AIME, Washington D.C., Feb. 16-20, 1969, AIME Preprint 69-AS-74, 4 pp.

120. Guarnera, B. J. Uranium Exploration Activities in the U.S. Min. Eng., V. 30, No. 10, October 1978, pp. 1414-1416.

121. Gubkin, N. V., D. T. Desyatnikov, and I. K. Rudneva. Advantages of Mining Uranium in Inundated Sheet Deposits by Underground Leaching. Atomic Energy, V. 24, No. 6, June 1968, pp. 511-514.

122. Guilinger, T., M. Breland, M. Mcgarry, D. Magid, and R. S. Schechter. Environmentally Attractive Leachants for In Situ Uranium Mining. Dept. of Chem. Eng., Dept. of Petrol. Eng., University of Texas at Austin. BuMines Contract No. H0282016, Apr. 10, 1979, 113 pp.

123. Hancock, W. A. Uranium In Situ Leaching: Its Advantages, Practice, Problems, and Computer Simulation. Pres. at 107th Ann. Meeting, AIME, Atlanta, Ga., March 1977, Preprint 77-AS-68, 20 pp.

124. Hard, R. A., and R. L. Ripley (assigned to Union Carbide Corporation, New York, N.Y.). Process for Leaching Base Elements, such as Uranium Ore In Situ. U.S. Pat. 3,708,206, Jan. 2, 1973.

125. Harden, K. C. The Economic Production of Uranium by In Situ Leaching. Fourth Ann. Uranium Seminar, South Texas Min. Sect., SME, AIME, Corpus Christi, Tex., Sept. 14-17, 1980, 8 pp.

126. Harloff, G. J., and A. C. Riese. Experimantal and Theoretical Study of Uranium In Situ Solution Mining with H2SO4. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9484, 13 pp.

127. Harrison, V. F., W. A. Gow, and M. R. Hughson. Factors Influencing the Application of Bacterial Leaching to a Canadian Uranium Ore. J. Metals, V. 18, No. 11, November 1966, pp. 1189-1194.

128. Harshman, E. N. Genetic Implications of Some Elements Associated with Uranium Deposits, Shirley Basin, Wyoming. U.S. Geol. Survey Prof. Paper 550-C, 1966, pp. C167-C173.

129. Harshman, E. N. Geology and Uranium Deposits, Shirley Basin Area, Wyoming. U.S. Geol. Survey Prof. Paper 745, 1972, 82 pp.

130. Harshman, E. N. Uranium Deposits of Wyoming and South Dakota. Ch. in Ore Deposits of the United States, 1933-1967, ed. by J. D. Ridges. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, V. 1, Pt. 7, Ch. 40, 1968, pp. 815-831.

131. Hartmann, B. E. Solution Mining System. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section IX, 10 pp.

132. Henderson, T. B., Jr. Variations in South Texas Uranium Hosts. Pres. at Uranium In Situ Symp., South Texas Minerals Sect., AIME, Corpus Christi, Tex., Sept. 25-28, 1977, 3 pp.

133. Henrickson, A. V. (assigned to Kerr-McGee Oil Industries, Inc.). Recovery of Uranium Values by Solvent Extraction. U.S. Pat. 3,241,909, Mar. 22, 1966.

134. Higgins, I. R. Update of CHEM-SEPS Continuous Ion Exchange Operation Relations to Uranium Recovery. Pres. at 1978 Uranium Mining Seminar South Texas Minerals Section, Corpus Christi, Tex., September 1978, 8 pp.

135. Hill, A. D., M. P. Walsh, W. M. Breland, I. H. Silberberg, M. J. Humenick, and R. S. Schechter. Restoration of Uranium in Situ Leaching Sites. Pres. at 53rd Ann. Fall Technical Conference and Exhibition of the Soc. of Pet. Eng., AIME, Houston, Texas, Oct. 1-3, 1978, SPE Preprint 7534, 8 pp.

136. Hohne, F. C. Projections of the Impact of Solution Mining on Uranium Production in the United States. Pres. at Uranium Mining Technology Conference, the Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Apr. 25-29, 1977.

137. Howell, E. P., and O. J. Gant, Jr. (assigned to Atlantic Richfield Company, Los Angeles, Calif.). Method for the Production of Minerals. U.S. Pat. 4,032,194, June 28, 1977.

138. Huang, W. H. Geochemical and Sedimentologic Problems of Uranium Deposits of Texas Gulf Coastal Plain. AAPG Bull., V. 62, No. 6, June 1978, pp. 1049-1062.

139. Huang, W. H., and K. Pickett. Factors Controlling In-Situ Leaching of Uranium from Sandstone and Lignite Deposits in South Texas. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section XI, 18 pp.

140. Huff, R. V., and D. H. Davidson. Technology for In Situ Uranium Leaching. Min. Eng., V. 32, No. 2, February 1980, pp. 163-166.

141. Huff, R. V., and H. Davidson. In-Situ Leaching Materials Considerations. Pres. at 54th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Las Vegas, Nev., Sept. 23-26, 1979, SPE Preprint 8320, 6 pp.

142. Humenick, M. J., and D. G. Johnson. Nitrification and In-Situ Uranium Solution Mining. Univ. Texas, Austin, Tex.

143. Humenick, M. J., R. Turk, and R. S. Schechter. Literature Review and Preliminary Analysis of Inorganic Ammonia Pertinent to South Texas Uranium In-Situ Leach. Center for Research in Water Resources Report No. CRWR155, EHE 78-01, Univ. Texas, Austin, Tex., 1978. [in press]

144. Hunkin, G. G. Concentration Processes for Uranium In Situ Leach Liquors. Pres. at 105th Ann. Meeting, AIME, Las Vegas, Nev., Feb. 22-26, 1976, Preprint 76-B-77, 7 pp.

145. Hunkin, G. G. The Environmental Impact of Solution Mining for Uranium. Min. Cong. J., V. 61, No. 10, October 1975, pp. 24-27.

146. Hunkin, G. G. Oral Presentation Uranium In-Situ Solution Mining. The Royal Commission of Inquiry Concerning the Health and Environmental Protection Uranium Mining, 1979, 24 pp.

147. Hunkin, G. G. A Review of In Situ Leaching. Pres. at AIME Ann. Meeting, Soc. of Min. Eng., AIME, New York, N.Y., Feb. 26 - Mar. 4, 1971, AIME Preprint 71-AS-88, 23 pp.

148. Hunkin, G. G. Uranium In-Situ Solution Mining. The Royal Commission of Inquiry Concerning the Health and Environmental Uranium Mining 1979, October 1979, 93 pp.

149. Hurd, B. G., and J. L. Fitch (assigned to Mobil Oil Corporation, a Corporation of New York). In Situ Leaching of Subterranean Deposits. U.S. Pat. 3,278,233, Oct. 11, 1966.

150. Jacoby, C. H. (assigned to Akzona Inc., Asheville, N.c.). In Situ Extraction of Mineral Values from Ore Deposits. U.S. Pat. 3,822,916, July 9, 1974. .

151. Jayaram, K. M. V., A. S. Deshpande, and C. V. Sharma. Leaching and Precipitation of Uranium from Quartzite Ores at Chhinjra, Kulu District, Himachal Pradesh. Proc. of the Indian National Science Academy. V. 36, A, No. 5, 1970, pp. 298-305.

152. Johnson, D. Nitrification and In Situ Uranium Leach Mining. Dept. of Civil Eng., University of Texas, Austin, November 1978, 54 pp.

153. Johnson, D. G. Nitrification and In-Situ Uranium Solution Mining. M.S. Thesis, Univ. Texas, Austin, Tex., 1979.

154. Johnson, D., and M. J. Humenick. Nitrification and In-Situ Uranium Solution Mining. Soc. Petrol. Eng. J., V. 20, No. 5, October 1980, pp. 415-422.

155. Johnson, J. M. Recovery of Uranium by Multiple-column Countercurrent Ion Exchange. July 1969, 7 pp.

156. Johnson, P. H. Acid-ferric Sulfate Solutions for Chemical Mining. Min. Eng., V. 17, No. 8, August 1965, pp. 64-68.

157. Johnson, P. H., and R. B. Bhappu. Chemical Mining - A Study of Leaching Agents. New Mexico Bureau of Mines and Mineral Resources, Circ. 99, 1969, 7 pp.

158. Johnson, P. H., and R. B. Bhappu. Chemical Mining - Theoretical and Practical Aspects. Pres. at SME Fall Meeting - Rocky Mountain Minerals Conf., Las Vegas, Nevada, Sept. 6-8, 1967, 20 pp.

159. Kabir, M. I., L. W. Lake, and R. S. Schechter. Evaluation of the One Well Uranium Leaching Test: Restoration. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9486, 11 pp.

160. Kalabin, A. I. Winning of Useful Elements from Minerals by Leaching Underground. Min. Mag. (London), V. 118, No. 2, February 1968, pp. 129-134.

161. Kallus, M. F. Environmental Aspects of Uranium Mining and Milling in South Texas. U.S. Environmental Protection Agency, EPA 906/9-75-004, October 1975, 86 pp.

162. Kasper, D. R. Optimization of Reverse Osmosis Treatment of In Situ Wastewaters. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9492, 5 pp.

163. Kasper, D. R., and W. H. Engelmann. Compliance with Environmental Regulations for In Situ Uranium Mining: from Discovery to Clousure. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section XVII, 36 pp.

164. Kehrman, R. F., A. J. Farstad, and D. R. Tweeton. Use of Resistivity Measurements to Monitor Lixiviant Migration During In-Situ Uranium Leaching. 10 pp.

165. King, J. W., and S. R. Austin. Some Characteristics of Roll-Type Uranium Deposits at Gas Hills, Wyoming. Min. Eng., V. 18, No. 5, May 1966, pp. 73-80.

166. Koch, L. W. Economics of Uranium Mining and Milling. Pres. at Uranium Resource Tech. Seminar, Colorado School of Mines, Golden, Colorado, Mar. 12-14, 1979, 12 pp.

167. Kolodney, M., and S. C. Hyman (assigned to Nuclear Development Corporation of America, a Corp. of New York). Recovery of Uranium and Vanadium Values from Ores. U.S. Pat. 2,964,380, Dec. 13, 1960.

168. Kurth, D. I., and R. D. Schmidt. Computer Modeling of Five-Spot Well Pattern Fluid Flow During In Situ Uranium Leaching. BuMines RI 8287, 1978, 76 pp.

169. Lackey, J. A. Environmental Aspects of Uranium Extraction. Amdel Bull. (The Australian Mineral Development Laboratories), No. 19, April 1975, pp. 11-20.

170. Lackey, J. A. Solution Mining (In Situ Leaching) A Literature Survey. Amdel Bull., (The Australian Mineral Development Laboratories), No. 19, April 1975, pp. 40-61.

171. Lang, E. A., and W. R. Archibald. Innovative Systems for the Recovery of Uranium. Pres. at the National Western Min. Conf., Denver, Colo., Feb. 7, 1975, pp. 1-13.; Colorado Mining Assoc., 1975 Mining Yearbook, pp. 114-118.

172. Lang, L. C., and W. B. Morrey. Scientific Blasting for In-Situ Leaching Proves Successful at Agnew Lake Mines. Eng. and Min. J., V. 177, No. 1, January 1976, pp. 100-102.

173. Langen, R. E., and A. L. Kidwell. Geology and Geochemistry of the Highland Uranium Deposit, Converse County, Wyoming. The Mountain Geol., V. 11, No. 2, April 1974, pp. 85-93.

174. Langston, B. G. Ammonium Carbonate Pressure Leaching of Uranium Ores. J. Metals, V. 9, No. 6, June 1957, pp. 752-756.

175. Larson, W. C. Nomograph for Uranium In Situ Leaching. Eng. and Min. J., V. 178, No. 9, September 1977, p. 159.

176. Larson, W. C. Uranium In Situ Leach Mining - A Third Alternative. Pres. at AAPG Ann. Conference, Houston, Texas, Apr. 1-4, 1979, 23 pp.

177. Larson, W. C. Uranium In Situ Leach Mining in the United States. BuMines IC 8777, 1978, 87 pp.

178. Lawes, B. C. Effect of Sodium Silicate on Leaching Uranium Ores with Hydrogen Peroxide. Pres. at Am. Nuclear Soc. Meeting, Golden, Colo., Apr. 14, 1977, 12 pp.

179. Leaming, G. F. The Economic Impact of the South Texas Uranium Industry. Southwest Economic Info. Center, Marana, Arizona, February 1979, 60 pp.

180. Learmont, R. P. (assigned to United States Steel Corporation, Pittsburgh, Pa.). In Situ Solution Mining Technique. U.S. Pat. 4,082,358, Apr. 4, 1978.

181. Learmont, R. P. (assigned to United States Steel Corporation). Process for Leaching Mineral Values from Underground Formations In Situ. U.S. Pat. 3,860,289, Jan. 14, 1975.

182. Lewis, F. M., and R. B. Bhappu. Evaluating Mining Ventures Via Feasibility Studies. Min. Eng., V. 27, No. 10, October 1975, pp. 48-54.

183. Lewis, F. M., C. K. Chase, and R. B. Bhappu. Economic Evaluation of In Situ Extraction for Copper, Gold, and Uranium. Proc. Joint Meeting of the Mining and Metallurgical Institute of Japan and the American Institute of Mining, Metallurgical, and Petroleum Engineers, Denver, Colo., Sept. 1-3, 1976 (pub. as World Mining and Metals Technology, ed. by A. Weiss), V. 1, 1976, pp. 333-348.

184. Li, T. A., and J. D. Wiebmer. Uranium Mining in the U.S.-Producers Rush to Meet Energy Needs. Min. Eng., V. 30, No. 10, October 1978, pp. 1405-1410.

185. Litz, L. M. In Situ Uranium Mining with Oxygen. Pres. at 109th Annual Meeting, Soc. Min. Eng., AIME, Las Vegas, Nevada, Feb. 24-28, 1980.

186. Livingston, C. W. Method of Mining Ores In Situ by Leaching. U.S. Pat. 2,818,240, Dec. 31, 1957.

187. Loest, K. W. Development of an In Situ Operation: Nine Mile Lake. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 75-77.

188. Loo, W. W. Production Optimization of In-Situ Leaching of Uranium by Proper Well Field Design. Pres. at Uranium Mining Technology-Update 78 Conf., Nov. 13-17, 1978, Reno, Nev., 11 pp.

189. Lootens, D. T. Uranium Production Methods and Economic Considerations. Dames and Moore Consulting Co., Park Ridge, Ill., 1976, 11 pp.

190. Macgregor, R. A. The Bacterial Leaching of Uranium. Nuclear Applications, V. 6, January 1969, pp. 68-72.

191. Macgregor, R. A. Recovery of U3O8 by Underground Leaching. Can. Min. and Met. Bull., V. 59, No. 649, May 1966, pp. 583-587.

192. Macgregor, R. A. Uranium Dividends from Bacterial Leaching. Min. Eng., V. 21, No. 3, March 1969, pp. 54-55.

193. Mackay School of Mines, University of Nevada--Reno. In-Place Leaching and Solution Mining. Short Course given at Incline Village, Nev., Nov. 10-14, 1975, 225 pp.

194. Malouf, E. E. Introduction to Dump Leaching Practice. Part I of Second Tutorial Symp. on Extractive Metallurgy, Univ. Utah, Dec. 14-16, 1972, 26 pp.

195. Malouf, E. E. Leaching as a Mining Tool. Internat. Symp. on Hydrometallurgy, Chicago, Ill., Feb. 25-Mar. 1, 1973, Ch. 23, pp. 615-626.

196. Malouf, E. E. The Role of Microorganisms in Chemical Mining. Min. Eng., V. 23, No. 11, November 1971, pp. 43-46.

197. Marrs, L. F. Underground Leaching of Uranium at the Pitch Mine. Pres. American Min. Cong. Convention, Denver, Colo., Sept. 27-30, 1970, 14 PP.; Min. Cong. J., V. 56, No. 11, November 1970, pp. 35-43.

198. Martin, J. W. (assigned to Oil Recovery Corporation, New York, N.Y., a Corporation of New York). Recovery of Uranium by Carbonated Water and Surface Action Agents and Wetting Agents. U.S. Pat. 3,130,960, Apr. 28, 1964.

199. May, H. D. Environmental Considerations of In-Situ Uranium Mining/Milling. Pres. at Seminar on Uranium Solution Mining and Milling for State and Federal Regulatory Personnel, Corpus Christi, Texas, Mar. 6-9, 1979, 17 pp.

200. Mays, W. M. Engineering an In Situ Uranium Well Field. Proc. Third Ann. Uranium Seminar, Wyoming Min. and Metals Sect., AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 69-70.

201. McCreedy, H. H. Bacterial Leaching to be Applied to a New Canadian Uranium Mine. Coordinated Research Committee Meeting of the International Atomic Energy Agency, Coventry, England, Dec. 1976. [in press]

202. Mccreedy, H. H., V. F. Harrison, and W. A. Gow. A Proposed Method, Using Bacteria, for the Continuous Leaching of a Uranium Ore. Can. Min. and Met. Bull., V. 62, No. 682, February 1969, pp. 135-140.

203. McKee, C. R. Preliminary Proposal to the Environmental Protection Agency on Controlling Solution Movement and Groundwater Restoration for Uranium Solution Mining. University of Wyoming Through Water Resources Research Institute, January 1977, 9 pp.

204. McKee, C. R., and J. I. Drever. Reservoir Engineering Update--Uranium In Situ Extraction. to Be Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979.

205. McKinney, W. A. Solution Mining. Min. Eng., V. 25, No. 2, February 1973, pp. 56-57.

206. Mc Knight, W. M. Jr., and H. L. Anthony, IV. Well Field Operations. Proc. Third Ann. Uranium Sem., Wyoming Min. and Metals Sect., AIME, Casper, Wyo., Sept. 9-12, 1979, pp. 71-73.

207. Melin, R. E. Description and Origin of Uranium Deposits in Shirley Basin, Wyoming. Econ. Geol., V. 59, 1964, pp. 835-849.

208. Menke, J. R. (assigned to Nuclear Development Corp. of America, a Corp. of New York). Method of Recovering Uranium from Underground Deposit. U.S. Pat. 2,896,930, July 28, 1959.

209. Merritt, R. C. The Extractive Metallurgy of Uranium. Colo. School Mines Research Inst., Prepared Under Contract with U.S. Atomic Energy Commission. Johnson Pub. Co., Boulder, Colo., 1971, 576 pp.

210. Merritt, R. C. The Metallurgy of Uranium Extraction. Pres. at Uranium Mining Technology Conference, The Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Apr. 25-29, 1977, 41 pp.

211. Meyer, A. E. (assigned to Kerr-McGee Oil Industries Inc.). Method of Acid Leaching Uranium Ores. U.S. Pat. 3,250,589, May 10, 1966.

212. Mining Engineering. An Economic Analysis of Open-pit and In Situ Mining. V. 30, No. 10, October 1978, pp. 1420-1422.

213. Mining Engineering. Hydrometallurgy Is Key in Winning U3O8. V. 26, No. 8, August 1974, pp. 26-27.

214. Mining Engineering. Kerr-McGee's Ambrosia Complex: from Mined Rock to Yellowcake. V. 26, No. 8, August 1974, pp. 28-30.

215. Mining Magazine. Development of Argentinian Uranium Deposits. V. 142, No. 1, January 1980, pp. 9-10.

216. Mining Magazine (London). In Situ Leaching - A Review. V. 125, No. 3, September 1971, pp. 213-215.

217. Mining Record (Denver, Colorado). Hydrogen Peroxide Can Maximize Uranium Leaching. V. 90, No. 4, Jan. 24, 1979, p. 8.

218 Mining Record (Denver, Colorado). Solution Mining - Can It Speed Development of Uranium Reserves? V. 87, No. 26, June 23, 1976, pp. 1, 7.

219. Minobras. Uranium Deposits of the Northern U.S. Region. P.O. Box 262, Dana Point, Calif., 92629, 1977, 99 pp.

220. Minobras. Uranium Guidebook for Wyoming. P.O. Box 262, Dana Point, Calif., 92629, 1976, 63 pp.

221. Mrak, V. A. Uranium Deposits in the Eocene Sandstones of the Powder River Basin, Wyoming. Ch. in Ore Deposits of the United States, 1933-1967, ed. by J. D. Ridges. American Institute of Mining, Metallurgical, and Petroleum Engineers, New York, V. 1, Pt. 7, Ch. 42, 1968, pp. 838-848.

222. Mutschler, P. H., J. J. Hill, and B. B. Williams. Uranium from the Chattanooga Shale; Some Problems Involved in Development. BuMines IC 8700, 1976, 85 pp.

223. Naden, D., and G. Willey. The Use of Fluid Bed Ion Exchange to Reduce Uranium Recovery Costs. Pres. at the AIME Ann. Meeting, Soc. Min. Eng., AIME, Las Vegas, Neveda, Feb. 22-26, 1976, Preprint 76-B-65, 33 pp.

224. Narayan, K., and R. D. Pick (assigned to Atlantic Richfield Company, Los Angeles, Calif.). Recovery of Uranium from Carbonate Leach Solutions. U.S. Pat. 4,092,399, May 30, 1978.

225. Narayan, K., and P. J. Rand. Environmental Considerations in Uranium Solution Mining. Trans. Soc.of Min. Eng., AIME, V. 262, June 1977, pp. 117-119.

226. Narayan, K., P. J. Rand, and R. B. Hill. Environmental Considerations in Uranium Solution Mining. Pres. at 105th Ann. Meeting, AIME, Las Vegas, Nev., Feb. 22-26, 1976, Preprint 76-AS-70, 12 pp.

227. Neesham, R. Texas Uranium Producers Take a Growing Market Share. Eng. and Min. J., V. 179, No. 11, November 1978, pp. 143-147.

228. New Mexico Department of Health and Environment. Radioactive Material License No. NM-GRA-UL-CO Issued to Michael P. Grace For Pilot Scale In Situ Uranium Leaching Tests, McKinley and Sandoval Counties, New Mexico. Permit Issued Mar. 5, 1976.

229. Nigrini, A. Thermodynamic Calculation of U Loadings and Reaction Paths with Carbonate Lixiviants in Insitu Leaching Systems. to Be Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979.

230. Nuclear Regulatory Commission. Ground-Water Elements of In Situ Leach Mining of Uranium. NUREG/CR-0311, 1978, pp. 17-34.

231. Olson, J. J. Bureau of Mines Research in In-Situ Leaching and Borehole (or Slurry) Mining. Pres. at Fall Meeting of Soc. of Min. Eng., AIME, St. Louis, Mo., Oct. 19-21, 1977, Preprint 77-AS-340, 58 pp.

232. Olson, J. J., W. C. Larson, D. R. Tweeton, and Others. Mining Research for Improved In Situ Extraction of Uranium. Pres. at Uranium In Situ Leaching Conf., Sponsored by AAPG, SME, and SPE, Vail, Colo., Aug. 25-27, 1976, BuMines Preprint, 37 pp.

233. Olson, J. J., G. A. Savanick, and D. R. Tweeton. In Situ Mining Technology for Uranium -- A Progress Report on Bureau of Mines Research. Proc. 1978 Energy Technology Conf. and Exhibition, Houston, Texas, Nov. 6-9, 1978 (pub. as Mining Technology for Energy Resources - Advances for the 80's. The American Society of Mechanical Engineers, New York, 1979, pp. 35-46.

234. O'Rourke, J. E., R. J. Essex, and B. K. Ranson. Field Permeability Test Methods with Applications to Solution Mining. Woodward-Clyde Consultants (San Diego, Calif.), Contract No. J0265045. BuMines Open File Rept. 136-77, July 1977, 180 PP.; Available from National Technical Information Service, Springfield, Va., PB 272 452/AS.

235. Ortloff, G. D., C. E. Cooke, Jr., and D. K. Atwood (assigned to Esso Production Research Company). Mineral Recovery. U.S. Pat. 3,574,599, Apr. 13, 1971.

236. Phillips, P. Experience with Acid Leaching. Pres. at South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978.

237. Phillips, P. E. A Comparison of Open Pit and In Situ Leach Economics. Pres. at Uranium Mining Technology Conference, The Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Apr. 25-29, 1977, 12 pp.

238. Phillips, P. E. Rocky Mountain Energy's Experiences with In Situ Leaching of Uranium with Acid. Proc. South Texas Uranium Sem., Corpus Christi, Texas, Sept. 10-13, 1978. American Insitute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 9, Pt. 3, 1979, pp. 57-59.

239. Pings, W. B. Bacterial Leaching. Miner. Ind. Bull., V. 2, No. 3, May 1968, 19 pp.

240. Popoff, D. R. Bacterial Leaching Means New Life for Mine. Canadian Nuclear Technology, V. 5, No. 4, July - August 1966, pp. 31-33.

241. Potter, G. M. Solution Mining. Min. Eng., V. 21, No. 1, February 1969, pp. 68-69.

242. Potter, R. W., J. M. Thompson, M. A. Clynne, and V. L. Thurmond. Equilibrium, Kinetic, and Chromatographic Controls of the Solution Composition Obtained During the In Situ Leaching of a Uranium Orebody. Reprint from ACS Symposium Series, No. 93, Nov. 16, 1978, pp. 761-769.

243. Potter, R. W., II. Some Geochemical Parameters Effecting the In-Situ Leaching of Uranium. U.S. Geol. Survey Open-File Report 76-835, 1976, 24 pp.

244. Potter, R. W., II, M. A. Clynne, J. M. Thompson, V. L. Thurmond, R. C. Erd, N. L. Nehring, K. A. Smith, P. J. Lamothe, and J. L. Seeley. Chemical Monitoring of the In-Situ Leaching of a South Texas Uranium Orebody. U.S. Geol. Survey Open File Rept. 79-1144, 54 PP.; Available for Consultation at the U.S. Geol. Survey Open File Reports Services Section, Box 25425, Denver, Colo. 80225.

245. Rabb, D. D. Solution Mining. Min. Eng., V. 24, No. 2, February 1972, pp. 62-64.

246. Rackley, R. I. Concepts and Methods of Uranium Exploration. Wyoming Geo. Assoc. Guidebook of the Twentieth Ann. Field Conf., Casper, Wyoming, 1968, pp. 115-124.

247. Reed, E. L. The Application of Groundwater Hydrology to In Situ Leach Mining. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Insitute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 8, Pt. 3, 1979, pp. 53-55.

248. Reed, V. S. Disposal Well Design for In Situ Uranium Operations. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

249. Resource Engineering & Development, Inc. Analysis of Groundwater Criteria and Recent Restoration Attempts After In Situ Uranium Leaching. V. 1, BuMines Contract No. J0295019, Final Draft, October 1980, 132 pp.

250. Rhoades, V. W. (assigned to Cities Service Oil Company, Tulsa, Okla.). Uranium Solution Mining Process. U.S. Pat. 3,713,698, Jan. 30, 1973.

251. Rhoades, V. W. (assigned to Dalco Oil Company; United States Steel Corporation; part interest to each). Uranium Solution Mining Process. U.S. Pat. 3,792,903, Feb. 19, 1974.

252. Rickard, R. S. Chemical Constraints on In-Situ Leaching and Metal Recovery. Proc. Solution Mining Symp., AIME Ann. Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 185-192.

253. Riding, J. R., F. J. Rosswog, T. D. Chatwin, G. Buma, and D. R. Tweeton. Groundwater Restoration for In Situ Solution Mining of Uranium. Pres. at Ann. Meeting, Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979, Preprint 79-127, 24 pp.

254. Robb, N., V. Opratko, and L. S. Price. Milliken's Two-Stage Sulphuric Acid Leaching Process for Uranium Ores. Can. Min. and Met. Bull., V. 56, No. 614, June 1963, pp. 476-479.

255. Rocky Mountain Energy Company. Nine Mile Lake Environmental Report. Prepared for the U.S. Nuclear Regulatory Commission, January 1979, 194 PP.; Available for Consultation at U.S. NRC Offices in Washington, D.c.

256. Roman, R. J. Solution Mining. Min. Eng., V. 26, No. 2, February 1974, pp. 43-44.

257. Root, T. Environmental Law Aspects of Extracting and Processing Uranium. Natural Resources Lawyer, 1979, 11(3); pp. 419-454.

258. Root, T. E. Legal Aspects of Mining by the In-Situ Leaching Method. Pres. at 22nd Ann. Rocky Mountain Mineral Law Inst., Sun Valley, Idaho, July 22-24, 1976, 18 pp.

259. Rosenbaum, J. B., and D. R. George. Cost Reductions in Ion Exchange Processing of Uranium Ores. Internat. Atomic Energy Agency, IAEA-SM-135/24, 1971, pp. 297-309.

260. Rosholt, J. N., Jr. Uranium Migration and Geochemistry of Uranium Deposits in Sandstone; Above, At, and Below the Water Table. Part I. Calculation of Apparant Dates of Uranium Migration in Deposits Above and At the Water Table. Econ. Geol., V. 56, 1961, pp. 1392-1403.

261. Rouse, J. V. Environmental Aspects of In Situ Mining and Dump Leaching. Proc. Solution Mining Symp., AIME Ann. Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 3-14.

262. Rouse, J. V. Environmental Considerations of Uranium Mining and Milling. Min. Eng., V. 30, No. 10, October 1978, pp. 1433-1436.

263. Rowswell, M. D. Solution Mining for Uranium Being Pioneered at Agnew Lake. The Northern Miner, V. 63, No. 28, Sept. 22, 1977, pp. C-2, C-5.

264. Rutledge, C. In-Situ Uranium Solution Mining--Environmental and Licensing Regulations. Pres. at AAPG-SEPM Ann. Convention, Houston, Texas, Apr. 1-4, 1979.

265. St. Peter, A. L. In Situ Mining -- A Design for Positive Results. Pres. at 105th Ann. Meeting, AIME, Las Vegas, Nev., Feb. 22-26, 1976, Preprint 76-AS-36, 43 pp.

266. Savanick, G. A. Borehole (Slurry) Mining of Coal and Uraniferous Sandstone. Pres. at 1979 AIME Ann. Meeting, Feb. 18-22, New Orleans, La., SME Preprint 79-53, 11 pp.

267. Savanick, G. A. Borehole (Slurry) Mining of Coal and Uraniferous Sandstone. Proc. Third Ann. Uranium Seminar Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 115-125.

268. Savanick, G. A. Water Jet Perforator for Uranium Leaching Wells. Pres. at Uranium Mining Technology Conference, the Mackay School of Mines, Univ. Nevada--Reno, Reno, Nev., Apr. 25-29, 1977, 24 pp.

269. Savanick, G. A., and W. G. Krawza. Well Perforating Method for Solution Well Mining. U.S. Pat. 4,113,314, Sept. 12, 1978.

270. Schechter, R. S., and P. M. Bommer. Optimization of Uranium Leach Mining. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, Soc. Petrol. Eng., AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9488, 13 pp.

271. Schechter, R. S., and P. M. Bommer. Post In-Situ Uranium Leaching Site Restoration - Numerical Analysis. Pres. at 54th Ann. Fall Technical Conf. and Exhibition of Soc. of Petrol. Eng. of AIME, Las Vegas, Nevada, Sept. 23-26, 1979, SPE Preprint 8322, 11 pp.

272. Schecter, R., M. P. Walsh, W. M. Breland, M. J. Humenick, I. H. Silberberg, and A. D. Hill. Restoration of Uranium In Situ Leaching Sites. Pres. at 53rd Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Houston, Texas, Oct. 1-3, 1978, SPE Preprint 7534, 8 pp.

273. Schlitt, W. J., and D. A. Shock. In Situ Uranium Mining and Ground Water Restoration. SME of AIME Proceedings of the New Orleans Symp., Feb. 19, 1979, 137 pp.

274. Schmidt, D., and W. Floter. Urangewinnung Durch Solution Mining - Verfahren (Extraction of Uranium by the Solution Mining Process). Braunkohle, Heft 10, October 1980, pp. 334-339.

275. Schultz. Kosten Des Solution Mining. Diplomarbeit, Ueb, Bonn, W. Germany, 1980.

276. Seidel, D. C. Stored Technology for Possible Use in Uranium Ore Processing. Pres. at IAEA Advisory Group Meeting, Washington D.C., Nov. 24-28, 1975, Paper No. AG/33-7, 17 pp.

277. Shabbir, M., and K. E. Tame. Hydrogen Peroxide Precipitation of Uranium. BuMines RI 7931, 1974, 13 pp.

278. Sharp, W. N., and A. B. Gibbons. Geology and Uranium Deposits of the Southern Part of the Powder River Basin, Wyoming. U.S. Geol. Bull. 1147-D, 1964, 5 Plates (6 Maps).

279. Shock, D. A. Developments in Solution Mining Portend Greater Use for In Situ Leaching. Min. Eng., V. 22, No. 2, February 1970, p. 73.

280. Shock, D. A. The Vail Conference on In Situ Leaching of Uranium. In Situ, V. 1, No. 1, 1977, pp. 103-113.

281. Shock, D. A., and F. R. Conley. Solution Mining-Its Promise and Its Problems. Proc. Solution Mining Symp., AIME Ann. Meeting, Dallas, Texas, Feb. 25-27, 1974, pp. 79-97.

282. Shock, D. A., and J. G. Davis. Hydrofracing as a Mining Technique. Pres. at Ann. Meeting, Soc. of Min. Eng., AIME, Washington, D.c., Feb. 16-20, 1969, AIME Preprint 69-AS-63, 25 pp.

283. Showalter, W. E. (assigned to Union Oil Company of California). Process for Recovery of Mineral Values from Underground Formations. U.S. Pat. 4,105,253, Aug. 8, 1978.

284. Shuck, D. L. an Overview of Solution Mining. Pres. at Uranium Resource Tech. Seminar II, Colorado School of Mines, Golden, Colorado, Mar. 12-14, 1979, 7 pp.

285. Sievert, J. A. (assigned to Continental Oil Company, Ponca City, Okla.). In Situ Mining Using Bacteria. U.S. Pat. 3,937,520, Feb. 10, 1976.

286. Sievert, J. A., W. L. Martin, and F. R. Conley. In Situ Leaching of Uranium. Pres. at Soc. of Min. Eng. Fall Meeting, St. Louis, Mo., Oct. 21-23, 1973, 18 pp.

287. Skillings Mining Review. Nuclear Dynamics Test Plant for Uranium Mining. V. 66, No. 22, May 28, 1977, p. 5.

288. Smith, R. B. Geology of South Texas Uranium Deposits. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 6, Pt. 2, 1979, pp. 45-46.

289. Smith, R. B. The Theory of Multiple Oxidation and Reduction of Uranium Deposits in South Texas. Pres. at Uranium In Situ Symp., South Texas Minerals Sect., AIME; Corpus Christi, Tex., Sept. 25-28, 1977, 10 pp.

290. Spence, A. P. (assigned to Atlantic Richfield Co., NM Uranium Inc., and U.S. Steel Corp.). Method for the Recovery of a Mineral. U.S. Pat. 4,082,359, Apr. 4, 1978.

291. Stone and Webster Engineering Corporation, Denver, Colorado. Administrators Guide for Solution Mining of Uranium. Prepared for Western Interstate Energy Board/WINB, formerly the Western Interstate Nuclear Board, Under Contract to the U.S. Environmental Protection Agency, Contract No. 68-01-4490, May 1979, 92 PP.; Available from the National Technical Information Service PB-301 173.

292. Stover, D. E. Evaluating Uranium Deposits for Solution Mining. Pres. at the 55th Ann. Fall Tech. Conf. and Exibition, Soc. Petrol. Eng., AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9504, 6 pp.

293. Stover, D. E. Grade Control for In Situ Uranium Leaching. Pres. at Fourth Ann. Uranium Seminar, South Texas Miner. Sect., Soc. Min. Eng., AIME, Corpus Christi, Tex., Sept. 14-17, 1980. [in press]

294. Stover, D. E. (assigned to Atlantic Richfield Co.). Method for the Restoration of an Underground Reservoir. U.S. Pat. 4,108,722, Aug. 22, 1978.

295. Sundar, P. S. In-Situ Leaching Simulation Studies of Uranium Ores--Phases I through III. Westinghouse Research and Development Center, 1310 Beulah Road, Pittsburgh, Penn., BuMines Contract No. H0262004, June 1977, 392 pp. Available from National Technical Information Service, Springfield, Va., PB 272 717.

296. Sundar, P. S. In-Situ Leaching Simulation Studies of Uranium Ores. Pres. at 1978 Ann. Meeting, Denver, Colo. Feb. 28 - Mar. 2, 1978, SME Preprint 78-AS-102, 16 pp.

297. Sundin, R. E. Regulations on In Situ Uranium Mines in Wyoming. Proc. Third Ann. Uranium Seminar, Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 3-4.

298. Taylor, W. R. Ground Water Quality Protection in In Situ Uranium Mines. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 1-5; SME Preprint 79-10, 3 pp.

299. Taylor, W. R. Regulation of In Situ Uranium Mining for Purposes of Protecting Groundwater Quality. Pres. at Uranium In Situ Symp., South Texas Minerals Sect., Soc. Petrol. Eng., AIME, Corpus Christi, Tex., Sept. 25-28, 1977, Preprint 7536, 12 pp.

300. Terry, G. A. Environmental Assessment of In-Situ Leaching of Uranium. Pres. at AAPG-SEPM Ann. Convention, Houston, Texas, Apr. 1-4, 1979.

301. Terry, R. C. (assigned to In Situ Technology, Inc., Denver, Colo.). Recovering Uranium from Coal In Situ. U.S. Pat. 4,113,313, Sept. 12, 1978.

302. Texas Department of Water Resources. Permit to Conduct Underground Injection. Longoria Mining Project, Permit No. 02222, 1979, 6 pp.

303. Texas Department of Water Resources. Nondischarge Permit No. 02051 Issued to Union Carbide Corporation for a Full Scale In Situ Uranium Leaching Operation in Duval County, Texas. Permit Issued January 1977.

304. Texas Department of Water Resources. Nondischarge Permit No. 01941 Issued to Mobil Oil Company for a Full Scale In Situ Uranium Leaching Operation in Webb County, Texas. Permit Issued June 1975.

305. Texas Department of Water Resources. Nondischarge Permit No. 01942 Issued to Wyoming Mineral Corporation for a Full Scale In Situ Uranium Leaching Operation in Webb County, Texas. Permit Issued June 1975.

306. Texas Department of Water Resources. Nondischarge Permit No. 01949 Issued to Wyoming Mineral Corporation for a Full Scale In Situ Uranium Leaching Operation in Live Oak County, Texas. Permit Issued August 1975.

307. Texas Department of Water Resources. Nondischarge Permit No. 02050 Issued to Intercontinental Energy Corporation for a Full Scale In Situ Uranium Leaching Operation in Bee County, Texas. Permit Issued January 1975.

308. Texas Department of Water Resources. Nondischarge Permit No. 01890 Issued to Atlantic Richfield Company (operation now U.S. Steel) for a Full Scale In Situ Uranium Leaching Operation in Live Oak County, Texas. Permit Issued January 1975.

309. Texas Department of Water Resources. Nondischarge Permit No. 02025 Issued to U.S. Steel Corporation for a Full Scale In Situ Uranium Leaching Operation in Live Oak County, Texas. Permit Issued August 1976.

310. Texas Department of Water Resources. Nondischarge Permit No. 02130 Issued to U.S. Steel Corporation for a Full Scale In Situ Uranium Leaching Operation in Live Oak County, Texas. Permit Issued December 1977.

311. Texas Uranium Operations - U.S. Steel Corporation. Appliction for In Situ Uranium Mine Production Area Authorization - Pawlik Mine. 1980, 81 pp.

312. Thiede, D. M., and D. W. Walker. South Texas Uranium Leach Drilling and Completion Technology. Pres. at Uranium In Situ Symp., South Texas Minerals Sect., AIME, Corpus Christi, Tex., Sept. 25-28, 1977, 17 pp.

313. Thompson, W. E., W. V. Swarzenski, D. L. Warner, G. E. Rouse, O. F. Carrington, and R. Z. Pyrih. Groundwater Elements of In Situ Leach Mining of Uranium. Geraghty and Miller, Inc. (Tampa, Florida), Prepared for U.S. Nuclear Regulatory Commission Under Contract No. NRC-02-77-187, August 1978, 173 pp.; Available from National Technical Information Service, Springfield, Va., NTIS No. NUREG/CR-0311, $9.00.

314. Tiepel, E. In-Situ Mining of Uranium, Groundwater Restoration Methods and Field Test Data. Pres. at South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978.

315. Timmons, T. Pilot Testing In-Situ Leach in Texas and New Mexico. Pres. at South Texas Urainium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978.

316. Toth, G. W. Cost Estimating Technique for Uranium Solution Mining Projects. Pres. at Northwest Min. Assoc. 83rd Ann. Convention, Spokane, Washington, Dec. 2, 1977, 38 PP.; Available from NUS Corp., 4 Research Place, Rockville, Maryland 20850.

317. Toth, G. W. A Cost Model for Uranium Solution Mining. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section V, 42 pp.

318. Traut, D. E., I. L. Nichols, and D. C. Seidel. Design Criteria for Uranium Ion Exchange in a Fluidized System. Trans. Soc. of Min. Eng., AIME, V. 260, March 1976, pp. 24-28.

319. Traut, D. E., I. L. Nichols, and D. C. Seidel. Design Requirements for Uranium Ion Exchange from Acidic Solutions in a Fluidized System. BuMines RI 8282, 1978, 29 pp.

320. Traut, D. E., I. L. Nichols, and D. C. Seidel. Design Requirements for Uranium Ion Exchange from Ammonium Bicarbonate Solutions in a Fluidized System. BuMines RI 8280, 1978, 27 pp.

321. Trussell, P. C., D. W. Duncan, and C. C. Walden. Biological Mining. Can. Min. J., V. 85, No. 3, March 1964, pp. 46-49.

322. Tuovinen, O. H. Microbiological Aspects in the Leaching of Uranium by Thiobacillus Ferrooxidans. Atomic Energy Review, V. 10, No. 2, 1972, pp. 251-258.

323. Tweeton, D. R., G. R. Anderson, J. K. Ahlness, O. M. Peterson, and W. H. Engelmann. Geochemical Changes During In Situ Uranium Leaching with Acid. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 23-51; SME Preprint 79-43, 27 pp.

324. Tweeton, D. R., G. R. Anderson, and W. H. Engelmann. Bureau of Mines Research in Injection Well Construction and Environmental Aspects of In Situ Uranium Leaching. Pres. at 1978 AIME Ann. Meeting, Denver, Colo., Feb. 26-Mar. 2, 1978, Preprint 78-AS-111, 8 pp.

325. Tweeton, D. R., and K. Connor. Well Construction Information for In Situ Uranium Leaching. BuMines IC 8769, 1978, 19 pp.

326. Tweeton, D. R., and K. A. Peterson. Selection of Lixiviants for In Situ Uranium Leaching. BuMines IC.

327. Tweeton, D. R., T. R. Guilinger, W. M. Breland, and R. Schecter. The Advantages of Conditioning an Orebody with a Chloride Solution Before In Situ Uranium Leaching with a Carbonate Solution. Pres. at the 55th Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9490, 4 pp.

328. U.S. Energy Research and Development Administration. National Uranium Resource Evaluation Preliminary Report. Grand Junction Office, Grand Junction, Colo., Rept. GJO-111(76), June 1976, 132 pp.

329. U.S. Energy Research and Development Administration. Statistical Data of the Uranium Industry. Grand Junction Office, Grand Junction, Colo., Rept. GJO-100(76), April 1976, 87 pp.

330. U.S. Energy Research and Development Administration. Statistical Data of the Uranium Industry. Grand Junction Office, Grand Junction, Colo., Rept. No. GJO-100(77), Jan. 1, 1977, 107 pp.

331. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Campbell County, Wyoming. Docket No. 40-8200, Source Material License No. SUA-1199, Issued to Cleveland Cliffs Iron Company, May 1974.

332. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Johnson County, Wyoming. Docket No. 40-8511, Source Material License No. SUA-1273, Issued to Cotter Corporation (formerly operated by Uranerz, U.S.A.), June 1976.

333. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Highland Uranium Operations, Converse County, Wyoming. Docket No. 40-8064, Source Material License No. SUA-1064, Issued to Humble Oil and Refining Company (now Exxon Company, U.S.A.), November 1970.

334. U.S. Nuclear Regulatory Commission. Application to Conduct a Full Scale In Situ Uranium Leach Mining Operation, Highland Uranium Operation, Converse County, Wyoming. Docket No. 40-8102, as Amendment to Source Material License SUA-1139, Issued to Exxon Company, U.S.A., August 1977.

335. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Shirley Basin, Wyoming. Docket No. 40-8586, Submitted by Kerr McGee Nuclear Corporation, November 1976.

336. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Sweetwater County, Wyoming. Docket No. 40-8348, Source Material License No. SUA-1223, Issued to Minerals Exploration Company, December 1974.

337. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Crook County, Wyoming. Docket No. 40-8663, Submitted by Nuclear Dynamics, November 1977.

338. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Converse and Natrona Counties, Wyoming. Docket No. 40-8380, Source Material License SUA-1228, Issued to Rocky Mountain Energy Corporation, February 1975.

339. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Sweetwater County, Wyoming. Docket No. 40-8636, Submitted by Wold Nuclear Company, June 1977.

340. U.S. Nuclear Regulatory Commission. Application to Conduct Pilot Scale In Situ Uranium Leach Mining Tests, Johnson County, Wyoming. Docket No. 40-8304, Source Material License No. SUA-1204, Issued to Wyoming Mineral Corporation, Submitted July 1974.

341. U.S. Nuclear Regulatory Commission. Application to Conduct a Full Scale In Situ Uranium Leach Mining Operation, Johnson County, Wyoming. Docket No. 40-8502, submitted by Wyoming Mineral Corporation, September 1977.

342. Uranium Resources Inc. Application and Technical Report, Benavides In Situ Uranium Leach Project. 1979, 162 pp.

343. Uranium Resources Inc. Application and Technical Report, Longoria In Situ Leach Project. 1978, 175 pp.

344. Wadsworth, M. E., J. Milbourne, and S. Y. Han. A Kinetic Study of the Carbonate Leaching of Uranium Ore with Hydrogen Peroxide and Oxygen. To be Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979.

345. Wallace, R. E. Aspects of In Situ Solution Mining of Uranium. Pres. at Ann. Meeting of the Arizona Conf. of AIME, Dec. 3-4, 1978, 6 pp.

346. Walsh, M. P., W. M. Breland, R. S. Schechter, and J. M. Humenick. Multicomponent Ion Exchange at In Situ Uranium Solution Mining Sites. Tech. Report EHE-79-06, Univ. Texas, Austin, Tex., 1979, 103 pp.

347. Walsh, M. P., R. S. Schechter, and M. J. Humenick. Cation Exchange Processes in the Chromatographic Movement of Ammonium: Application to Restoration of Uranium In Situ Leaching Sites. Pres. at AIME Ann. Meeting, New Orleans, La., Feb. 18-22, 1979, SME Preprint 79-73.

348. Walsh, M. P., R. S. Schechter, and M. J. Humenick. The Displacement and Migration of Ammonium Ions from Uranium In Situ Leaching Sites. Proc. of New Orleans Symp. of Soc. Min. Eng., AIME, New Orleans, La., Feb. 18-22, 1979 (pub. as In Situ Uranium Mining and Ground Water Restoration, ed. by W. J. Schlitt and D. A. Shock), pp. 99-111; SME Preprint 79-73, 12 pp.

349. Walsh, M. P., R. S. Schechter, M. J. Humenick, A. D. Hill, and I. H. Silverberg. A Model for Predicting the Restoration of and Ammonium Migration from In Situ Mine Sites. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 4, Pt. 1, 1979, pp. 29-38.

350. Ward, M. H. Engineering for In Situ Leaching. Min. Cong. J., V. 59, No. 1, January 1973, pp. 21-27.

351. Westinghouse Electric Corp. Solution Mining of Uranium. Report 5923, 3 PP.; Available from Westinghouse Electric Corp., Nuclear Fuel Division, Box 355, Pittsburgh, Pa. 15230.

352. Westinghouse Electric Corp. Uranium Solution Mining. 1975, 16 PP.; Available from Westinghouse Electric Corp., Nuclear Fuel Division, Box 355, Pittsburgh, Pa. 15230.

353. Westinghouse Research Laboratories. Correlation of Rock Structure with Uranium Reserves. Tech. Report SM792, November 1975, 4 PP.; Available from Westinghouse Electric Corp., Nuclear Fuel Division, Box 355, Pittsburgh, Pa. 15230.

354. Westinghouse Electric Corporation. Detection of Lixiviant Excursions with Geophysical Resistance Measurements During In Situ Uranium Leaching. BuMines Contract No. J0188080, Final Report, December 1979, 156 pp.

355. White, G., Jr. Uranium: Continued Price Stability Seen for 1979, as Supply and Demand Stay in Balance. Eng. and Min. J., V. 180, No. 3, March 1979, pp. 145-147.

356. White, L. In Situ Leaching Opens New Uranium Reserves in Texas. Eng. and Min. J., V. 176, No. 7, July 1975, pp. 73-80.

357. White, L. Wyoming Uranium Miners Set Sights on Higher Production. Eng. and Min. J., V. 152, No. 12, December 1975, pp. 61-71.

358. Whiting, D. L. Hydrology of Dump Leaching and In Situ Solution Mining. Pres. at SME-AIME Fall Meeting, St. Louis, Mo., Oct. 19-21, 1977, Preprint 77-AS-336, 37 pp.

359. Whittington, D., and W. R. Taylor. Regulations and Restoration of In Situ Uranium Mines in Texas. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 2, Pt. 1, 1979, pp. 7-10.

360. Williams, R. L., P. Smith, and P. Osborne. The Environment, EPA, and the In Situ Mining of Uranium. Proc. Third Ann. Uranium Seminar, Wyoming Min. and Metals Section of AIME, Casper, Wyoming, Sept. 9-12, 1979, pp. 5-10.

361. Winkley, D. C. The Effect of Uranium Leach Conditions on the Kinetics of Hydrogen Peroxide Reactions. Proc. Update on Uranium Mining Technol. Conf., Reno, Nevada, Nov. 13-17, 1978 (pub. as Uranium Mining Technology, ed. by Y. S. Kim), Section X, 14 pp.

362. Winters, H. J., C. K. Chase, and R. B. Bhappu. Technical Notes Economic Evaluation for In Situ Extraction of Uranium. Pres. at 104th AIME Ann. Meeting, New York, Feb. 16-20, 1975, 5 pp.

363. Wood, S. Characterization of the Uranium Occurence in Pre- and Post-Leach Ore Samples from Sandstone Deposits in Texas & Wyoming. Pres. at the 53rd Ann. Fall Tech. Conf. and Exhibition, SPE, AIME, Houston, Texas, Oct. 1-3, 1978, SPE Preprint 7537, 8 pp.

364. Woolery, R. G. Processing Marginal Uranium Reserves. Pres. at Uranium Resource Tech. Seminar II, Colorado School of Mines, Golden, Colorado, Mar. 12-14, 1979, 10 pp.

365. Woolery, R. G., D. J. Hansen, J. A. Weber, and S. Ramachandran. Heap Leaching of Uranium -- A Case History. Pres. at 107th Ann. Meeting, AIME, Atlanta, Ga., Mar. 6-10, 1977, Preprint 77-AS-93, 20 pp.

366. Woolery, R. G., and S. Ramachandran. An Alkaline Heap Leach Evaluation. Proc. South Texas Uranium Seminar, Corpus Christi, Texas, Sept. 10-13, 1978. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, Ch. 14, Pt. 4, 1979, pp. 87-90.

367. Wyoming Mineral Corp. Uranium Solution Mining. 1976, 12 PP.; Available from Wyoming Mineral Corp., 3900 S. Wadsworth Blvd., Lakewood, Colo. 80235.

368. Wyrick, R. Solution Mining in Old Stopes. Pres. at Uranium Min. Technol. Conf., the Mackay School of Mines, Univ. Nevada-Reno, Reno, Nevada, Apr. 25-29, 1977, 16 pp.

369. Yan, T. Y. Calcite Control in In-Situ Uranium Leaching Process. Mobil Research and Development Company.

370. Yan, T. A Method for Removing Ammonium Ions from Subterranean Formation After In Situ Uranium Leaching. Pres. at the 55th Ann. Fall Tech. Conf. and Exibition, SPE, AIME, Dallas, Texas, Sept. 21-24, 1980, SPE Preprint 9491, 7 pp.

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Underground In Situ Mining—A New Mining Method

J. Wayne Erickson

Hundreds of millions of dollars have been spent to discover or purchase uranium resources that cannot, or should not, be mined with conventional methods if human, natural, and financial resources are to be conserved.

Three years ago, an industry-supported research study was initiated to determine whether a safer and more efficient (in terms of cost and environment) uranium mining method could be designed to replace existing techniques. As a result of this study, the "underground in situ" method was conceived and developed to the stage where it is now feasible. This approach involves: (1) sinking a shaft; (2) driving a drift on the ore horizon the length of the ore body; (3) drilling almost-horizontal long holes the width of the ore body; and (4) oxidizing and leaching the uranium drawn from these holes. The method is unique in that the uranium is removed with a minimum of disturbance to the natural hydrology of host or surrounding sands.

What the Concept Entails

In the late 1950's, Teton Exploration and Drilling Co. began drilling 1.5- to 3.7-m-diam (5- to 12-ft) shafts for uranium mines and stabilizing the wet, unconsolidated sands by filling the shaft with water and drilling mud until it was lined. Using this method, the water table was left undisturbed. Consequently, Teton's technique will be used with the underground in situ mining method.

The principle of maintaining the water table with a minimum of disturbance will also be followed while driving the drift, using slurry mining methods with a shield and shotcrete support system immediately behind the advancing face of the drift. The result will be a 3.4-m-diam (11-ft) concrete tube extending the length of the ore body with a 100-mm (4-in.) wall thickness and 150-mm (6-in.) ribs at 1.2-m (4-ft) intervals. Careful control of aggregate size, chemical additives, and shotcrete temperature will provide support equal to 75 mm (3 in.) of poured concrete for each inch of shotcrete.

In applications where this approach was used, shotcrete has provided a strong, competent support system. In instances where the shotcrete was applied to the back and ribs only, the toes of the ribs have "kicked in." To provide a flat floor and to support the drift floor and rib toes, a 450-mm (18-in.) layer of concrete will be poured.

The shotcreted tube will provide multiple drilling stations for horizontal long-hole drilling. Three parallel long holes will be drilled from each station, stacked on top of each other. Percussion drilling will compact the sands as drilling proceeds, sealing the long holes to permit probing, surveying, and lining. The holes will be lined with PVC tubing, and the tubing and the sand surrounding the holes will then be perforated with a hydraulic jet perforation system developed by the Bureau of Mines.

Alternate banks of long holes will be used to inject and collect the oxidizing and leaching reagents along the entire length of the ore deposit. Control of solution movement will be maintained by close monitoring of the solution and water pressures. A single pump will transfer the pregnant solution to the surface, where an ion-exchange plant will recover the uranium.

Due to greater exposure and better control of solution movement, the rate of production will be faster and more predictable than with other methods, resulting in 10% to 35% greater recovery of the total resource than possible with surface in situ leaching. Capital cost on a per-pound basis would be less than other methods; however, the total capital required to initiate this method would be slightly more than required for surface in situ recovery. The actual cost of operation on a per-pound basis would be equal or slightly less than that of surface-recovery leaching techniques.

In the event a conventional underground mine is considered as a viable alternative method, the risk factor of attempting underground in situ leaching as the primary method is extremely low. An expenditure limited to a few hundred thousand dollars may be the extent of risk, as nearly all the underground in situ work will be complementary to an underground conventional mine should this alternative be pursued.

Limitations of Surface Leaching

A quarter-century of surface in situ leaching experimentation has proven that many uranium ore bodies are leachable if exposed to the proper oxidizing and leaching reagents. Recovery of the uranium from ion-exchange plants is also a proven process. However, there are technical, economic, and environmental problems which limit the use of this leaching method.

In many cases where surface leaching is now being considered, the underground in situ method could be more desirable considering total pounds recovered, predictable recovery rates, development cost per pound recovered, and environmental problems.

A major problem arising from the use of wells is exposure of the uranium to the oxidizing and leaching reagents and the recovery of these reagents. Close well spacing is normally required to adequately expose the mineral, control solution movement, and recover the pregnant solution, due to (1) the varying lithology of the sands, (2) changes in permeability and porosity, and (3) chemical and physical contaminants in the host sands. Oxidizing and leaching reagents flow through the relatively highly permeable sections of the host sand; unfortunately, the uranium mineralization is not limited to these sections and appreciable quantities of the total mineral resource may not be oxidized or leached.

Surface in situ leaching activity has demonstrated that recovery wells have sharply declining production curves,

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64

caused by the chemical and physical contaminants released by the flow of the reagents. These contaminants reduce and sometimes eliminate the permeability of the sands surrounding the recovery wells. Proximity of the plugged sands to the recovery well determines whether the well can be reworked or if a new well is required.

These conditions severely restrict the spacing of wells; in Wyoming, for example, a 15-m (50-ft) grid appears to be the maximum. The cost of drilling closely spaced wells leads to definite economic limits to be applied to the ore body before surface leaching can be considered feasible. Even within the boundaries of a given uranium deposit, recovery of substantial portions of the deposit may not be economically viable. This often leads to high-grading when surface in situ leaching is used, and an appreciable percentage of the total resource will remain untouched and abandoned.

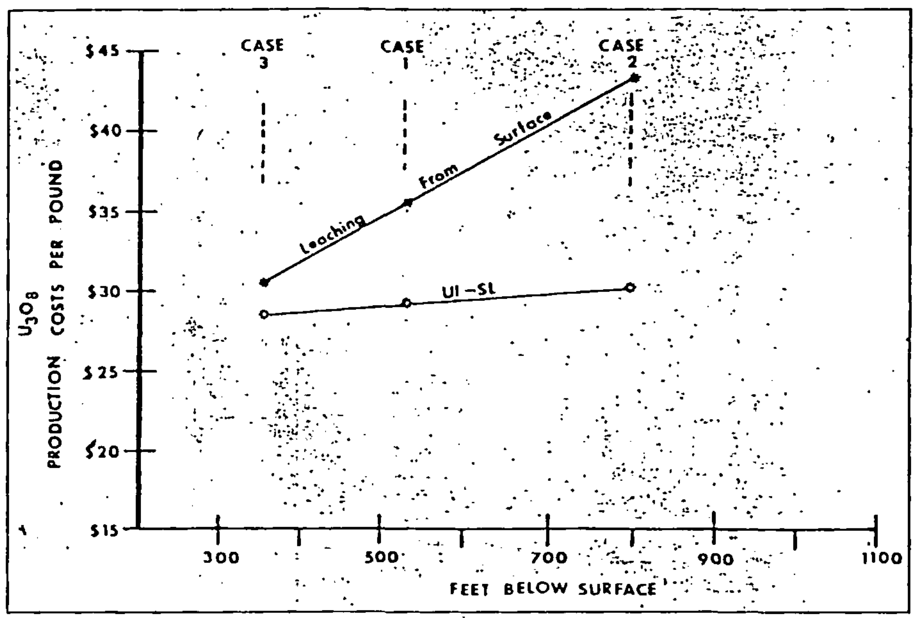
Other problems involved in surface leaching include: (1) maintaining a uniform temperature for the oxidizing, leaching, and pregnant solutions; (2) preventing surface injection and recovery lines from freezing; (3) control of direction and completion of new wells; and (4) controlling hydraulic pressure in deep wells when the recovery rates fluctuate. Unpredictable production rates and lack of definitive results with this method are also factors to be reckoned with, but perhaps the most important question is: How does one clean this underground environment involving injected chemicals when the recovery wells are only partially operable?

These factors combine to make surface in situ leaching feasible in only a limited number of instances. In addition, 25 years of development effort in this area have failed to establish an efficient or effective means of recovering uranium resources above the water table.

Limitations of Conventional Open-Pit and Underground Mining

Conventional open-pit mining is feasible only if the mineralization is large enough, shallow enough, and rich enough to support the cost of stripping, mining, and milling operations plus the cost of rehabilitating the environment. Capital requirements, reclamation costs, and the cost of radioactive waste disposal continue to spiral upward, thus limiting the application of open-pit methods to an estimated 20% of the nation's uranium resources under the existing price structure. Although open-pit mining will continue to make a substantial contribution to the total uranium production of the US in the near future, it is not the method which will be either economically or environmentally acceptable for bulk production of our uranium resources. Open-pit mining will decline in use as shallow, large, high-grade deposits are depleted.

Conventional underground mining faces significant physical, environmental, and economic problems caused by the need to recover deeper, more dispersed, and lower-grade resources located in wet, unconsolidated sands. These are not new problems; the industry has contended with them for almost 30 years, proving that shafts can be drilled, stations built, drifts driven and supported, and long holes drilled. However, it can also be demonstrated that conventional underground methods face definite limitations and also leave much of the total uranium resource untouched, since uranium is left in the ground if it is too dispersed, too thick, too thin, or too low-grade.



Results of a series of case studies showed that surface in situ leaching may be applicable to ore bodies less than 150 m (500 ft) deep but, under certain criteria, should not be used beyond a 90-m (300-ft) depth. Beyond those depths, underground in situ leaching is the more favorable method.

Ground support, water, swelling clays and shales, dilution, and ventilation problems contribute to the limited application potential of this method.

Factors Affecting Underground Mining

Despite the ever-increasing state and federal regulations designed to protect the miner, underground mining remains one of the most hazardous and unpleasant occupations, creating labor problems associated with high accident rates, high turnover (sometimes approaching 300% to 400% annually), cost overruns, and difficulty in maintaining targeted production rates. Experienced underground uranium miners are hard to find; thus the mining ranks are filled with unskilled and inexperienced workers. Tonnage produced per man-shift has generally declined despite the increased capital expenditures and growing mechanization involved in underground mining.

Environmental factors also complicate underground operations. The method must deal with the problems of operating a conventional mill, disposal of radioactive waste material, and eliminating subsidence problems. Ventilation and radioactive gases are also important considerations. Perhaps the most serious environmental problem is a mine's lowering of the surrounding water table, thus eliminating the alternatives of surface or underground leaching for that particular mine, as well as for any adjacent property. This effect can delay and even negate the possibility of recovering certain uranium resources.

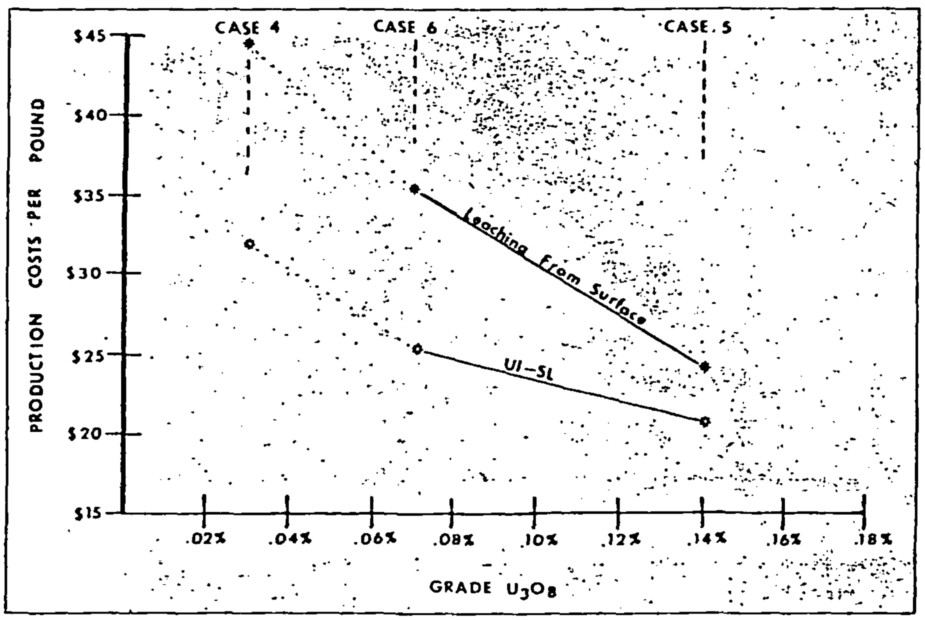
Companies have addressed the problem of high-grading in underground mining by implementing underground in situ leaching as a secondary method. This procedure has been only marginally successful. Before underground leaching can be effective as a secondary method, all underground workings must be sealed and the water level restored. Although this can be done, it is more efficient to design the mine with underground leaching as the primary method, since the company will have to seal as many as ten times the workings, and will have to contend with unnatural water courses which otherwise would not exist if conventional underground mining techniques had not been used.

In addition, the conventional underground mining operation requires a sizable capital investment for a conventional treatment plant. If followed by implementation of the underground in situ method, an additional investment

belt of 55 m (180 ft). This hypothetical deposit was located at a depth of 162 m (530 ft) and contained 227 000 kg (500,000 lb) of uranium per mile.

Study of the model indicated that the resource was too deep to mine by open-pit and that less than 60% of the uranium would be recovered by conventional underground mining. In comparing the surface leaching method with the underground in situ approach, indications were that the underground method would provide 12 times greater exposure of the uranium to oxidizing and leaching solutions than would the surface method. The technological problems of shaft sinking, drifting, long-hole drilling, and injecting and recovering solutions were addressed. Although existing technology could be used, there is much room for improvement.

A comparison of development costs revealed that it would cost \$15.07 per pound recovered for the surface leaching method, compared to \$5.41 per pound recovered for the underground in situ approach. The cost of leaching, reagents, and operation of the ion-exchange plant would be nearly equal regardless of the method.



Recovery rates of 68% are shown for both methods. Every indication exists that higher recovery rates should be expected when using the underground in situ leaching method.

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Conventional underground mining should therefore be attempted only if the underground in situ method is demonstrably infeasible in a given situation. Almost everything involved in recovering a resource by this method will be directly beneficial to underground mining should the conventional method become necessary; however, the reverse is not true. For conventional mining, larger shafts and ventilation systems, more long holes, increased water pumping capacity, and larger waste tonnage removal capacity would be necessary in comparison with the underground leaching approach, yet the in situ method will address the recovery of the total resource, not just the percentage defined as ore—ore which remains to be milled.

Case Study Results

As an example, a case study was made on a typical uranium roll front deposit 3.2 km (2 miles) long, with an average grade of 0.075% U_3O_8 (minimum cutoff grade 0.02%) and an average width throughout the mineralized

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Given the existing maze of governmental regulations, a mining company must now consider all alternatives in the initial phases of project planning, including underground in situ leaching. Furthermore, the government must introduce some flexibility into its requirements to allow a company to recover a resource with more than one method; for instance, with underground in situ leaching followed by a companion method should it prove necessary.

This new method will require one-tenth the normal labor force needed for a conventional operation, yet will produce more uranium. This permits a highly trained, well-paid, and stable work force, which can be interpreted to a 90% reduction in underground mine accidents. This aspect alone should be incentive enough for government and industry to work together in the implementation of this promising new method. □

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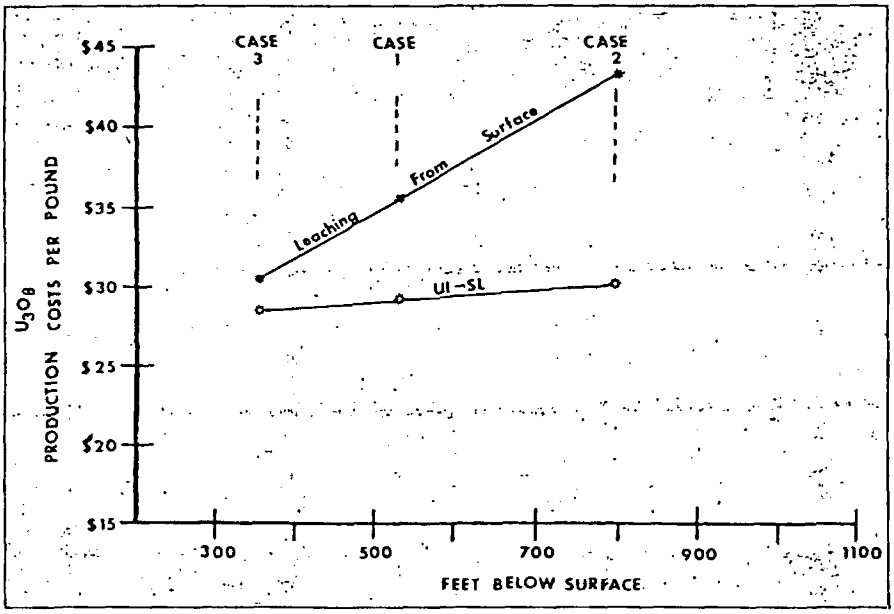
mated 20% of the nation's uranium resources under the existing price structure. Although open-pit mining will continue to make a substantial contribution to the total uranium production of the US in the near future, it is not the method which will be either economically or environmentally acceptable for bulk production of our uranium resources. Open-pit mining will decline in use as shallow, large, high-grade deposits are depleted.

Conventional underground mining faces significant physical, environmental, and economic problems caused by the need to recover deeper, more dispersed, and lower-grade resources located in wet, unconsolidated sands. These are not new problems; the industry has contended with them for almost 30 years, proving that shafts can be drilled, stations built, drifts driven and supported, and long holes drilled. However, it can also be demonstrated that conventional underground methods face definite limitations and also leave much of the total uranium resource untouched, since uranium is left in the ground if it is too dispersed, too thick, too thin, or too low-grade.



Results of a series of case studies showed that surface in situ leaching may be applicable to ore bodies less than 150 m (500 ft) deep but, under certain criteria, should not be used beyond a 90-m (300-ft) depth. Beyond those depths, underground in situ leaching is the more favorable method.

injection and recovery lines from freezing; (3) control of direction and completion of new wells; and (4) controlling hydraulic pressure in deep wells when the recovery rates fluctuate. Unpredictable production rates and lack of definitive results with this method are also factors to be reckoned with, but perhaps the most important question is: How does one clean this underground environment involving injected chemicals when the recovery wells are only partially operable?

These factors combine to make surface in situ leaching feasible in only a limited number of instances. In addition, 25 years of development effort in this area have failed to establish an efficient or effective means of recovering uranium resources above the water table.

Limitations of Conventional Open-Pit and Underground Mining

Conventional open-pit mining is feasible only if the mineralization is large enough, shallow enough, and rich enough to support the cost of stripping, mining, and milling operations plus the cost of rehabilitating the environment. Capital requirements, reclamation costs, and the cost of radioactive waste disposal continue to spiral upward, thus limiting the application of open-pit methods to an esti-

Ground support, water, swelling clays and shales, dilution, and ventilation problems contribute to the limited application potential of this method.

Factors Affecting Underground Mining

Despite the ever-increasing state and federal regulations designed to protect the miner, underground mining remains one of the most hazardous and unpleasant occupations, creating labor problems associated with high accident rates, high turnover (sometimes approaching 300% to 400% annually), cost overruns, and difficulty in maintaining targeted production rates. Experienced underground uranium miners are hard to find; thus the mining ranks are filled with unskilled and inexperienced workers. Tonnage produced per man-shift has generally declined despite the increased capital expenditures and growing mechanization involved in underground mining.

Environmental factors also complicate underground operations. The method must deal with the problems of operating a conventional mill, disposal of radioactive waste material, and eliminating subsidence problems. Ventilation and radioactive gases are also important considerations. Perhaps the most serious environmental problem is a mine's lowering of the surrounding water table, thus eliminating the alternatives of surface or underground leaching for that particular mine, as well as for any adjacent property. This effect can delay and even negate the possibility of recovering certain uranium resources.

Companies have addressed the problem of high-grading in underground mining by implementing underground in situ leaching as a secondary method. This procedure has been only marginally successful. Before underground leaching can be effective as a secondary method, all underground workings must be sealed and the water level restored. Although this can be done, it is more efficient to design the mine with underground leaching as the primary method, since the company will have to seal as many as ten times the workings, and will have to contend with unnatural water courses which otherwise would not exist if conventional underground mining techniques had not been used.

In addition, the conventional underground mining operation requires a sizable capital investment for a conventional treatment plant. If followed by implementation of the underground in situ method, an additional investment will be required for the ion-exchange plant.

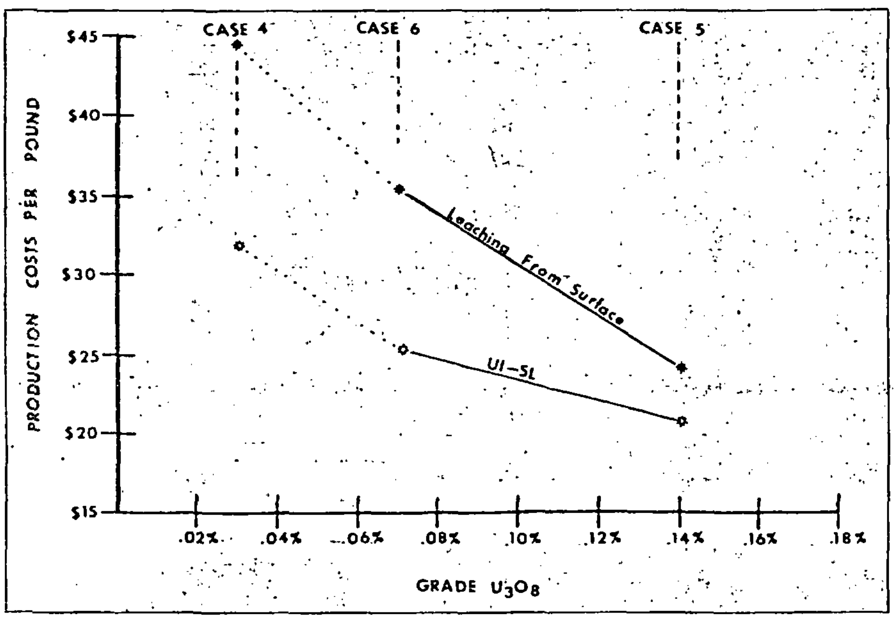
Conventional underground mining should therefore be attempted only if the underground in situ method is demonstrably infeasible in a given situation. Almost everything involved in recovering a resource by this method will be directly beneficial to underground mining should the conventional method become necessary; however, the reverse is not true. For conventional mining, larger shafts and ventilation systems, more long holes, increased water pumping capacity, and larger waste tonnage removal capacity would be necessary in comparison with the underground leaching approach, yet the in situ method will address the recovery of the total resource, not just the percentage defined as ore—ore which remains to be milled.

Case Study Results

As an example, a case study was made on a typical uranium roll front deposit 3.2 km (2 miles) long, with an average grade of 0.075% U_3O_8 (minimum cutoff grade 0.02%) and an average width throughout the mineralized belt of 55 m (180 ft). This hypothetical deposit was located at a depth of 162 m (530 ft) and contained 227 000 kg (500,000 lb) of uranium per mile.

Study of the model indicated that the resource was too deep to mine by open-pit and that less than 60% of the uranium would be recovered by conventional underground mining. In comparing the surface leaching method with the underground in situ approach, indications were that the underground method would provide 12 times greater exposure of the uranium to oxidizing and leaching solutions than would the surface method. The technological problems of shaft sinking, drifting, long-hole drilling, and injecting and recovering solutions were addressed. Although existing technology could be used, there is much room for improvement.

A comparison of development costs revealed that it would cost $15.07 per pound recovered for the surface leaching method, compared to $5.41 per pound recovered for the underground in situ approach. The cost of leaching, reagents, and operation of the ion-exchange plant would be nearly equal regardless of the method.



Recovery rates of 68% are shown for both methods. Every indication exists that higher recovery rates should be expected when using the underground in situ leaching method.

Results of a series of case studies showed that surface in situ leaching may be applicable to ore bodies less than 150 m (500 ft) deep but, under certain criteria, should not be used beyond a 90-m (300-ft) depth. Beyond those depths, underground in situ leaching is the more favorable method.

Given the existing maze of governmental regulations, a mining company must now consider all alternatives in the initial phases of project planning, including underground in situ leaching. Furthermore, the government must introduce some flexibility into its requirements to allow a company to recover a resource with more than one method; for instance, with underground in situ leaching followed by a companion method should it prove necessary.

This new method will require one-tenth the normal labor force needed for a conventional operation, yet will produce more uranium. This permits a highly trained, well-paid, and stable work force, which can be interpreted to a 90% reduction in underground mine accidents. This aspect alone should be incentive enough for government and industry to work together in the implementation of this promising new method. □

Underground Leaching at Cananea

Ore in Old Shrinkage Stopes Economically Treated by This Method—Scrap-Iron Precipitation Plants Both Underground and on Surface

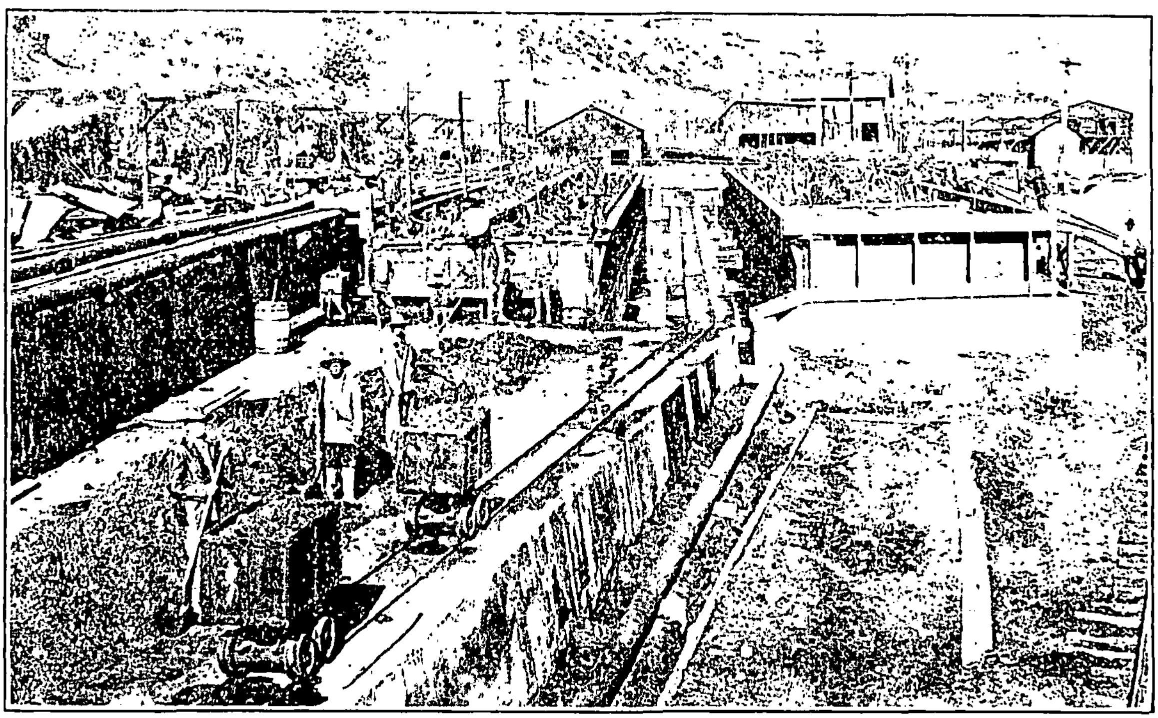
By C. C. Greenwood
Superintendent, Precipitation Department, Cananea Consolidated Copper Co.

C. C. Greenwood

UNDERGROUND leaching and subsequent precipitation of cement copper has now been commercially practiced at the mines of the Cananea Consolidated Copper Co., Cananea, Sonora, Mexico, for four or five years. Production this year is likely to be about 3,000,000 lb. by this method, the practice and economy of which will be described and illustrated in this article. The Capote 15 shaft is the deepest in the Capote Basin, where most of the mines of the company are situated, and where most of the pumping is done. As the mines are connected by drifts on the lower levels, the water finds its way to this shaft. This water always contained more or less copper in solution and was destructive to the pumps, so precipitation boxes were installed some years ago, filled with scrap iron, through which the water was passed to precipitate the copper and protect the pumping equipment. Later, the practice was started of intentionally passing water through old stopes for the extraction of copper. Precipitation on scrap iron was slow in the boxes constructed to care for this water, and the settling out of the iron salts reduced the grade of the product. H. M. Lavender, who was then in charge of operations, experimented with the use of air agitation in the boxes, this proving very successful, as it tended to keep the iron clean by preventing the precipitated copper from tightly plating it. It also kept suspended matter and precipitated salts in suspension, with the net result that the copper precipitate formed was of high grade and the capacity of the precipitation boxes was increased many times. The use of air in this way has been the biggest factor in making underground leaching a profitable operation.

Boxes were first installed on the 900, 1,000, and 1,200 levels of the Capote 15 mine. Later, an old filled stope was selected for leaching in the Oversight mine near the "Eleven Shaft." Precipitation boxes were installed on the 300 level of this shaft and later on the 400. These being successful, the leaching was extended to the Twelve shaft of the same mine, and boxes were installed there on the 350 level. Water from all the Oversight boxes was allowed to flow underground to the boxes in the Capote 15 mine, which extracted the last of the copper.

All of this work had been done on operating account



Surface precipitation plant

The cement copper on the drying platform is the product of fifteen days' operations. The Americans standing at the

—that is, all money spent in connection therewith had been charged to the copper so produced, and in 1924 more than a million pounds of copper, as cement copper, was produced at a cost of 4.32c. per pound. This included all expenditures at the mines, including installation costs, but no smelter charges were included. Up to that time, all of the boxes had been installed underground, utilizing convenient drifts which were widened sufficiently to accommodate the installation. Other drifts had been bulkheaded and used for storage of the head water for the plants.

New Precipitating Plant Put on Surface

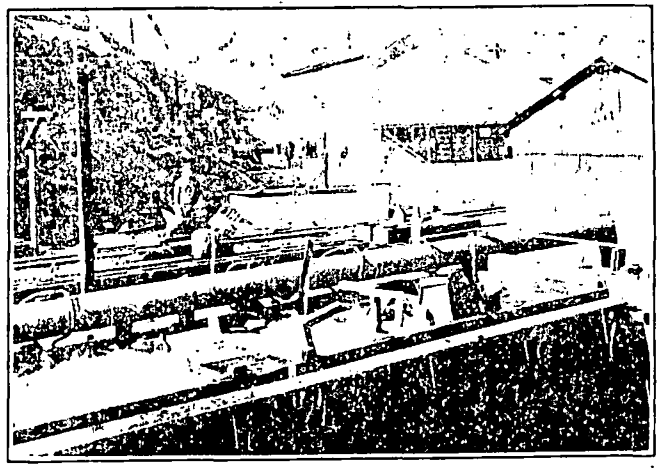
Desiring further expansion, it was decided to fit up a new precipitation plant on the surface where it would be more convenient to handle the scrap to the boxes and take the copper precipitate away from them; also, larger individual boxes could be built to accommodate larger pieces of iron. The location selected was near the Veta Five shaft at the portal of the Veta 9 tunnel. Here there was connection with the company railway and near by were old workings which it was desired to leach. The new plant was completed and was put into operation on Feb. 24, 1925. The complete cost, including necessary pumps, pipe lines, and blower, was $17,124. During 1925, this plant produced 695 wet tons of precipitate, containing 19.3 per cent moisture; or 563 dry tons, containing 485 tons of metallic copper. The precipitate shipped to the smelter assayed 85.48 per cent copper.

Precipitation boxes in this new plant are of 7,000 cu.ft. capacity, and the flow of solution through the boxes is obtained by a grade of one-fourth of 1 per cent. The water going to these boxes contained, on an average, 3,653 parts per million of copper in solution and the tailing water, 45 parts per million. Tailing water goes to a pump sump, from which it is returned to the old workings for leaching. It is necessary to discard a portion of this tailing water continuously, otherwise the iron salts in solution would become too concentrated. Some of the ground being leached permits the collecting of the water that has been through the stopes, at points where it will flow by gravity to the precipitation boxes, whereas other water must be pumped against a 300-ft. head. Fir pipe and redwood lined iron pipe is used, the latter being preferable on the discharge lines of the pumps. The pump parts in contact with the water are of acid-resisting bronze made in the local foundry.

For agitation, the precipitation boxes require about 1,750 cu.ft. of low-pressure air per minute, this air being furnished by a Root type blower. Each box is supplied with air through a $\frac{3}{4}$-in. air hose, plugged at the end, from which the air escapes through $\frac{3}{16}$-in. holes spaced about nine inches apart and staggered. The hose lies on the bottom of the precipitation box, being covered and protected by a narrow box into which the air discharges and from which it escapes through holes in the side, to bubble up evenly through the scrap iron. Formerly, the precipitation boxes were provided with a false bottom to support the iron, but this has been found to be undesirable. Another set of boxes of the same capacity is now being installed on this site.

Cost Is Close to 7c. per Lb.

During 1925 there was produced from leaching and precipitation, 2,012,108 lb. of copper at a cost of 6.87c. per pound in bullion at Cananea. This includes all equipment and installation costs. The consumption of iron is not known definitely, but is estimated to be about 1.2 lb. per pound of copper. Practically all the iron used so far has come from the company's scrap heaps, and more is available, but eventually iron must be purchased.



Tank and weirs ahead of precipitating plant

The precipitation boxes in use at the end of 1925 were as follows:

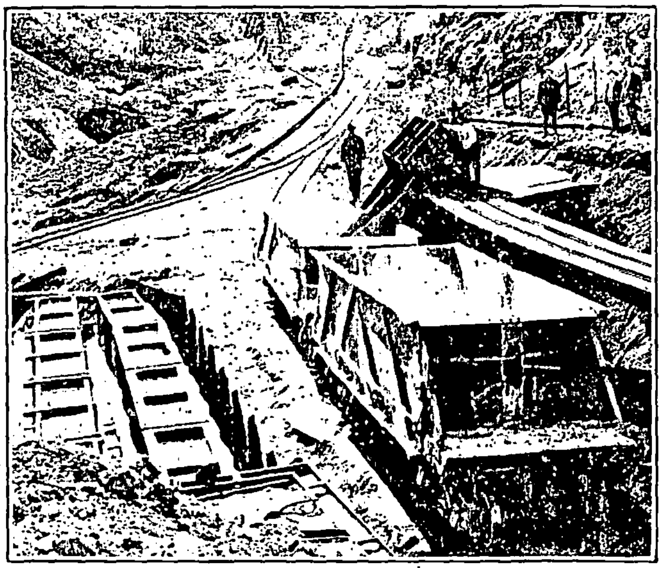
	Capacity, Cu.Ft.
900 level Capote	780
1,000 level Capote	1,086
1,200 level Capote	980
300 level Oversight	920
400 level Oversight	1,104
350 level Oversight	1,000
Veta surface	7,000
Total	12,870

Also, the new Veta surface plant, of 7,000 cu.ft., was nearly completed. Most of the country being leached is an unknown quantity so far as tonnage and grade are concerned. However, one stope—namely, the 3-39 stope of the Oversight mine—was situated so that it could be handled by itself and yielded some quite reliable data. The same might also be said of the Veta 15 stope, above the Veta 17 tunnel in the Democrata Gulch.

The 3-39 stope had been mined by the shrinkage system in 1916 and was left full of broken ore. This stope extended from the 300 level to the 200 and had an area of approximately 31x93 ft. The ore was of such a character that it broke in comparatively small pieces; its analysis was about as follows:

SiO_2	Al_2O_3	Fe	CaO	S	Cu	Cu, Acid soluble
49.0	15.4	10.8	0.5	9.2	1.5	0.05

Flashlight in the 3-39 stope



Loading platform and settling tanks

The copper occurred as secondary chalcocite in tiny veinlets and seams. Old workings above and below the stope were in good condition, so that the stope could be entered at any time and the water could be accurately distributed over its surface. The stope was estimated to contain 15,790 tons of broken ore of 1.50 per cent grade, or 473,700 lb. of copper.

Water was delivered to the stope through a 2-in. iron pipe, a hose being used to distribute the water, as it could be moved readily. A 50-ft. length was utilized, the last ten feet being perforated to spray the water and distribute it evenly over the surface. Leaching of the stope was started on March 12, 1924, and the test was considered complete on July 2, 1925, as on that date conditions made it impossible to continue to get accurate data on account of interference from other leaching operations. All the water which percolated through this stope was treated in the precipitation boxes on the 350 level of the Twelve shaft of the Oversight mine and no other water was treated in these boxes during the test period. During the test, 9,488,000 gallons of water was treated, containing 378,000 lb. of copper, or 80 per cent of all the copper estimated to be in the stope. The boxes made an extraction of 98.13 per cent of the copper in solution and were actually in operation 7,372 hours during the test. A tabulation is given in the accompanying table showing the details of operation of the boxes by months.

The "first wash of the stope" took 261 days and yielded 3,275,620 gal. of water, containing 229,977 lb. of copper, representing 48.5 per cent extraction of the total copper in the stope. "First wash of stope" is a term used to describe the actual time required to cover the total area of the ore with water. The back end of the stopes is usually washed first and then the wash water is moved when the analysis of solution is below the grade that it is desired to feed into the boxes. The water going into the stope had the following analysis, in parts per million:

Cu, Nil   Fe'', 140   Fe''', 100   Acid, Nil

Leaching of the stope is still in progress, though the test is completed.

The plant employed to treat the copper water from the 3-39 stope on the 350 level of the No. 12 shaft has a capacity of 1,000 cu.ft., consisting of ten 100-cu.ft. boxes. To accommodate this plant, one side of the crosscut leading from the shaft was blasted out for a distance of 150 ft., making the adit 10 ft. wide and 9 ft. high for the full length of the plant. The boxes are placed in a line on one side of the tunnel. This method leaves space to lay the mine track in front of the boxes. Beneath the track a sump 18 in. x 18 in. x 150 ft. was dug and the sides and bottom were faced with concrete. The copper is removed from the boxes in fifteen-day periods, by washing and shoveling through side doors into the sump. As soon as the water drains from the cement copper, it is shoveled into mine cars and run to the surface for shipment.

Air to agitate the solution in the boxes is supplied by a Connersville blower, with a discharge of 1,152 cu.in. per revolution, and driven by a 5-hp. electric motor. The plant operates efficiently with about ¼ cu.ft. of free air per minute per cubic foot of box on this type of installation, the pressure being 3 lb. per square inch.

Cost of Plant

Blasting side of drift	$600
Labor and material attached to boxes	1,000
Electric motor, blower, pipe lines, and air hoses	1,000
	$2,600

A plant of this type will produce 1,000 lb. of copper per day, when scrap iron is used to precipitate the copper, and will quite easily double this production with de-tinned iron.

Data of Operations in 3-39 Stope, Oversight Mine—350 Level Plant, No. 12 Shaft—Leaching and Plant Averages

			Heads, Pregnant Solution — Parts per Million					Discharge or Tailing Water — Parts per Million								
	Total Hours	Gals. per Min.	Cu	Fe''	Fe'''	Acid	Pounds Copper in Solution	Cu	Fe''	Fe'''	Acid	Total Fe in Solution	Lb.Cu in Solution	Gal. Water per Lb.Cu	Gal. Water per Month	Per Cent Extraction
March, 1924	228	10.0	11,550	490	816	130	13,428	1,080	7,990	1,221	50	9,211	1,036.9	10.80	136,800	90.63
April	456	13.2	6,913	....	.....	468	19,927	78	.....	....	19	.....	230.7	20.92	361,380	98.65
May	418	13.6	8,983	....	.....	468	25,577	87	.....	....	15	.....	264.3	13.91	343,140	98.97
June	475	11.8	10,688	....	.....	325	28,853	183	.....	....	3	.....	523.6	12.38	336,300	98.08
July	494	16.9	7,576	....	.....	251	31,125	86	.....	....	5	.....	388.2	17.64	501,600	98.63
August	513	20.0	5,939	....	.....	287	31,064	125	.....	....	17	.....	651.6	26.75	605,600	97.99
September	475	14.0	8,661	....	.....	311	27,158	83	.....	....	10	.....	317.0	18.51	399,000	98.78
October	494	11.3	10,227	960	1,880	281	27,809	21	.....	....	4	.....	56.3	16.09	336,300	99.76
November	437	11.9	9,808	....	.....	284	25,036	87	.....	....	3	.....	242.6	16.29	313,500	99.07
December	456	20.8	4,780	583	2,763	322	22,666	110	8,611	174	12	8,785	517.3	32.50	560,880	97.41
January, 1925	494	27.0	3,391	577	2,383	348	23,058	145	6,600	315	35	6,915	984.9	49.92	800,280	92.32
February	380	25.4	4,737	1,395	2,938	296	22,063	96	8,534	132	25	8,666	455.1	37.27	580,260	92.32
March	494	27.0	3,963	1,037	3,445	301	26,949	54	6,704	91	12	6,794	371.1	45.22	800,280	98.24
April	513	36.4	1,675	721	2,406	198	15,031	56	6,080	231	10	6,314	532.6	104.40	1,121,760	95.87
May	475	32.0	2,694	859	2,693	286	20,846	40	3,805	203	11	4,008	307.8	56.45	912,000	98.77
June	532	40.0	1,541	853	2,450	106	16,697	18	5,478	277	8	5,755	197.5	86.40	1,276,800	98.74
July	38	40.0	665	650	1,800	110	516	Nil	4,150	200	Neut.	4,350	......	197.60	91,200	100.00
Total	7,372	371.0	103,791	8,125	23,574	4,772	378,003	2,349	57,952	2,844	239	60,798	7,077.5	745.05	9,487,080	......
Average	....	21.8	6,105	812	2,357	281	22,235	138	6,439	316	14	6,755	416.3	43.83	558,063	98.13

Note: The iron in heads and tailings does not reflect the iron consumed in the boxes, for various reasons.

Cost of Underground Operations at Precipitation Plant

	Cents per Lb. Copper Produced
Blower air	0.15
Pumping	0.07
Sundries	0.03
Supplies	0.03
Superintendence	0.07
General mine repair	0.75
Installation	1.15
Actual attendance	0.03
Cleaning copper from tanks	0.70
Handling, drying, cleaning and shipping	0.30
Fills development	0.41
Iron from bone yard, handling from railway cars and stockpiles into precipitating vats	1.00
	4.69

The analyses shown in the accompanying table, which were made daily, were to check underground operations and to obtain a record of leaching in place and precipitation of copper, together with a reliable record of discharged water from the plants. The check on the cement copper produced from this plant against the solution analysis was so close that a tabulation of the results of the test was justified.

Leaching of the Veta 15 Stope

The Veta 15 is an old shrinkage stope in the bottom of which was left about 42,000 tons of 1 per cent copper ore containing about 840,000 lb. of copper. One-tenth of the copper was acid-soluble, equal to 84,000 lb. The ore in this stope consists of large rocks, many of which have caved into the stope from the back. The surface of the ore pile is uneven, varying in thickness from a few feet to forty or more. Copper, as in the 3-39 stope, occurs as secondary chalcocite, concentrated in the same manner along the tiny seams and veinlets. The rock, however, is harder and much more compact. Near this stope is a large tonnage of low-grade material, designated as "near ore," which may possibly be broken for leaching at a later date.

Leaching of this stope was started Feb. 24, 1925. The copper extracted, and the main facts in regard to the operation of the precipitation boxes up to Dec. 31, 1925, are as follows:

Hours Operating	Gals. per Minute	Parts Copper per Million Head	Parts Copper per Million Tailing	Pounds Copper in Solution	Extraction in Boxes, Per Cent
2,714	70.5	2,963	37	284,330	98.65

This copper production represents about 34 per cent of the total copper in this stope, and indicates that the ore is very amenable to this method of treatment. The first wash of this stope is not completed. From general indications about 40 per cent of the total copper will probably be extracted with the first wash.

The general analysis of cement copper shipped to the smelter during 1925 is as follows:

Wet Tons Cement Copper	Per Cent Moisture	Per Cent Silica	Per Cent Iron	Per Cent Copper
1,701.2	18.7	1.1	5.2	85.40

The general lay-out of the plants is shown in the photographs.

Electric Shovel Efficient

Increased output in a shorter period of time, together with a reduction in labor, resulted from the installation of an electric shovel by the Cowell Portland Cement Co. at Cowell, Calif. This company had been using steam shovels in its quarrying operations, but on account of the obvious economies and the ease of operation, decided to purchase an electric shovel. It was found that six cars could be loaded with the electric shovel while the steam shovel was loading five. The operator of the steam shovel was an experienced man, whereas the electric shovel was operated by a steam operator who had had no previous experience with electrical equipment. The dipper on the steam shovel had a capacity of three cubic yards; the electric shovel had a dipper of only 1¾ cu.yd. capacity.

In operating the steam shovel, nine men were required, including a shovel runner, a craneman, a fireman, and six pit men. Only three men were needed for the electric shovel; an operator and two pit men.

No boiler being required for the electric shovel, replacement of tubes, and troubles from leaks, scaling, and like occurrences, were eliminated. A further saving was found by the elimination of a night watchman for keeping the boilers fired at night. Approximately three-fourths of the time necessary to move from one location to the next is saved by the electric shovel, as temporary roadbeds and tracks are unnecessary.

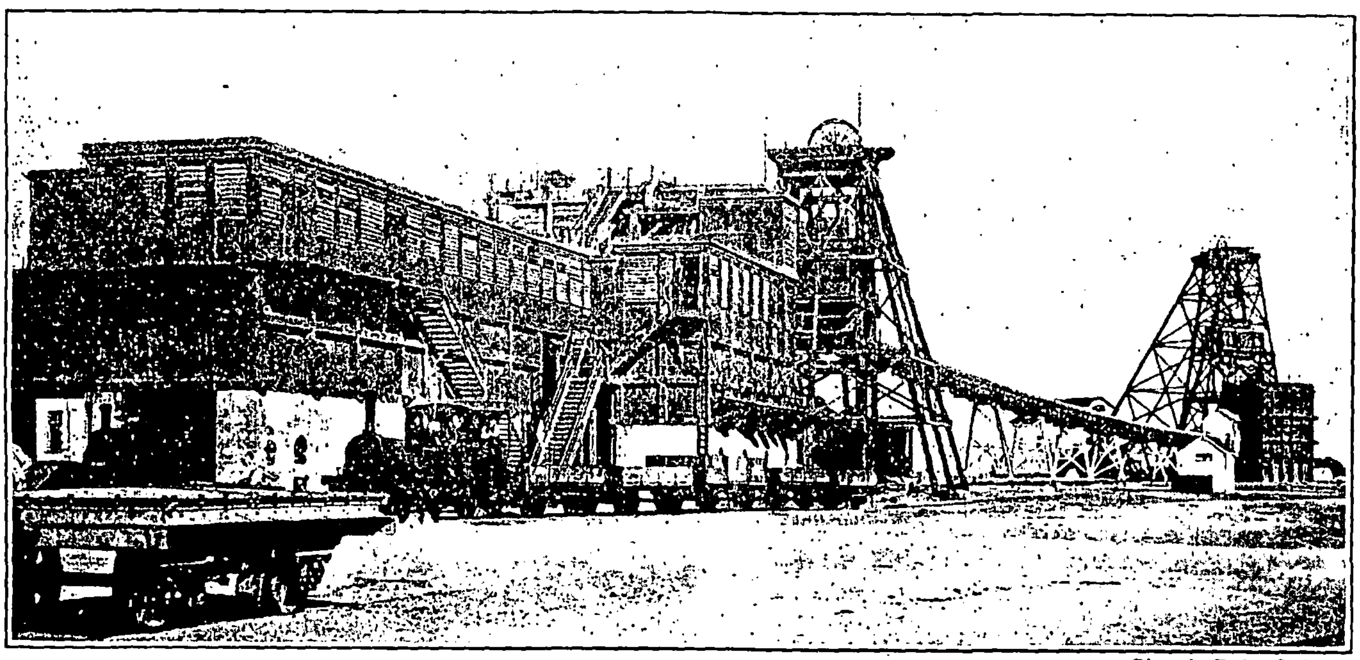


Photo by Ewing Galloway

Shafts of the Wallaroo copper mine, Wallaroo & Moonta Mining & Smelting Co., South Australia ing nahcolite through secondary ushing and photosorting; retorting ; and leaching alumina and soda ash om spent shale.

Superior, along with McDowell-Wellman Engineering Co., has reportedly tested and proven a new type of oil shale retort for the process. A circular grate retort concept patented by McDowell-Wellman is used in the oil retorting process developed by Superior. According to the company, oil can be produced in the range of $10 to $15 per bbl. Economics of the multimineral process depend on credits assumed for revenues generated by the other products.

A single module, costing $270 million, would process 28,000 tpd of oil shale feed to produce 4,500 tons of nahcolite, 13,300 bbl of oil, 700 tons of cell grade alumina, and 1,500 tons of dense soda ash. According to Superior, tests of raw nahcolite as a dry scrubbing agent have shown that it will absorb nearly 100% of the sulphurous oxides and up to 50% of the nitrous oxides from flue gas, under controlled conditions. The company states that 1 ton of nahcolite can clean the stack gas from the burning of about 25 tons of low sulphur coal and about 8 tons of high sulphur coal at present air pollution control standards.

Alumina would be extracted in the process at a price competitive with alumina from foreign bauxite, the company said.

Superior now owns 6,500 acres of contiguous oil shale land in Colorado, but the configuration of the land does not lend itself to efficient mining. According to Superior, construction of a module cannot be started until a land exchange has been completed with the Department of the Interior. Negotiations for the exchange have been under way since 1970. ☐

Getty studies surface mining of shallow sediments in mature oil field

GETTY OIL plans a pilot operation starting late this year to evaluate the commercial feasibility and environmental compatibility of open-pit mining and recovery of oil from diatomaceous sediments at McKittrick, Calif. Located 35 mi southwest of Bakersfield, the diatomaceous sediments of the McKittrick field overlie deeper traps in the Tremblor formation of Miocene age. The deeper traps have been developed by conventional wells.

If the pilot project is successful, it could lead to mining and oil recovery, adding the equivalent of four 100-million-bbl oil fields to California production. In oil parlance, a field containing 100 million bbl of crude is a giant. There are now 45 giants in California.

The target of the investigation is an estimated 412 million bbl of probable, in-place crude contained within shallow deposits of oil-impregnated diatomaceous sediments. The formations underlie 1,680 acres owned by Getty. The estimated content of crude oil in the diatomaceous zone is almost double the 218 million bbl produced by the entire McKittrick field since its discovery more than 80 years ago.

The diatomaceous sediments vary in depth from the surface to about 400 ft. Getty engineers estimate that the shallow deposits can be mined at an 8:1 ratio of overburden to oil-bearing sediment. The pilot plant will seek engineering data to facilitate the design and construction of a full scale processing plant and related mining facilities if commercial mining appears feasible. Oil wells in the McKittrick property have produced from zones about 1,500 to 2,000 ft deep for many years, but no oil has been recovered from the diatomaceous deposits because they did not respond to conventional recovery techniques.

No extraction processes have yet been commercially applied to the recovery of crude from the oil-impregnated diatomaceous sediments. According to Getty, it now appears that certain techniques devised to recover oil shale and tar sands could be modified for application.

If the pilot is successful, full scale operations could start up in late 1982. An independent consulting firm, DeGolyer & McNaughton, estimated oil-bearing diatomaceous sediments at 627 million tons, with an average grade of 28.188 gal per ton of crude. After retorting, the density is about 15° API.

If mining operations are undertaken, it will be necessary to plug producing wells on the property as the pit is extended. Ultimately, about 70% of the wells would have to be abandoned. As of June 1976, the wells that would be abandoned produced 5,158 bpd of oil with the assistance of steam stimulation. After mining operations, new wells would be drilled to recover the remaining recoverable deeper crude oil from the currently producing zones.

An E/MJ article by Earl C. Herkenhoff in June 1972 pointed out that mining of the 383 known shallow oil fields in the US is a practical way to increase oil production. Many such fields are merely downtip extensions of bituminous rock deposits that outcrop and are at depths of about 500 ft. With secondary or tertiary recovery techniques, the recovery of crude from conventional wells may be only 10-15%. Even with utilization of fire-flooding, steaming, and other exotic stimulants to recovery, the extraction ratio rarely is more than half the oil in the formation. Herkenhoff concluded that it might be possible to recover up to 90% of the oil in such shallow deposits by conventional surface mining methods.

Aside from in-situ combustion and condensation of vapors, various recovery schemes have been suggested for recovery of bitumens, including a number of retorting systems. The US Bureau of Mines pioneered a hot water flotation process in 1948. Great Canadian Oil Sands, which pioneered the recovery of Athabasca tar sands in Alberta, makes an initial extraction of bitumen using a hot water separation of pulped feed in a conical vessel. The bitumen is recovered as a froth from the separator.

In summary, Herkenhoff indicated that recovery of oil from shallow fields looked marginally economic in 1972; that such resources may precede development of oil shale because the economics look better; and that mining of such deposits could well open a significant energy resource. Most of his assumptions, however, were based on a mining operation qualifying for a 23% depletion allowance—the level used by the oil industry. ☐

Uranium leach project snarled in New Mexico's environmental rules

UNION CARBIDE CORP. has applied to the New Mexico Environmental Improvement Agency (EIA) for a permit to conduct experimental in-situ solution mining tests in a region 25 mi northeast of Albuquerque. The company plans to drill 10 holes, nine of which will monitor leaching activities in a central hole. Union Carbide will reportedly use a hydrogen peroxide leach solution. The leach liquor will be concentrated and then trucked to Benevides, Tex., for processing.

Union Carbide's proposal is the second plan for solution mining of uranium in New Mexico. Al Topp, of EIA's radiation division, said that leach mining of uranium will attract

(Continued on p 36)

more New Mexico uranium companies in coming years as better grades of ore are mined out. The first uranium solution mine in the state was developed in the Grants region by Grace Nuclear, but that operation has been halted.

A decision on the Union Carbide application hinges largely on the results of an appeal of the state's newly established ground-water regulations. Under the contested rules, a company is required to file a "discharge plan" on its operations, and the amount of pollutants that can be released to surface waters is limited. Parties to the appeal of these regulations, in addition to Union Carbide, are United Nuclear Corp., United Nuclear-Homestake Partners, Exxon, Gulf, Bokum Resources, Continental, Phillips, and Ranchers Exploration and Development.

Union Carbide may also face opposition from residents near the leach mining area, who are already fighting a copper leach mining test being conducted by Oxymin. County officials in the area are weighing a blasting ordinance that would require a company to obtain a blasting permit before undertaking mining. A bill in the state legislature to give county commissions the power to approve or disapprove leach mining activities failed on the grounds that it would encroach on EIA. □

(Continued on p 39)

New and expanding mines and plants

Company	Location	Project	Capacity Planned	Now	Units	Investment	Start	Class	Notes
Alcan Aluminium	Grande Baie, Que., Can.	sm	63M		tpy Al	$1B		B	Final decision due.
Brinex	Kitts-Michelin, Lab., Can.	mi			U			B	Environmental studies under way.
Cities Service	Miami, Ariz.	mi/pl	50M	42.4M	tpd Cu ore		1978	A	45M tpd in 1977.
Comalco	Weipa, Australia	mi	11.25MM	10MM	mtpy bauxite	$89MM	1979	AB	
Comalco	Bell Bay, Tasmania	sm	114.5M	95.6M	mtpy Al metal		1977	A	
Cominco	Trail, BC, Can.	cx	300M 200M	195M 170M	tpy Zn tpy Pb	$C125MM	1980	A	
Cons. Rutile	N. Stradbroke I., Australia	mi			rutile, zircon	$14MM	-	AB	Switching to dredging.
Cyprus Mines	Ghent, Belgium	pl			talc	$3MM	1978	AB	Doubling capacity.
De Beers Cons.	Orapa, Botswana	pl	4.5MM	2.3MM	mtpy ore		1978	A	Mining diamonds.
De Beers Cons.	Koingnaas, S. Afr.	mi	45M		carats/mo diamonds		1978	AB	
Denison Mines	Elliot Lake, Ont., Can.	mi	10M		tpd U ore		1977	A	
Dolomite Mining	Cebu I., Phil.	mi	700M		tpy dolomite rock		1980	B	Feasibility study under way.
Greenex	Marmorilik, Greenland	mi			Zn		1978	A	Opening adjacent ore zone.
Lucky Mc Uranium	Big Eagle mi, Wyoming	OPmi			U		1978	A	Mine life 10 years.
Maria Cristina Chemical Ind.	Ayungon, Phil.	mi			silica quartz		1977	A	OR 500MM t.
Minerals Exploration	Rawlins, Wyo.	mi	3M		tpd U ore		1978	A	
Mississippi Chemical	Carlsbad, NM	mi/pl			potash	$14MM		A	Doubling mi/pl capacity.
Northgate Exploration	Tynagh, Ireland	mi/co	650M	595M	tpy Pb-Zn ore		1977	A	
Potash Corp. of Saskatchewan	Saskatoon, Sask., Can.	mi/pl			potash	$12.2MM	1979	B	Increasing production 30%.
SABIC/Korf-Stahl	Al-Jubail, Saudi Arabia	pl	800M		mtpy Fe			B	Midrex direct reduction process.
Texasgulf	Kidd Creek, Ont., Can.	mi/co	5MM	3.6MM	tpy Cu ore		1978	A	
Vale do Rio Doce	Vitoria, Brazil	pp	3MM		tpy Fe pellets				New company—Cia. Italo-Brasileira de Pelotizacao.

Abbreviations: JV—joint venture; UG—underground; OP—open pit; OR—ore reserves; co—concentrator; cx—complex; mi—mine; pl—plant; pp—pellet plant; re—refinery; sm—smelter; MM—millions; M—thousands; B—billions; tpy—tons per year; mtpy—metric tons per year; A—projects now under construction; B—projects with development program but for which further financing may be required and for which construction has not yet begun; C—projects in the initial proposal stage.

Use of Ore Guides

SUBJ
MNG
UOG

Roland Blanchard

ORE GUIDES that are infallible cannot be established in a district until the last of its ore has been found; but in ...icts where development has been ...ied on over a period of years, and ...re parts of the ground have been ...oughly cut up, as in the older and ...e active mining camps, certain ore ...trols may be established that have ... proved to be nearly invariable for ...ground dissected, that leave little to ... imagination for that particular ...und, and that constitute the firmest ...s for guiding exploration into ad...nt poorly explored or wholly un...ored areas.

...o be practicable, ore guides must ...form to the following requirements:

... They must be based upon some ...ple relation to the ore, such as the ...ciation of orebodies with a certain ...phyry dike, fracture zone, or lime...e bed. As a general working prin...le, subject to few modifications, the ...e involved the reasoning back of an ...loration program, the less likely is ... program to yield ore.

... They must be so clearly defined ... so easy to grasp that the mine fore...n or shift boss will have no difficulty ...comprehending and applying them. ... day for the highly technically ...ased report, learned and mysterious ...tone, has passed. The geologist's ...gnized function today, be he con...ting or mine geologist, is to simplify, ... complicate for the operating staff, ... problem of finding ore. Unless the ...jor ore controls are so simply de...ed that the more responsible staff ...mbers engaged in operations under...ound are able to recognize them ...dily and grasp their significance, a ...al chance exists that factors impor... in ore discovery will be overlooked.

3. Ore guides must be larger and ...ier to find than the ore; otherwise it ...y cost more to find the guide than to ...d the ore itself. The pegmatite with ...een feldspar, which serves as fore...nner to the great Broken Hill lode (...ustralia), is an excellent guide, since ... presence signifies approach to the ...e. The envelopes or "shells" of ...ilized porphyry that surround the ...sseminated porphyry copper orebodies ... certain districts likewise are excel...nt guides in such districts, because ...ally they are two or three times as ...ge as the ore, and the more impor... ore occurs entirely within them. ... veins of native sulphur associated ...th the copper orebodies at the ...annia mine, on the other hand, are ...or guides, because the volume of ore ...ceeds the volume of sulphur many hundred times, the sulphur veins do not necessarily exist where the ore exists, and the veins, even when present, frequently are not found until the ore itself has been disclosed.

4. The major guides should be clearly distinguished as long-range and short-range guides, so the operating management may be in position to appraise the risk, and apportion expenditures accordingly. At Bisbee, for example, manganese at the surface in association with fissure silicifications is regarded as a guide to copper ore in the limestone beneath. A large surface area with prominent manganese showings corresponds usually to a large ore area, whereas a surface area with small and spotty manganese showings corresponds usually to small and spotty ore. The manganese showings occur as much as 1,800 ft. above the ore, and in many instances play out in depth before the ore is reached. Since they serve only as general guides to the ore areas, they are termed long-range guides. On the other hand, the larger occurrences of hematite are rarely more than 300 ft. from important ore, and nearly always touch that ore at some point. Since these hematite bodies lead directly to ore within a few hundred feet, they are termed short-range guides.

5. The guides should be demonstrated *facts* of ore occurrence that will stand without the crutch of theory to support them. Many ore occurrences may be better understood in the light of geologic theory. But when an exploration program becomes based to an important degree upon theoretical considerations, it is usually foredoomed to failure. One proved fact of ore association, such as the fact that the ore in a given district actually does occur repeatedly in a certain limestone horizon, or in another district occurs consistently a certain distance beneath the old erosion surface regardless of character of rock involved, is worth a dozen theories of where the ore ought to occur.

Though numerous ore guides exist in every mining district, the dominant guides usually may be reduced to three or four major ore controls so simple that even the miners have no difficulty in recognizing them. In favored districts a single major guide often dominates. Thus, at Christmas and San Pedro most of the important orebodies touch somewhere along the "marble line"; that is, along the imaginary line between the garnet zone and the marbleized and unaltered limestone lying beyond. Prospecting the marble line there would have disclosed most of the commercial ore produced by the mines to date. At Pilares the more important orebodies lie within 75 ft. of the outer edge, or periphery, of the 1,000x2,000-ft. fractured oval; prospecting this outer zone would likewise account for probably 85 per cent of the mine's production. At the O. K. mine, near Milford, Utah, the orebodies in the monzonite are associated with small quartz veins that make out from a central plug or cylinder of quartz; and the ore decreases irregularly but rapidly with distance from that central plug. These examples illustrate the simplicity to which prospecting may be reduced in especially favored districts.

IN some districts the problem is not so simple. In one of the larger garnet copper producers of the Southwest, prospecting the marble line would have yielded only a small percentage of the total garnet ore; some of the richest oreshoots were embedded deep within the garnet without touching at any point the marble line. The explanation is that at Christmas and San Pedro mineralization took place under comparatively quiet conditions, and the sulphide orebodies were deposited without disturbance in the reducing zone at the outer edge of the oxidizing zone—in other words, at the outer edge of the garnet-epidote zone, along the marble line. At the larger garnet district referred to, turbulent conditions prevailed throughout the period of ore deposition. Though some of the sulphide ore began depositing along the marble line, disturbances occurred which crushed and broke open the garnet areas; and the ore still in solution penetrated and was precipitated more or less at random within the garnet zone itself.

From the foregoing the fact is evident that ore controls established as dependable in one district may be wholly misleading in another district, even though the same ore mineral occurs at both places and the same type of deposit is involved. Because bends concave to the footwall of a vein are the ore localizers at one place, the assumption is not warranted that bends concave to the hanging wall may not be the ore localizers at some other place, even within a single district. Differences in the character of the faulting movements may readily account for this seeming discrepancy, as has been discussed and illustrated with diagrams by Hulin[1]. Emmons[2] has quoted from some unpublished data of my own, showing the results of checking up the prospector's conviction that vein intersections or junctions are the most favorable places to look for rich oreshoots.

Out of 137 cases that have come under my observation in which both legs of the vein carried commercial ore, 74.45 per cent proved richer at the intersection or junction; 11.68 per cent showed no appreciable change; and 13.87 per cent proved poorer at the junction. In this last class, fifteen deposits, or 10.95 per cent of the total cases under consideration, showed noncommercial values at the junction, and seven of the fifteen, or 5.11 per cent of the total, were entirely barren, even though profitable ore had been extracted from each of the veins near-by.

Again, the fact that a formation or type of rock is favorable or unfavorable to ore in a given district does not necessarily suggest that it is similarly favorable or unfavorable in another district. In various parts of western North America limestone is the ore carrier; shales and slates are so barren that often they are not considered worth prospecting. Yet in various parts of Australia the despised shales and slates carry large, rich oreshoots, Mount Isa being the outstanding recently discovered example. Nor can it be argued that the shales and slates are here mineralized because limestone is absent; for in several places in northwestern Queensland the ore solutions have passed by the limestone to deposit almost exclusively within the shales and slates. Even within the favored limestone belt of southwestern United States, at the Lookout property, in the Black Range, in New Mexico, the limestone traversed by the ore solutions shows only low-grade mineralization; whereas, an 18- to 20-ft. bed of the usually inhospitable quartzite, lying beyond, carries the commercial orebodies. These examples illustrate the danger of projecting too far or with too much assurance the ore habits of a given district, deposit, or occurrence.

USUALLY, each district presents examples of individual ore habits which must be in large part mastered before exploration programs may be intelligently and economically laid out. Such effective (though admittedly incomplete) mastery may require from several weeks in simple cases to several years in districts whose geology is complicated, as at Bisbee, Ely, Tintic, or Broken Hill; but during that period progress will be made which will continually reduce the exploration hazards. For guidance of the operating staff, as well as to guard against unsound deductions on the part of the geologist himself, the data on which conclusions are based should distinguish clearly between (1) agencies within the district that have a proved and direct bearing upon the finding of ore; (2) agencies within the district not yet fully proved but which seem likely to have such bearing; (3) agencies which have proved effective as ore guides in other districts under conditions closely resembling those in ground being explored. Manifestly, the third group is least reliable. Its inclusion is justified chiefly because of the resulting tendency to sharpen observation and maintain alertness in all concerned.

IN ferreting out the less obvious guides, the temptation to surrender simply because a problem is difficult and seemingly insoluble must continually be combated. Shortly after the World War a certain valuation engineer declared to me that after many years of familiarity with the Bisbee limestone deposits he had concluded that the only way limestone ground could be appraised in the district was on the basis of proximity to Sacramento Hill; any other method was hopeless. On that assumption, ground would be regarded as decreasing uniformly in value outward into the limestone from the main ore locus, Sacramento Hill. This sort of nonsense implies physical and mental laziness on the part of the person making the statement. To work out detailed ore controls in ground like that at Bisbee so as to permit proper evaluation of the various limestone areas is no simple task; but the fact that it has been done proves that it may be done again.

WHEN compiling for discussion in a report the ore guides of a district, one should first create a perspective, or mental framework, upon which to hang the various details. A private report on an Arizona property which I have seen drew an analogy between the deposit and an ocean liner. Commercial ore, dependent upon secondary enrichment, was represented as the deck and that part of the hull above water line; unenriched primary ore, too low in grade to be profitably extracted, was represented as the hull below water line. Although more than a dozen detailed guides were subsequently discussed, the reader was not confused, because each guide was referred to its respective position above or below water line, and likened to some well-known feature of the ship, such as the smokestack or engine room. Shift bosses are usually able to visualize the commercial aspects of a deposit when thus portrayed.

Discussion of any specific guide should be brief. It should contain a clear, full statement of the relation of that guide to the problem of finding ore, together with pertinent applications. Beyond that everything should be ruled out, however tempting the occasion for the author to air his ideas or knowledge. Ordinarily, for such discussion two hundred to five hundred words suffice; rarely are more than a thousand words justified, including references to illustrative cases. If facts alone are presented, as distinguished from ideas and theories, and brevity of style is cultivated, prolongation of the discussion of a single feature beyond six to eight hundred words is usually difficult. Should the author feel that discussion of geologic theory is essential, the appendix constitutes an appropriate cemetery for its interment. That the more reports one writes on the subject of ore finding, the less need does there seem to be for discussion of theory, is a striking fact.

The number of guides to be discussed varies with the scope of the report. Fewer usually will be available or required for an isolated, moderately small deposit than where a major mining district is involved. In a certain silver-lead district in the andesite belt of New Mexico which I have examined, oreshoots occur wholly within a 2-mile length of the X fault zone, which is variably from 40 to 110 ft. wide. Within that zone commercial ore is restricted to sections which exhibit pronounced concave bends with respect to the footwall. Within those bends ore is still further confined to the more highly brecciated areas. And within the brecciated areas the richest ore occurs where the andesite is strongly altered to chlorite with minor epidote. Leached products above the ore are locally helpful in directing exploration, but this guide is of limited application because (1) oxidation does not penetrate below the 150 level; (2) most of the surface ore has been mined; (3) the ore is lenticular down the dip, so that an oreshoot does not necessarily extend upward to the oxidized zone. The major guides in this case are:

1. X fault zone.
2. Concave bends with respect to the footwall.
3. Brecciated parts of the bends.
4. Highly chloritized areas within the breccia portions.
5. Leached capping (local).

Several minor guides dealing with the beginning and ending of veins within the chloritized areas need to be discussed, but so far as the general operating staff is concerned the guides enumerated suffice. For the Ely district I used the classification delineated in the following:

General Guides—three headings.
Guides Within the Porphyry:
A. Structural Features—five headings.
B. Expression of Mineralization Above the Ore—two headings.

[1]Carlton D. Hulin. *Engineering and Mining Journal*, Vol. 127, p. 228, 317. Also, "Structural Control of Ore Deposition." *Econ. Geol.*, Vol. 24, No. 1, January-February, 1929.

[2]W. H. Emmons. Vol. 76, p. 308, *Trans. A.I.M.E.*

Within the Limestone:

A. Structural Features—thirteen headings.

B. Expression of Mineralization Above the Ore—eight headings.

C. Expression of Mineralization Below the Ore—four headings.

Miscellaneous—seven headings.

Work done in the Ely district since my visit in 1928 presumably has added to the guides in certain divisions and probably eliminated others that were tentatively included. A list of ore guides once cataloged does not remain stationary so long as exploration continues; imagination remains active, and application and search for new guides are energetically enforced.

With the current guides established for a given mine or district, their application in mine exploration has been found in some instances most effectively carried out through discussion in conference, at which the presence of all members of the operating staff down to and including mine foremen is desirable. Each member is generally handed, a week in advance, the list of prospects to be discussed, and each is required to submit in writing his conception of the favorable and unfavorable factors affecting a given prospect. Mere verbal discussion is unsatisfactory; it permits shirking, and often degenerates into irresponsible and flippant quibbling. The written statement, on the other hand, fixes responsibility, compels sound reasoning, and conduces to sustained, clear thinking. By the time the favorable and unfavorable aspects of a prospect, as reasoned out by the full operating staff, have been collected and threshed over in conference, each member has obtained a vivid conception of why that prospect is to be run, what its chance is for success or failure, and what guides or ore localizing factors he must watch for as exploration progresses. Because each member has contributed something, each feels a personal interest in the outcome.

At times the most carefully thought-out program will be vitiated by accident or by factors that could not have been reasonably foreseen. In the limestone deposits of one Southwestern copper district, for example, certain surface evidences of mineralization occur that are clearly associated with ore deposition. Either by direct or devious routes those evidences have been found to lead downward to ore. But in several instances the orebodies have been cut out by an intrusion of post-ore rhyolite, which, with true irony, failed to destroy the evidence of vigorous mineralization above the ore. To have exploration encounter such a condition when everything pointed to a large, profitable orebody cannot but be disheartening. But since none of us is omniscient, we must become reconciled to the fact that in carrying out any prospecting campaign, disappointments will ensue—sometimes through oversight on our part, sometimes through the vagaries of mineralization which were not subject to analysis prior to actual exploration. A certain allowance must be made for this, particularly when prospecting limestone areas, where ore is characteristically erratic in behavior and occurrence. But that does not mean we should go to the other extreme, and fail to avail ourselves of the most carefully reasoned program that is possible at the time.

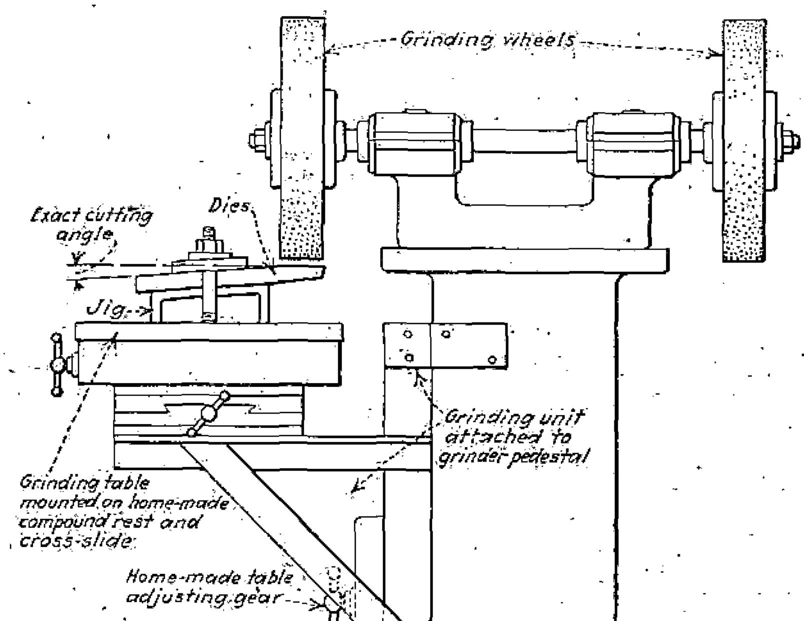
As Augustus Locke once stated to me[2], we must remember that we are not competing with a technique that is 100 per cent perfect. The science of finding ore is probably not more than 35 per cent efficient today. If we improve that efficiency 10, or even 5 per cent, we are accomplishing a great deal.

Mistakes that result from unsound deductions or lack of thoroughness in reasoning and applying existing data may be largely eliminated where proper distinction is insisted upon between ascertained fact, reasonable probability, and the more remote conjecture; and where conscientious attempt is made to recognize and acknowledge the degree of doubt involved in using guides not yet securely established in a district. Mistakes caused by the undisclosed vagaries of mineralization are not as immediately subject to control. Usually they can be reduced only in the proportion that such vagaries reveal themselves as distinct district habits. The important point to be kept in mind in any district or with any deposit is that, although a part of the ground may have been rather thoroughly cut up, and its ore habits ascertained, other large, well-mineralized areas have usually been but little explored, and concerning their ore habits little has been definitely established. To assume that most of the guides found dependable in proved areas will apply in adjacent untested ground is reasonable; but so long as ore continues erratic in occurrence, constant watch and diligent search must be maintained, both for local exceptions and for new, broad ore controls.

[2]Augustus Locke, oral communication. Acknowledgment for several ideas here discussed is due Mr. Locke, upon whose staff many years ago I acquired my first training in the use of ore guides.

Cutting Tools Are Cheaply Reconditioned

To AVOID the unsatisfactory manual grinding of pipe-threading dies and other cutting tools, and to render them serviceable at a lower cost, Charles R. Clarkson, master mechanic at the Hayden smelter of the American Smelting & Refining Company, Hayden, Ariz., built the attachable grinding unit shown in the accompanying sketch. The machined table is mounted on a home-made compound rest and cross-slide that rest on a frame made of channel and angle iron, which is fitted with an adjusting gear and secured to the grinder pedestal. Jigs are provided for the various grinding operations, to expedite the correct setting up of tools to be ground and to make possible the simultaneous grinding of several dies or tools at a material saving.



UNITIZED, PORTABLE, FLOTATION-LEACH PLANTS FOR TREATING PARTIALLY OXIDIZED GOLD AND SILVER ORES

by

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ABSTRACT

Resource Engineering and Development, Inc. is designing and building a portable 150 to 225 TPD, flotation-cyanide leach plant with unitized, skid-mounted components. This plant design, with its portability, low capital investment, and high recovery of silver and gold from many partially oxidized ores, is well suited to treat many small, high-grade deposits, old waste dumps, and old mill tailing piles. A description is given of flotation and/or cyanide leach tests run on about 17 partially oxidized, newly mined ores; waste dump materials; placer slimes; and old mill tailings.

UNITIZED, PORTABLE, FLOTATION-LEACH PLANTS FOR TREATING PARTIALLY OXIDIZED GOLD AND SILVER ORES

INTRODUCTION

The large increase in precious metal prices over the past few years has generated considerable interest in the milling or remilling of many old, partially oxidized, mine dumps, tailing piles, stope fill, and ores mined from oxidized surface zones.

The present technology is often inadequate to treat these oxidized gold and silver ores. In several instances, heap or pad leaching plants have failed because of low metal recoveries and the necessity of winter shut-downs. Many of these ores respond poorly to treatment with either flotation or cyanide leaching alone.

The size and grade of many of these types of deposits will usually not warrant the expenditure of capital needed for a conventional, stationary, flotation or cyanide leach plant.

A simplified, unitized, portable, flotation-cyanide leach plant may be the solution to these problems. Considerable testing has indicated that a combination flotation-leach plant will successfully recover most of the silver and gold values from many of these oxidized ores.

Resource Engineering and Development, Inc. (R.E.D.) is currently designing and building a 150 to 225 ton-per-day (tonnage dependent on ore feed size) unitized, portable, flotation-leach plant for Silver Bullion Milling and Refining, Joint Venture. The first operating site will be near Hailey, Idaho, where the plant will be used to treat old flotation mill tailings, old minus 1/4 inch jig mill tailings and several old mine dumps (95% minus 2 inch). Eventually, the plant may be used to treat other company-owned or custom ores in the Central Idaho area or it will be moved to another site(s).

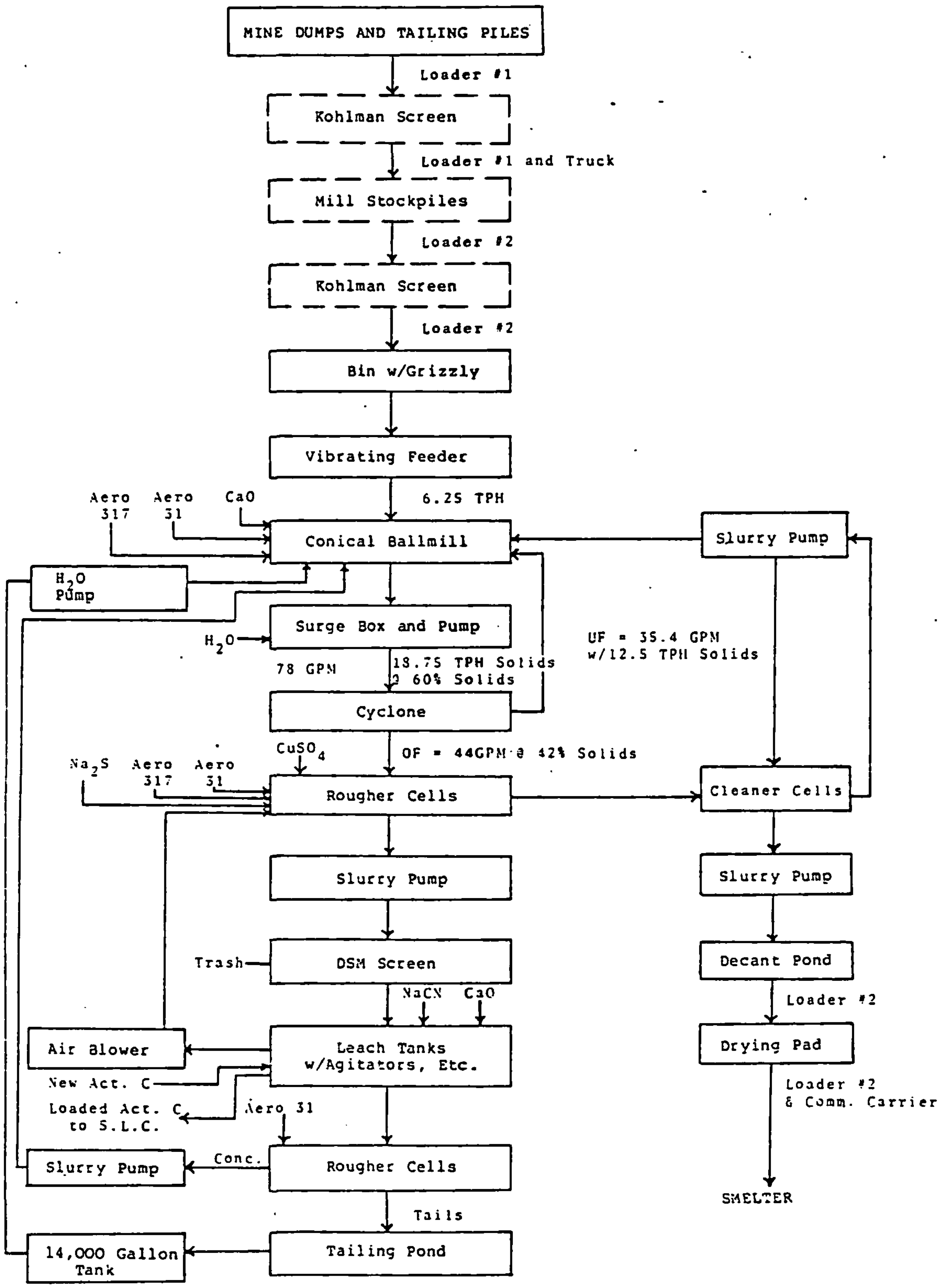
UNITIZED, PORTABLE, FLOTATION-LEACH PLANT DESIGN

The general concept of the unitized, portable, flotation-leach (UPFL) plant is one in which both flotation and carbon-in-pulp cyanide leach circuits are incorporated into a greatly simplified mill design of commercial size, built in unitized, skid-mounted modules.

The flowsheet of a 150 to 225 ton-per-day plant of this type is as shown in Figure 1. In this plant design, prescreened, minus 2-inch ore will be periodically loaded into a 35 ton ore storage bin, from which it is fed at a constant rate to a

FIGURE 1

FLOWSHEET OF 150-225 TON-PER-DAY PORTABLE MILL FOR PROCESSING OLD SILVER AND GOLD MINE DUMPS



7' x 48" Hardinge conical ball mill with an internal grate. A grizzly (6" opening) on the storage bin and a single, close-set jaw crusher might be used in the circuit if coarse, hard ores were to be fed to the plant. The ball mill discharge will be classified by a cyclone which produces an overflow product with a pulp density of about 40% to 45% solids and a product size of about 95% minus 65 mesh. Flotation reagents and recirculated solutions from the tailing pond will be added to the grinding circuit. The cyclone overflow will go to a DSM stationary screen with a 28 mesh deck to remove oversized ore particles and small wood pieces from the plant feed slurry, and then to a bank of rougher flotation cells with a 10 minute retention time. The flotation concentrates will be cleaned once or twice, as required, and then, since they are present as a small tonnage/day, sent to a decant pond and a concrete pad for air drying prior to shipment to a custom smelter. The flotation tails, at a pulp density of about 38% to 43% solids, together with added lime and sodium cyanide, will flow continuously through a series of eight, 9' diameter x 10' deep, agitated tanks where a simultaneous, 8 to 12 hour, carbon-in-pulp leach with 6 x 12 mesh carbon will be effected. In this leach circuit, the activated charcoal will be periodically advanced from one tank to another and retained in each leaching unit by a R.E.D. proprietory reactor design. The activated charcoal, which is expected to be loaded to about 500 oz/ton of precious metals, will be periodically removed from the first tank in the leaching system and shipped to a carbon stripping and regeneration and refining facility where pure gold and silver ingots will be produced. The leached tailings may be refloated for their remaining sulfide minerals and fine activated carbon in a second flotation step. The final tailings will be sent to an environmentally acceptable tailings pond with a proprietory R.E.D. design that allows for additional leaching and rinsing of the tailings in the tailings pond. The decanted solutions from the tailings pond, which contain small amounts of NaCN and CaO, will be collected in a holding tank and then returned to the grinding circuit.

This portable plant is to be "unitized", or built as several skid-mounted modules in a shop some distance from the mill site. The individual units that will comprise the plant described in Figure 1 would be: (1) the ore storage bin and feeder; (2) the ball mill, surge box, motor, cyclone pump, and cyclone; (3) the DSM screen, rougher and cleaner flotation cell banks, and two slurry pumps; (4) 8 agitator tanks as single tanks or units of two; (5) a small bank of rougher flotation cells and pump(s) (optional); (6) a power panel and; (7) a power plant (optional).

On-site preparations and facilities will include: (1) the water supply system; (2) the power system if a generator is not used; (3) trailer housing for the mill manager; (4) the plant sewer system; (5) portable office, lab and shop buildings; (6) concrete pad and shed for mill; (7) a ramp to the ore bin; (8) the tailings pond; (9) a concrete concentrate decant pond and drying pad; (10) parking and ore storage areas and;

(11) solution and pulp piping systems.

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This mill design has several features that are different than most plants that have been built to process partially oxidized gold and silver ores. First, it utilizes both flotation and cyanide leaching circuits. This should (1) insure a maximum recovery of both the sulfide and oxide gold and silver minerals, (2) give it a flexibility to efficiently treat a wide variety of ore types, and (3) reduce the pulp retention time requirements in both the flotation and leaching circuits. Secondly, the flowsheet is greatly simplified, i.e.; the complete or partial elimination of the crushing circuit should greatly reduce the plant and operating costs; the replacement of the flotation concentrate thickening and filtering section with a concrete decant pond and drying pad should also reduce the mill capital and operating costs and; the short term, simultaneous, carbon-in-pulp leach circuit should minimize the number and size of leach reactors that are required and reduce reagent consumptions. Thirdly, the portable nature of the plant makes it possible to build most of the plant in a shop at a greatly reduced cost, as compared with field construction; it divides its capital requirements between several sites; and keeps its resale value high.

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Capital and operating costs have been estimated for the 150 to 225 tons-per-day Hailey, Idaho plant, and its associated carbon regeneration and stripping and gold and silver refining facilities.

The capital costs, which include used mining equipment costs (1 track loader and 1 truck); mill equipment (new and used), modular assembly, and transportation to the millsite costs; millsite preparation costs; reagents and supplies for the mill; the carbon stripping and regeneration and refining circuit costs; engineering costs; overhead costs; environmental costs; startup costs; and miscellaneous and contingency costs; are estimated at $1,000,000 .

Mining, milling and refining costs are estimated at $12.04/ton on old flotation mill tailings, $19.25/ton on old jig tailings, and $22.38/ton on old mine dump ores. These costs do not include truck hauling costs over 4 miles, royalties paid on the ores, or plant amortization costs. These ores consume about 2.7 pounds of sodium cyanide per ton.

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In the leaching tests, the flotation tailings that remained after sampling were placed in a four liter beaker; NaCN, CaO and 120 grams of 6 x 12 mesh activated carbon reagents were added; and the pulp was stirred with a mechanical agitator with air bubbling through the pulp, for 8 to 24 hours. Four hundred ml pulp samples were taken periodically and analyzed to determine gold and silver dissolutions, cyanide consumptions, and the degree of adsorption of precious metals by the activated carbon.

It is usually better to have the flotation step first rather than a leaching step because (1) sulfide removal reduces the cyanide consumption in the subsequent leach step, (2) the flotation concentrate is higher grade when floated before the leaching step, and (3) the amount of activated carbon required in the system is less, as much of the silver and gold is removed in the prior flotation step. In some cases, however, the cyanide leach seems to clean the mineral surfaces and thereby improves a subsequent flotation step.

The tests shown in Table 1 indicate that many oxidized silver and gold ores respond quite well to the combined flotation and cyanide leaching processes, but poorly to either process used alone.

TABLE 1 (continued)

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Ore No.	Ore Source	Ore Grade, oz/ton or %	Ore Descrip- tion, Grind	Process Tested	Overall Ag or Au Recovered, %	NaCN Consumed, $/ton	Leach Time, Hours	Overall Flotation Cleaner Conc. Grade, oz/ton or %
8	Utah	5 Ag 0.01 Au 5 Pb	Underground, 95% -100m (mostly sul- fides)	F	80-83 Ag			40-80 Ag
9	Colorado	5 Ag 0.03 Au	Mine Dumps, 98% -100m	F1 L F2	11.5 Ag 50 Au 77 Au 50-62 Ag 50-62 Ag	8	24	21 Ag 21 Ag
10	Southern California	4.5 Ag	Mine Dumps, 95% -100m	F L	none poor	8	24	
11	Southwest Montana	30.3 Ag 0.02 Au 0.54 Cu	Mined Surface Ore, 80% -100m	F L	60 Ag 87 Ag	10-15	24	565 Ag
12	Central Utah	0.13 Au 0.6 Ag	Mined Surface, Jasperiod, 99% -100m	L	88 Au 40 Ag	6	24	
13	Southern Nevada	0.03-0.07 Au 0.6 Ag	CN Leach Tailings, 90% -100m (no regrind)	L	60-80 Au 20 Ag	4	12	
14	Nevada	1.81 Ag 0.062 Au	CN Leach Tailings, 98% -100m	F L F	Poor 58 Ag 92 Au	6.5	8	
15	Canada	0.10 Au	Tailings, reground to 98% -100m	F L	Poor 74.7 Au 43.5 Au w/o regrind	3	16	
16	Utah	1.5 Ag	Flotation Tailings, 90% -100m (no regrind)	F L	Poor 35 Ag	6	24	
17	Idaho	1.5 Ag 0.018 Au 0.5 Pb 0.1 Cu 0.6 Zn	Dump Material, 95% -100m	F	70 Ag 50 Au 81 Pb 32 Cu 11 Zn			1 Au 69 Ag 42 Pb 3.2 Cu 6.3 Zn
18	Southern California	0.03 Au 0.2 Ag	Placer Slimes, -100m	L	95 Au 95 Ag	2	8	

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2	Hailey, Idaho	3.5 Ag 2 Pb	Jig Tailings, 95% -100m	F1 L F2	42-50 Ag 78-86 Ag 80-87 Ag	2.5	8	15-30 Pb 50-80 Ag 15-30 Pb 50-80 Ag
3	Hailey Idaho	3.8 Ag 2 Pb	Mine Dumps, 95% -100m	F1 L F2	42-50 Ag 82-90 Ag 85-93 Ag	2.7	8	15-30 Pb 50-80 Ag 15-30 Pb 50-80 Ag
4	Central Idaho	4.0 Ag 2 Pb	Mine Dumps, 95% -100m	F1 L F2	62.6 Ag 82 Ag 85-86 Ag	2.5	8	30-50 Pb 50 Ag 30-50 Pb 50 Ag
5	North Idaho	0.17 Au 0.8 Ag	Stamp Mill Tailings, 95% -100m	F L	Poor 65 Au 48 Ag	5	8	
6	Utah	3-5 Ag 0.015 Au 2 Pb 3 Zn	Flotation Tailings, 80% -100m	F1 L F2	26-40 Ag, Au and Pb 65-78 67-80	7	8	25 Pb 50 Ag 0.15 Au 25 Pb 50 Ag 0.15 Au
7	Utah	3-5 Ag 2-10 Pb 0.004 Au 5 Zn	Mine Dumps, 95% -100m	F1 L F2	14-27 Au and Ag 70-75 Ag and Au	4	8	low Pb 34-78 Ag

* F = Flotation, L = Carbon-In-Pulp Cyanide Leach
** Overall recovery includes recovery in preceding process(es).
*** m = Tyler mesh

UNITIZED, PORTABLE, FLOTATION-LEACH PLANTS FOR TREATING PARTIALLY OXIDIZED GOLD AND SILVER ORES

by

Paul H. Johnson, Ph.D.
Vice President

Delivered at the 110th AIME Annual Meeting
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ABSTRACT

Resource Engineering and Development, Inc. is designing and building a portable 150 to 225 TPD, flotation-cyanide leach plant with unitized, skid-mounted components. This plant design, with its portability, low capital investment, and high recovery of silver and gold from many partially oxidized ores, is well suited to treat many small, high-grade deposits, old waste dumps, and old mill tailing piles. A description is given of flotation and/or cyanide leach tests run on about 17 partially oxidized, newly mined ores; waste dump materials; placer slimes; and old mill tailings.

UNITIZED, PORTABLE, FLOTATION-LEACH PLANTS FOR TREATING PARTIALLY OXIDIZED GOLD AND SILVER ORES

INTRODUCTION

The large increase in precious metal prices over the past few years has generated considerable interest in the milling or remilling of many old, partially oxidized, mine dumps, tailing piles, stope fill, and ores mined from oxidized surface zones.

The present technology is often inadequate to treat these oxidized gold and silver ores. In several instances, heap or pad leaching plants have failed because of low metal recoveries and the necessity of winter shut-downs. Many of these ores respond poorly to treatment with either flotation or cyanide leaching alone.

The size and grade of many of these types of deposits will usually not warrant the expenditure of capital needed for a conventional, stationary, flotation or cyanide leach plant.

A simplified, unitized, portable, flotation-cyanide leach plant may be the solution to these problems. Considerable testing has indicated that a combination flotation-leach plant will successfully recover most of the silver and gold values from many of these oxidized ores.

Resource Engineering and Development, Inc. (R.E.D.) is currently designing and building a 150 to 225 ton-per-day (tonnage dependent on ore feed size) unitized, portable, flotation-leach plant for Silver Bullion Milling and Refining, Joint Venture. The first operating site will be near Hailey, Idaho, where the plant will be used to treat old flotation mill tailings, old minus 1/4 inch jig mill tailings and several old mine dumps (95% minus 2 inch). Eventually, the plant may be used to treat other company-owned or custom ores in the Central Idaho area or it will be moved to another site(s).

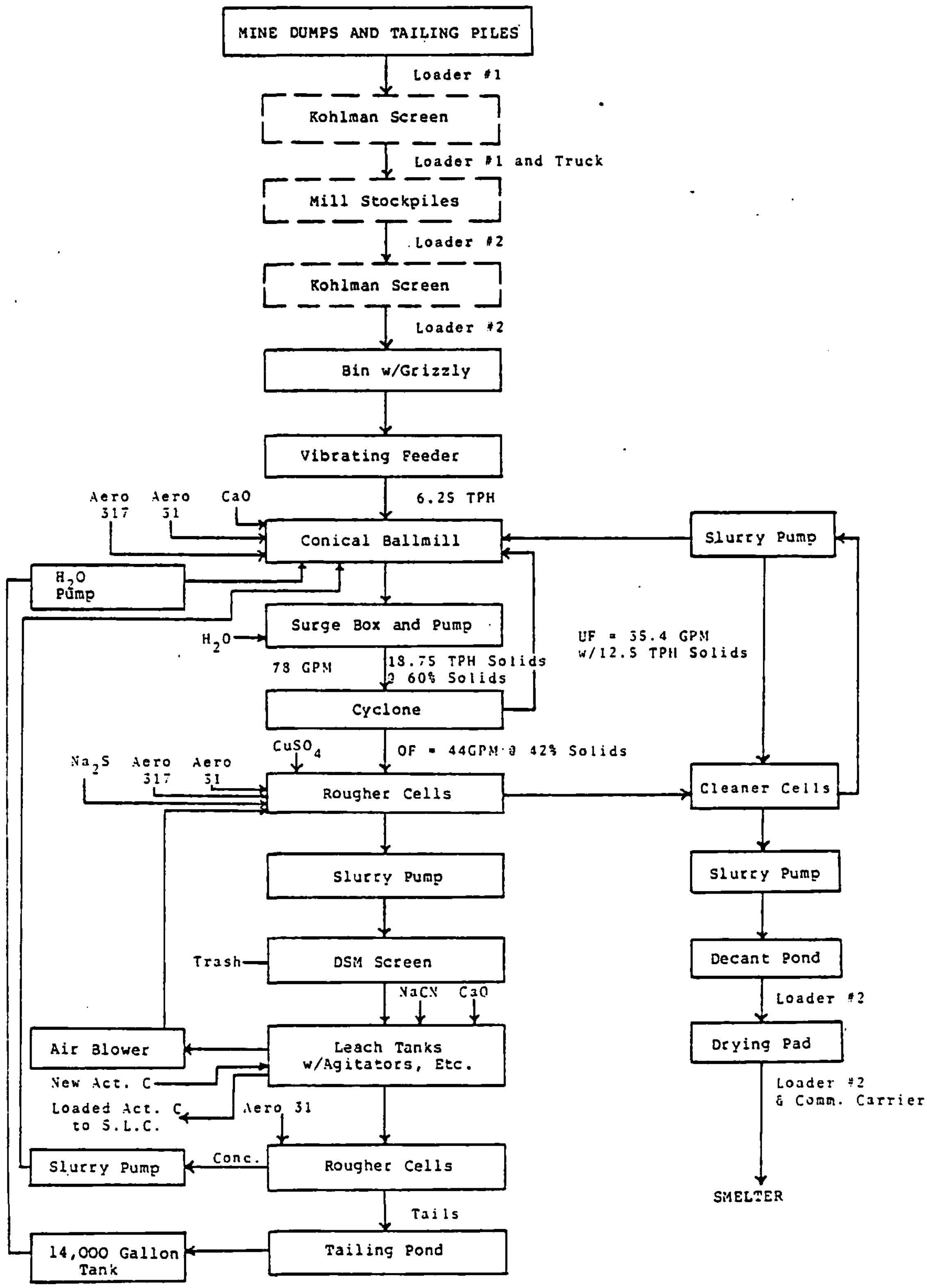
UNITIZED, PORTABLE, FLOTATION-LEACH PLANT DESIGN

The general concept of the unitized, portable, flotation-leach (UPFL) plant is one in which both flotation and carbon-in-pulp cyanide leach circuits are incorporated into a greatly simplified mill design of commercial size, built in unitized, skid-mounted modules.

The flowsheet of a 150 to 225 ton-per-day plant of this type is as shown in Figure 1. In this plant design, prescreened, minus 2-inch ore will be periodically loaded into a 35 ton ore storage bin, from which it is fed at a constant rate to a

FIGURE 1

FLOWSHEET OF 150-225 TON-PER-DAY
PORTABLE MILL FOR PROCESSING
OLD SILVER AND GOLD MINE DUMPS



7' x 48" Hardinge conical ball mill with an internal grate. A grizzly (6" opening) on the storage bin and a single, close-set jaw crusher might be used in the circuit if coarse, hard ores were to be fed to the plant. The ball mill discharge will be classified by a cyclone which produces an overflow product with a pulp density of about 40% to 45% solids and a product size of about 95% minus 65 mesh. Flotation reagents and recirculated solutions from the tailing pond will be added to the grinding circuit. The cyclone overflow will go to a DSM stationary screen with a 28 mesh deck to remove oversized ore particles and small wood pieces from the plant feed slurry, and then to a bank of rougher flotation cells with a 10 minute retention time. The flotation concentrates will be cleaned once or twice, as required, and then, since they are present as a small tonnage/ day, sent to a decant pond and a concrete pad for air drying prior to shipment to a custom smelter. The flotation tails, at a pulp density of about 38% to 43% solids, together with added lime and sodium cyanide, will flow continuously through a series of eight, 9' diameter x 10' deep, agitated tanks where a simultaneous, 8 to 12 hour, carbon-in-pulp leach with 6 x 12 mesh carbon will be effected. In this leach circuit, the activated charcoal will be periodically advanced from one tank to another and retained in each leaching unit by a R.E.D. proprietory reactor design. The activated charcoal, which is expected to be loaded to about 500 oz/ton of precious metals, will be periodically removed from the first tank in the leaching system and shipped to a carbon stripping and regeneration and refining facility where pure gold and silver ingots will be produced. The leached tailings may be refloated for their remaining sulfide minerals and fine activated carbon in a second flotation step. The final tailings will be sent to an environmentally acceptable tailings pond with a proprietory R.E.D. design that allows for additional leaching and rinsing of the tailings in the tailings pond. The decanted solutions from the tailings pond, which contain small amounts of NaCN and CaO, will be collected in a holding tank and then returned to the grinding circuit.

This portable plant is to be "unitized", or built as several skid-mounted modules in a shop some distance from the mill site. The individual units that will comprise the plant described in Figure 1 would be: (1) the ore storage bin and feeder; (2) the ball mill, surge box, motor, cyclone pump, and cyclone; (3) the DSM screen, rougher and cleaner flotation cell banks, and two slurry pumps; (4) 8 agitator tanks as single tanks or units of two; (5) a small bank of rougher flotation cells and pump(s) (optional); (6) a power panel and; (7) a power plant (optional).

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University of California

US Energy Sources and Materials Needs

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ENERGY BACKGROUND

It takes energy to explore for, mine, and process mineral ores into bulk materials such as copper, iron, and aluminum. It takes additional energy to process these into engineering materials, and additional energy to run the supply and construction equipment to fabricate these materials into systems hardware—electric generating stations, transmission lines, pipelines, solar collectors, replacement parts, and so on.

It also takes energy to explore for, extract, process, and distribute nonrenewable fuels such as coal, crude oil, gas, hydrogeothermal, and uranium. Solar, hydroelectric, tidal, and hot dry rock geothermal are renewable sources that do not generally take additional energy to process.

In summary it takes energy to build energy systems, and energy to obtain the nonrenewable fuels. This energy must be added to the energy used by consumers to obtain the total US energy demand shown in Fig. 1.

MINERALS CRISIS

Both nonfuel minerals and nonrenewable fuels are in finite supply in the world. Let's focus on nonfuel minerals.

A study done for a world population of 3 billion posed the following question. If all 3 billion people on Earth were instantly escalated to the same standard of living as those in the United States, how long would key nonfuel mineral resources last without recycling? The answers are startling, as shown in Fig. 2. Many key resources such as silver, tin, lead, and copper would be depleted within 12 years. Though the world on average does not have the US standard of living, emerging countries are trying to achieve it. And world population continues to grow: now about 4 billion, it is expected to reach 5.5 billion by the year 2000. Thus, the study should serve as a warning.

The United States has used up much of its higher grade nonfuel mineral resources and is increasingly dependent on imports, as shown in Fig. 3. Certain

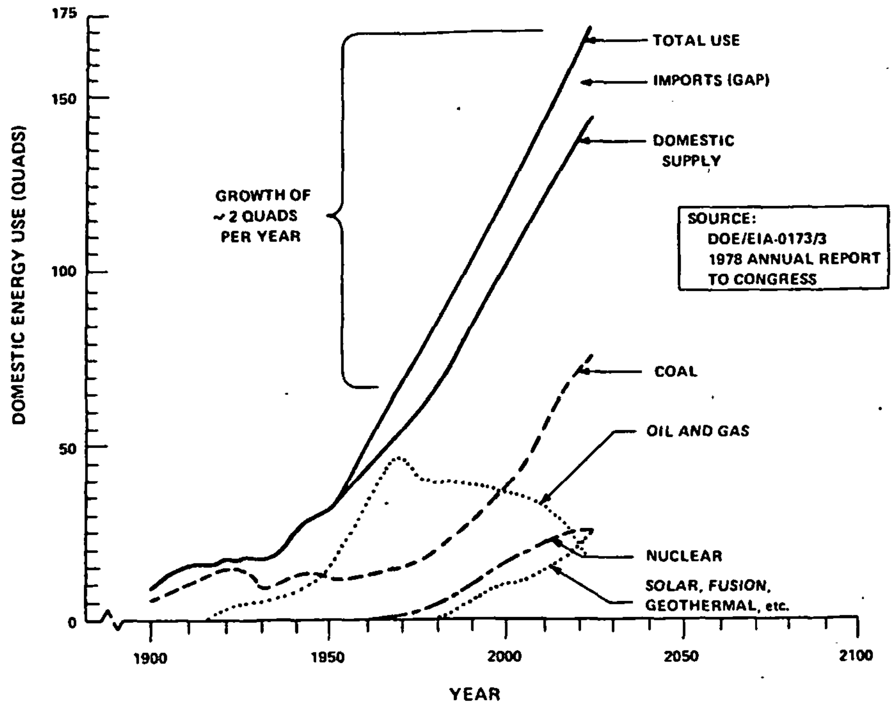

Fig. 1.

US energy supply and demand. Dashed curves of domestic supply types sum to give total domestic supply. Imports are now costing the US about $2000 per second.

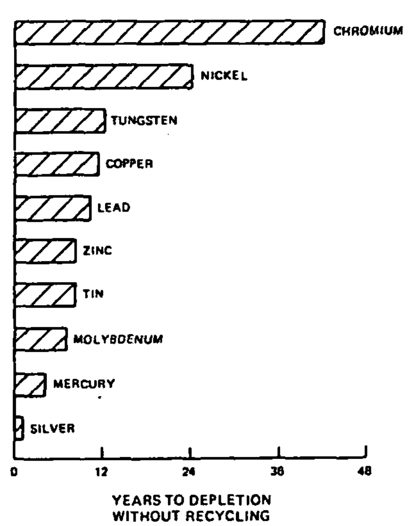

Fig. 2.

Lifetime of certain mineral resources in the world if all people (3 billion for the time of the study) had US standard of living. [W. C. Gough and B. J. Eastlund, "Energy, Wastes and the Fusion Torch," US Atomic Energy Commission report (April 27, 1971).]

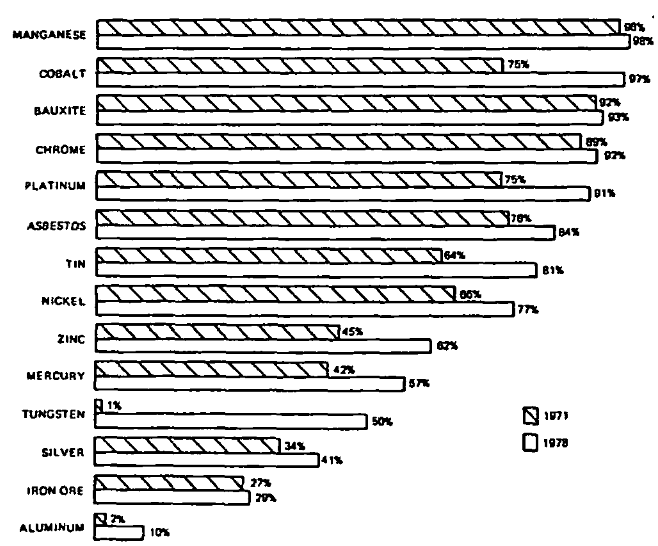

Fig. 3.

Increasing percentage of US reliance on imported minerals over only 7 years. (US News & World Report, November 12, 1979.)

key resources come from the Soviet Union or emerging nations with potentially unstable governments. The cost of mineral imports went from $10 billion in 1971 to $64 billion in 1978; over one-fourth of the bill in 1978 was for nonfuel minerals. Many of those minerals are key resources for building defense, energy, transportation, communications, and food-producing systems. This increasing dependence on imports of minerals extracted on land has made the United States vulnerable to world cartels, like OPEC, for nonfuel minerals. In addition, an attempt is being made in the United Nations among a cartel of Third World countries to limit the exploitation of seabed minerals by industrialized nations by amending the Treaty on the Law of the Sea.

As the world consumes its high-grade ores, lower grade ores will be used at increasing expense. Part of the expense is due to the fact that it takes much more energy at increasing expense to process low-grade ores. An example for copper is shown in Fig. 4.

The world situation has been studied by various groups and government agencies in the United States for several years. But no real substantive action has been taken, even though the situation is comparable in magnitude (import costs and vulnerability) to the US energy situation.

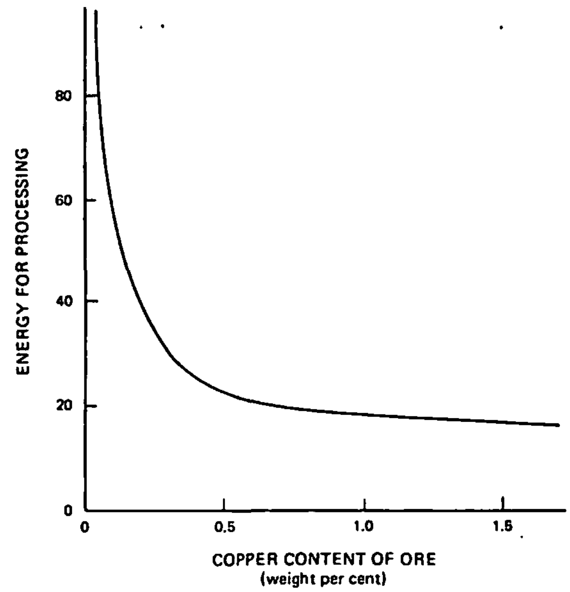

Fig. 4.
*Example, for copper, of energy needed to process ore vs grade of ore. Recycling uses much less energy (E. Cook, "Limits to Exploration of Nonrenewable Resources," in **Materials: Renewable and Nonrenewable Resources**, American Association for the Advancement of Science, 1976, p.63).*

ENERGY HARDWARE AND MATERIALS

In a recent study, Herbert Inhaber looked into the amount of materials needed for various kinds of energy systems. Inhaber's results, though not necessarily accurate in detail, stimulate thought. Shown in Fig. 5, they indicate that building soft energy systems like solar requires 20 times the amount of materials required to build hard technology systems like nuclear to obtain the same energy output. This suggests that overemphasizing soft technologies may result in a *nonconservation* ethic for nonfuel minerals and materials and may further aggravate the US nonfuel minerals-imports situation.

We must recognize that high-grade energy sources are needed to obtain and fabricate the materials for soft technology systems. Thus, emphasizing soft technologies may push up the need for high-grade energy sources for several years.

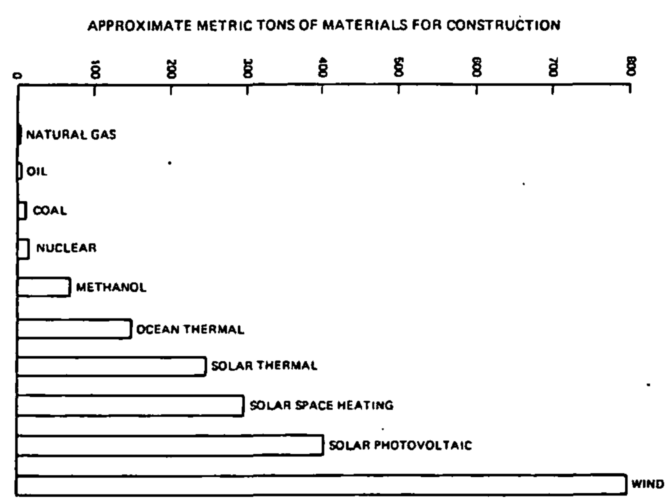

Fig. 5.
Estimate amounts of material required to build various energy sources for the same energy output of 1 megawatt-year. [H. Inhaber, "Risk of Energy Production," Atomic Energy Control Board of Canada report AECB-1119/REV-1 (May 1978).]

NEEDED ACTION

Energy and nonfuel minerals issues are tightly interwoven; they *cannot* be treated separately. We must learn in detail how they interrelate, and we must use the information for planning and decisionmaking. These important issues strongly influence our national security in the broadest sense.

We should take the following actions immediately.

- Expand stockpiles of strategic minerals that have no known substitutes.
- Determine materials requirements for the various energy paths that the United States may take, and then re-think those paths.
- Determine future energy needs for minerals extraction and processing, and factor that data into the National Energy Plan.
- Offer incentives for conservation and recycling.
- Stimulate industry to explore for new mineral resources *domestically* by increasing noncompetitive government programs to delineate favorable exploration areas through reconnaissance studies like the Department of Energy's National Uranium Resources Evaluation program, wherein collected samples can be analyzed for *several* minerals.
- Identify needs and stimulate work by funding the study and development of advanced mining and processing techniques for lower grade ores.
- Expand research to find substitutes for critical materials.

For additional information on US mineral inventories, deficits, import reliance, critical materials, and issues, see the following publications.

1. *Stockpile Report to the Congress*, (April 1978 - September 1978), GSA Federal Preparedness Agency, GSA-DC-01904931 (April 1979).
2. *Mineral Commodities Summaries 1979*, (Annual Summary) US Bureau of Mines, US GPO (1979).
3. *Report on the Issues Identified in the Nonfuel Minerals Policy Review*, from an Interagency Study for the White House Domestic Policy Staff, US DOI (August 1979).

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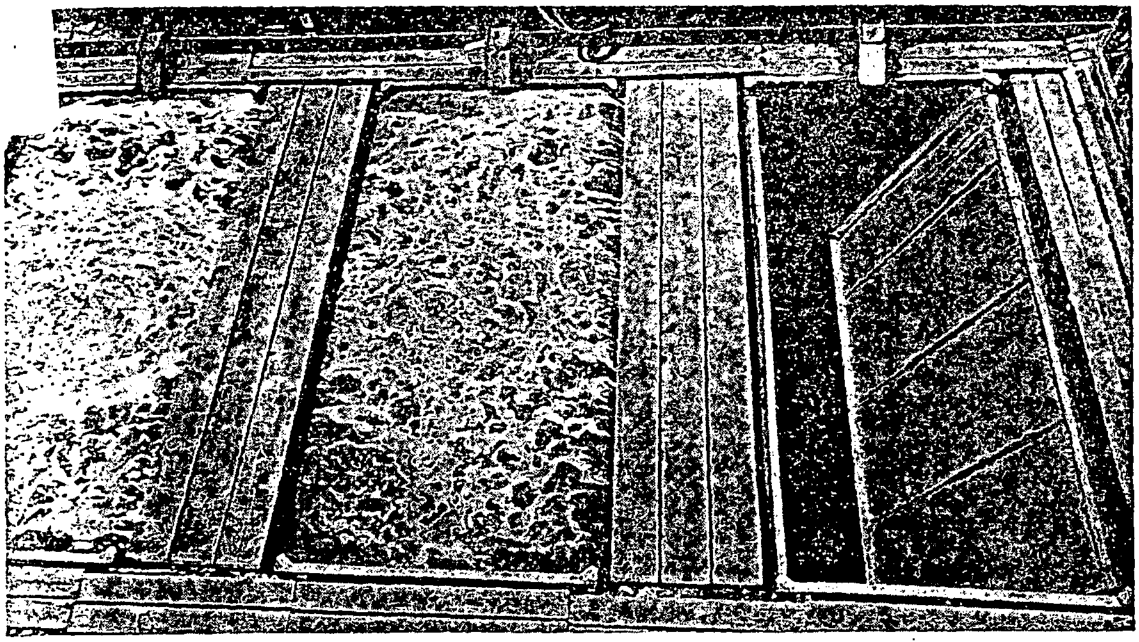


Pregnant liquor is introduced into the V-trough through a perforated pipe located on the bottom

Use of Sponge Iron in the V-Trough Precipitator

By W. G. HOGUE
Manager
Copper Queen Branch
Phelps Dodge Corp.

SEVERAL years ago at the Douglas, Ariz., smelter of Phelps Dodge Corp., a process for producing sponge iron from converter slag was developed. Sponge iron is the metallic product resulting from the chemical reduction of iron oxides at temperatures below the fusion point of iron or of any eutectic mixture in impure iron ores. It is characterized by its large surface area per unit of mass as compared to solid material.

In the process a molten, high-iron content converter slag is granulated in a water bath. The ferromag produced is dried in a rotary kiln and fed countercurrent through a stream of reformed natural gas in a reducing furnace. The resulting sponge iron assays about 75 percent total iron and 55 to 60 percent metallic iron.

Sponge Iron Pilot Plant Built

The sponge iron process was developed primarily to provide a precipitant for the company's Bisbee, Ariz., leaching and precipitation operation, located about 23 miles from the Douglas smelter. A six-tpd pilot sponge iron plant was built at the Douglas smelter and operated for 2½ years, during which the process of making sponge iron was studied and improved.

As was expected for a material with a large surface area, the sponge iron reacted rapidly in laboratory precipitation tests. The problem was to develop a field method that would utilize this reactivity on a tonnage basis. Preliminary attempts to use sponge iron by placing beds of it in the precipitation plant cells and passing the copper bearing solution through it were

Sponge Iron Screen Analysis

Size	*Percent*	*Cumulative Percent*
+ 4 Mesh	0.21	0.21
+ 6 "	0.71	0.92
+ 8 "	4.05	4.97
+ 10 "	13.89	18.86
+ 14 "	21.18	40.04
+ 20 "	23.83	63.87
+ 28 "	17.09	80.96
+ 35 "	10.18	91.14
+ 48 "	4.39	95.53
+ 65 "	2.04	97.27
+100 "	0.45	98.02
−100 "	1.98	
	100.00	

Typical Analysis

$Fe^{(tot)}$	76.0 percent
$Fe^{(met)}$	56.0
Cu	6.0
SiO_2	6.0
S	0.5
Zn	0.5

Weight = 137 lb per cu ft

unsatisfactory. Each particle of sponge iron quickly became coated with copper, and this effectively insulated the iron from further contact with the liquor, with the result that the reaction was either stopped or slowed down below the point of practical usefulness. The beds of sponge iron also became cemented and badly caked. It was obvious that "caking" and "blinding" would have to be overcome if sponge iron was to be used effectively as a precipitant.

"Caking" and "Blinding" Problems Solved

The solution to the problem was a V-shaped reaction vessel in the bottom of which was placed a perforated pipe. Pregnant solution was introduced into the V-trough through this pipe and the vessel was charged with sponge iron. The charge was levitated by the leach liquor and this effectively prevented caking of the sponge. At the same time the particles of sponge iron at the bottom of the trough were subjected to a violent abrading action that removed coatings of copper and presented fresh surfaces for further reaction.

According to Stokes' law, the rate at which a spherical body falls through a viscous medium varies as the square of the radius of the particle and directly as the difference in density between the particle and the medium through which it is falling. Therefore, size is very important in determining a settling rate, and density is relatively unimportant. Liquor introduced into the bottom of a V-trough has a constantly decreasing vertical velocity as it ascends in the vessel. It is therefore possible to set the discharge elevation of the V-trough at a height which permits the effluent liquor to carry with it essentially all of the small particles of abraded copper, but to retain essentially all of the larger particles of sponge iron.

As the particles of sponge iron continue to react in the V-trough they become smaller in diameter and lighter in weight. The lighter particles produced by reaction with strong headwater are then displaced upward in the charge of sponge iron and the relatively heavy copper coated particles from higher in the charge settle downward, eventually being forced by the sloping sides of the V-trough to cover the jets of entrant liquor and thus becoming subject to mechanical abrasion and chemical reaction.

This system effects the following results:

1) A fresh surface of iron is kept exposed for reaction.
2) Copper is removed from the field of reaction essentially as it forms. This is important because the Bisbee leach liquor has a rather high ferric iron content and freshly precipitated copper is a good reducing agent for ferric iron. If the copper is not removed, it tends to go back into solution.
3) There is a constant stirring of the charge which prevents caking and permits the sponge iron particles to react uniformly.

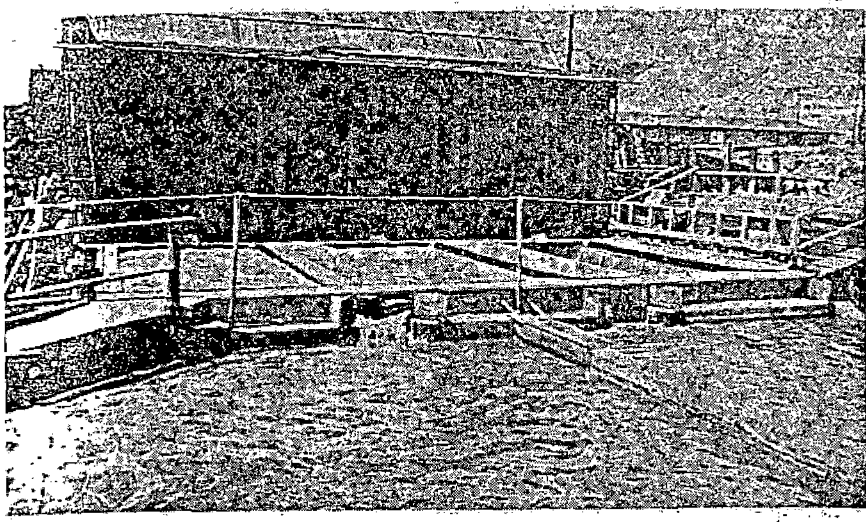
Two Products Produced in V-Trough

During the time the sponge iron pilot plant was in operation, a series of systematic tests was made at Bisbee to learn as much as possible about the action of sponge iron in a V-trough precipitator. Several different troughs were made and studied and enough data were accumulated to permit some confidence in the design for permanent modification of the existing precipitation plant. It was planned that sponge iron would replace shredded tin cans as the principal precipitant.

Among the more important items of general information ascertained during this period were:

1) The extreme reactivity of porous sponge iron was being successfully utilized. The original tin can plant was designed to keep the pregnant solution in contact with tin cans for one hour. By charging a slight excess of sponge iron into a V-trough, ferric iron can be reduced to a negligible amount and the optimum

W. G. Hogue began his career working as an engineer for U.S. Vanadium Corp. In 1946 he joined the Copper Queen Branch of Phelps Dodge Corp. as a geologist and has since served as chief geologist, chief engineer, and general superintendent. Hogue was promoted to his present position as manager at Copper Queen last year.



Sponge iron has replaced tin cans as the principal precipitant at the Bisbee leaching plant

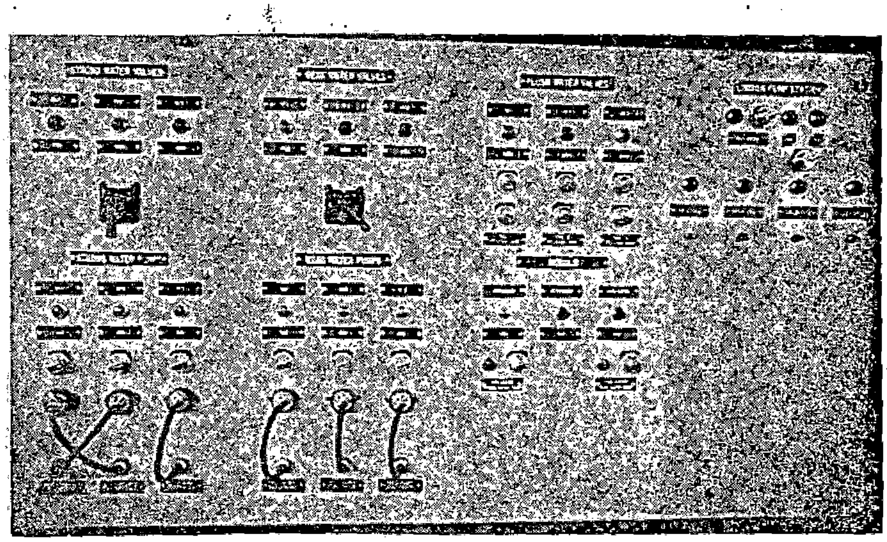
amount of copper precipitated with a time in residence of less than 30 seconds.

2) Two products are made in the V-trough. One is cement copper which assays about 70 percent copper. The other is residue which remains in the trough at the end of a batch run. This residue assays from 15 to 40 percent copper and one to two percent metallic iron, depending upon how long it was allowed to react. Numerous attempts were made in the laboratory to concentrate the copper in this residue and make a rejectable product, but without success. These attempts included attrition mixing and sizing, grinding and flotation, and magnetic separation. None of these methods produced a product containing less than five percent copper. Since the residue is not rejectable it is combined with the cement copper. This makes a lower grade cement, but it also improves the drying qualities of the precipitate. Carload shipments of this combination product have assayed as low as eight percent moisture while the normal cement copper usually contains from 25 to 30 percent moisture.

3) The fact that fresh sponge iron reacts very rapidly, but increasingly slower after it is partially reacted suggested a counter-current method of operation. In order to utilize substantially all of the metallic iron content of sponge iron, it must be reacted with strong headwater. In order for a pregnant solution to be stripped of substantially all of its copper, it must be reacted with fresh sponge iron.

During the test period, two V-troughs were operated in series. Strong water was pumped through the first V-trough which contained partially reacted sponge iron; tailwater from the first V-trough was pumped through a second V-trough which contained fresh sponge iron. A typical shift's result from this counter-current operation is tabulated below:

	Lb per 1000 Gal				
	Cu	Fe_2	Fe_3	$Fe^{(tot)}$	*pH*
Headwater V-trough no. 1	11.9	62.4	22.8	85.2	1.9
Tailwater V-trough no. 1	2.7	109.6	0.8	110.4	2.7
Tailwater V-trough no. 2	0.2	124.0	Nil	124.0	3.7



A single operator can completely control the V-trough operation. By setting selector switches, strong or weak water can be directed through any one of three precipitators

4) During the test period, one batch of sponge iron was allowed to react until no evolution of hydrogen could be observed. This residue, which was entirely non-magnetic, was allowed to completely air-dry. The dry residue weighed only 18.5 lb per cu ft compared with 137 lb per cu ft for the original sponge iron.

Tin Can Beds Filter Fines

During the period of testing a careful comparison was made of the relative efficiencies of the tin can precipitation plant and the sponge iron V-trough in terms of iron consumption. Although a direct comparison could not be made because of plant arrangement, it was concluded that the efficiencies were the same.

A substantial percentage of the copper produced in the V-trough is in very small particles, being at or near colloidal size, and settling is something of a problem. Flocculating agents do not seem to be particularly effective in speeding up the settling rates, but fortunately a bed of tin cans makes an effective filter for the fine copper. Current practice is to operate the V-trough plant so that the ferric iron is completely reduced and the tailwater contains between one and two lb of copper per 1000 gal. This tailwater is passed over tin can beds of the original precipitation plant where the fine copper is effectively filtered out. While it would appear that such a method should result in excessive iron consumption, this is not the case. Successive tin can cells become blinded with copper, which prevents appreciable iron consumption until the bed is washed.

Plant Has Two Water Systems

In 1965 the Bisbee precipitation plant was modified to use sponge iron as the principal precipitant and is currently using in excess of 40 tpd. The modified plant has a strong water and a weak water system. There are three V-troughs available and any one may be used for weak or strong water. Headwater enters the strong water sump, which has three 30-hp, abrasion-resistant and acidproof, rubber-lined sump pumps. The pumps are electrode controlled. In addition, a pneumatic device keeps the sump level constant by throttling a valve that controls the flow of liquor into the bottom of whichever V-trough has been selected. Overflow from this V-trough goes to a large settling sump whose overflow goes to a weak water sump.

A set of pumps and controls identical to those of the strong water system sends the partially stripped weak water to a second V-trough charged with fresh sponge iron. Effluent from the second V-trough goes to a settling sump whose overflow goes to the tin can beds of the original precipitation plant where the final pound or so of copper in solution is precipitated and any unsettled particulate copper is filtered out. Sponge iron is fed into the cells directly from storage bins by means of vibrating feeders having a feed range of up to seven tph.

Cells Cleaned Every 24 Hr

Present practice is to dump the residue from each V-trough once each 24 hours. To do this, the sponge iron feed is cut off from one cell at a time and the cell is operated for two hours without the addition of more feed. At the end of two hours the metallic iron content of the residue has been reduced to between one and two percent; copper content is usually about 20 percent. By throwing a switch in the control room the operator opens a rubber-lined, pneumatically-operated dump valve and the entire load of residue is flushed into a decant cell. Here the water is drained off and the mixed cement copper and residue are transferred onto a drying pad with a clamshell.

A single operator can completely control the V-trough operation from the control room. By setting selector switches, strong or weak water can be directed through any of the three V-troughs. Residue can be flushed from any desired trough by throwing a switch. The only operation still requiring manual labor is washing the settled copper from the settling cells into the decant cells. This is done once a week and is a much easier task than washing a large number of can cells. The use of sponge iron in the Bisbee precipitation plant has resulted in a substantial reduction in labor requirements.

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Uranium—Where are the Reserves?

by F.Q. BARNES
Geologist, Vice President, David S. Robertson & Associates Ltd.

The following remarks describe the size, grade and form of the various uranium reserves in the non-communist w producible at costs up to $25 per pound. The data has been compiled from a large number of sources and is comple varying degrees. In general, the data for the United States, Canada, South Africa and Australia is considered more c plete than that for other parts of the world.

Reference to reserves applies only to those tonnages which are reasonably assured and which are estimated in same manner as tonnages of other commodities. Large tonnages of uranium, yet undiscovered or inferred by lim factual data, are labeled as resources, estimated in a manner too loose to be acceptable by industry as reserves on w productive facilities can be planned for the future. In reference to official figures in the United States, we consider only some classes of reserves and, of course, no class of resources as fitting industries definition of reserves.

U.S. reserves are low cost. In Canada however, and particularly at Elliot Lake, Ont., there are large tonnages of low grade materials in the drill indicated category, producible from existing openings at costs up to $25 a pound which could be relied upon as mill feed when prices reach higher levels.

Uranium deposits around the world, regardless of their individual characteristics, can be classified into a few main types on the basis of origin, form or environment of occurrence. Geologists commonly refer to the four main world reserve types as the pyritic, quartz-pebble conglomerate, the porous sandstone and conglomerate, the vein and replacement, and the granitic and syenitic rock uranium deposits. The four types may be described in terms considered important to the producer as follows:

Pyritic, quartz-pebble conglomerate deposits. These are essentially of syngenetic origin, consequently the values relate to observable sedimentary rock units which form large blanket-like deposits in one or more stacked layers, aggregating as much as a hundred million tons. Individual stope grades of some deposits vary from 1 to 4 lb U_3O_8 per ton, averaging about 2 lb, whereas others are half a pound more or less where uranium is recovered as a by-product. The deposits are usually flat to moderately dipping, and stope muck is rarely free flowing. The stopes vary in height from 6 to 20 ft or more and average 10 ft. These deposits are mined underground from 100 to over 6000 ft in depth and all current workings are at 2000 ft or more. The ores are hard and impervious and require fine grinding, but mill recoveries of 95 percent are realized with low acid consumption.

Porous sandstone and conglomerate deposits. The deposits in porous sands and conglomerates are found mainly in the western United States but are also found in Australia and parts of Africa, eastern Europe and Russia. The mineralization is largely epigenetic, introduced by ground waters whose presence is a continuing mining hazard. The deposits are commonly pod-shaped, some are in blankets and others are stacked along fault zones. Individual tonnages vary from a few thousand to more than a million tons, and average thickness is about 10 ft variations from 2 ft to as much as 50.

The deposits are flat to low dipping and are being m in open pits and underground to about 2500 ft. Som are free digging and others are blasted, but all req transport from the face. Deposits near Mount Ta N.M., are at depths in excess of 4000 ft with rock tem tures in excess of 100°F. These deposits have not ye exploited. Grades vary from 2 to 10 lb U_3O_8 per to commonly average 4 to 6 lb. The uranium is gen readily soluble, with 95 percent recovery. Milling pre few problems except for high acid consumption wh individual deposits may be due to carbonate content.

Vein and replacement type deposits. Replacement deposits are represented by large vertical or steep clined, plum-shaped or sheet-shaped bodies simil those recently discovered in Australia. Vein-like occ rences are found at Beaverlodge in northern Sask wan and at the Swartzwalder mine in Colorado. The esis of these deposits is similar to those in porous s stones but in a different environment of emplacem

Vein and replacement deposits are generally high and are commonly at or near surface. Grades in ind ual deposits vary upward from 3 lb U_3O_8 per ton and percent, and overall size from a few to more than 50 tons of U_3O_8 per deposit. By-product copper, gold other metals will be available from a few of the bodies.

A large portion of world reserves of this type w mined in open pits and they can be considered as con ing the lowest cost and most readily available po There are milling problems associated with some de its because of certain ore and gangue minerals. T particularly true of deposits with significant seconda richment. In a few cases, it may be more economic to a carbonate leach process in spite of higher capita operating costs.

Granitic and syenitic uranium deposits. Granitic an nitic rock deposits, in spite of their low grade, pro have considerable future importance because of large potential reserves. Uraninite-bearing granitic matities at Bancroft, Ont., the supergenely enriched ite of the Rossing deposit in South West Africa and Ilimaussaq syenite of south Greenland are example

PRODUCTIVE CAPABILITY

...gardless of their size, ore reserves vary in their pro...tive suitability one from another. Depending on size, ...pe, depth and grade of the deposits, some orebodies ...be extracted economically in months whereas others ...require decades. In the case of vein-type deposits ...ing 5000 tons of U_3O_8 at surface and grading 10 to 20 ...ent U_3O_8, extraction and gravity concentration could ...ndertaken quickly at low cost. In the case of blanket ...ped quartz-pebble conglomerate deposits however, ...re capital costs are high, thickness and grade relative...ow, and back support and ventilation are continuing ...ing problems, the immense reserves will still be mined ...the next century. Therefore the size of a reserve has ...or no meaning in respect to demand. Rather, demand ...determine the required finding rate in respect to each ...of deposit sought.

RESERVES

...ed States

...he bulk of U.S. reserves are found in porous continen...sandstones of post Permian age. They occur pre...antly in the West, on the Colorado Plateau and in ...Wyoming Basins, with smaller deposits in the Gulf ...al plains near San Antonio, Tx. Minor deposits are ...found in Washington state. The deposits are mined ...underground and in open pit. Underground mines ...age about 350,000 tons of ore a year. Total U.S. re...res are approximately 300,000 tons of contained ...Extraction rates underground of about 80 percent ...mill recoveries of 95 percent will reduce this amount. ...e 1 shows the breakdown of the reserve by existing, ...mitted and potential future mills along with their pro...tive capacities through the year 2000.

...the Colorado Plateau, the bulk of uranium deposits ...found in a curving belt from west of Albuquerque ...gh Laguna, Grants, Gallup and Shiprock in New ...co to Moab in Utah (see fig. 1). In Wyoming, the de...s are found mainly in the Gas Hills and in the Shirley ...Powder river basins west and northeast of Casper. In ...Gulf Coastal Plains, the uranium deposits are likewise ...rous sands located southeast of San Antonio. Other ...sits are found near Denver, in South Dakota adja...to the Powder river basin, and near Spokane.

...addition to the outlined reserves, uranium could be ...vered as a by-product from the burning of lignites, ...copper solutions, and from phosphate rock in phos...ic acid production. The amounts involved are small, ...ever, on a yearly basis.

...S. uranium demand relative to productive capabili...dicates a short fall in supply by 1978 (fig. 2). The ...spects for additional discovery of reserves in the ...ounts required to meet projected demand are bleak. ...e required discovery lead time of about 5 years clearly ...cates that imports will be necessary. Required annual ...overy rates are calculated at 60,000 tons of U_3O_8 in ...increasing to 90,000 tons by 1985. Annual discovery ...s have reached 60,000 tons in only one year and sur...ssed 40,000 tons in only 5 years since inception of ex...ration about 1948. No new major uranium district has ...found in the U.S. since 1957, although annual explo...on drilling has not dropped below 10 million ft since ... Clearly, the projected demand cannot be met in the ...from high grade uranium sources, and uranium re...

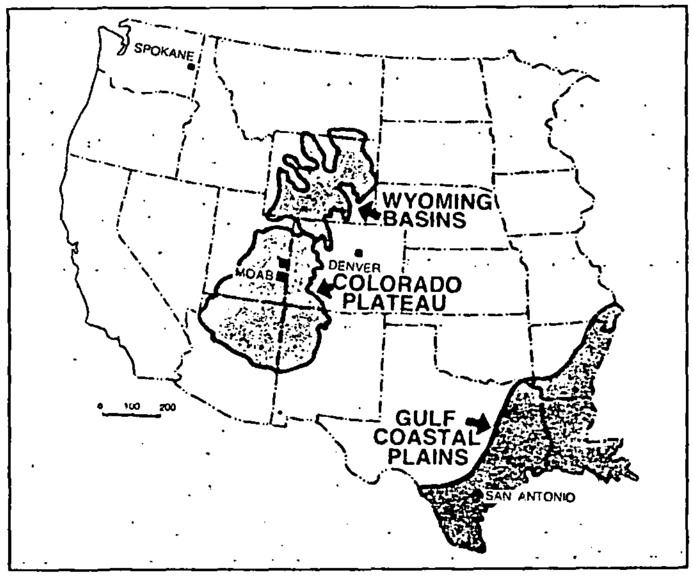

Fig. 1. Uranium deposits of the United States

sources of the required magnitude grade less than a pound U_3O_8 per ton.

Canada

Of Canada's 440,000 tons of U_3O_8 reserve, a full 85 percent is found in pyritic quartz-pebble conglomerates in the area of Elliot Lake, Ont. The replacement and vein-type deposits are located principally in northern Saskatchewan along the edges of the Athabasca sandstone basin, and account for most of the remaining reserves (fig. 3). Another smaller vein-type reserve is found in the Brinex deposits in Newfoundland. A few thousand tons

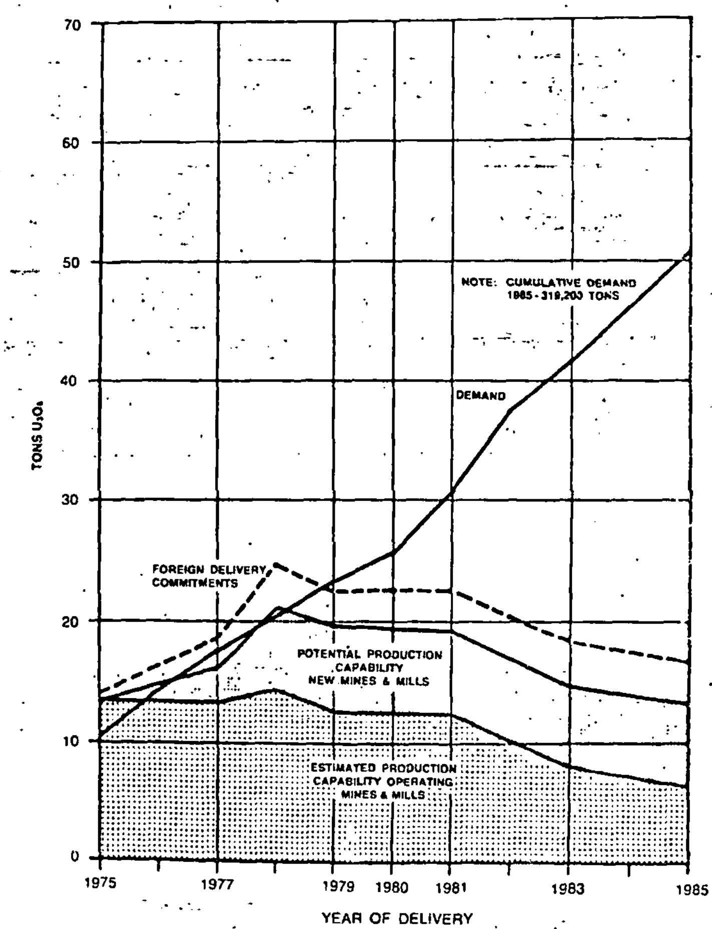

Fig. 2. U. S. uranium demand vs production capability

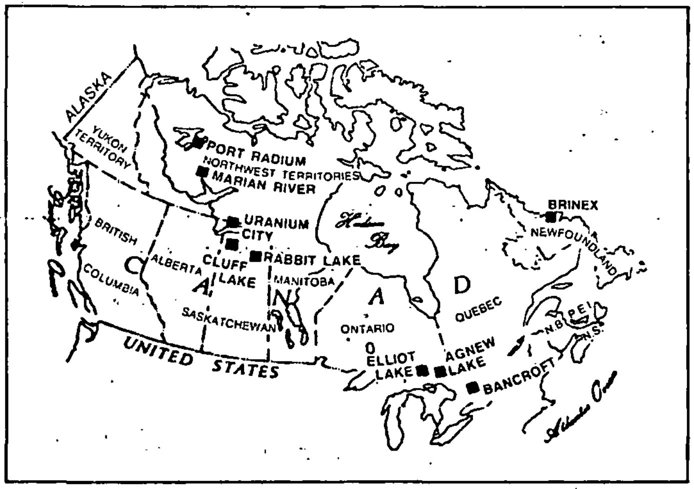

Fig. 3. Uranium deposits of Canada

are found in radioactive pegmatites in the Bancroft area between Toronto and Ottawa. They will require considerable underground development and grade control and mill feed will average no more than 2 lb U_3O_8 per ton.

Canadian reserves and productive capabilities to the year 2000 are listed in table 2, which shows the lower annual but sustained period of Canadian productive capability compared to the U.S. Canadian productive capability will reach an annual output of only three quarters of that in the U.S. in spite of the larger reserve. This is attributable to the nature of occurrence and grade of the ores in the Elliot Lake area.

Utilities in Canada are in a more favorable situation than those elsewhere insofar as Canadian reserves are about 50 percent greater while accummulative demand through the year 2000 is less than 10 percent of that in the U.S. Even so, Canada has recognized the inadequacy of its future productive capability in terms of demand and committed export sales. Consequently, it is now federal policy that Canadian producers set aside ore for a 30-year forward reserve for those reactors now operating and building. If the U.S. implemented such a policy, it wo require about 775,000 tons of U_3O_8 in reserves fo 114,000 mw already built or under construction.

In spite of Canada's large uranium reserves, availa production will be inadequate for Canada's needs 1987, as indicated in fig. 4. Further discoveries are quired to meet later needs and to continue as a ma world supplier of uranium.

Further discoveries can be expected in the areas of rent reserves; however, these will not come easily no the rate previously experienced. Other obvious bu productive target areas have been searched a numbe times over the past 25 years without success. In recog tion of the need for additional reserves, the Federal-P vincial Uranium Reconnaissance Program has bee tiated and will involve high sensitivity airborne gam ray spectrometry at 5 km spacings and geochemical veys in mountainous and overburden areas. Execu of the program will require 10 years and will outline a tional areas of uranium concentration which chara istically host the known reserves. Similar Erda sp sored projects are underway in the United States.

South Africa and South West Africa

South Africa and South West Africa's reserves are servatively estimated at 300,000 tons of U_3O_8 (see fig These reserves are largely by-product from gold mi in the Rand and, consequently, the productive capa is pre-determined regardless of the reserves.

The Rand deposits are in pyritic quartz-pebble glomerates and have an average grade of less than 0. U_3O_8 per ton. The annual production from the m could be an estimated 5000 to 6000 tons U_3O_8. Imme quantities of mill tailings average about 0.1 lb U_3O ton, although some slime areas of the ponds have hi values. The slimes could be a source at elevated p but their productive capability is low because grades about 0.3 lb U_3O_8 per ton.

Existing Mills	Reserve (Tons U_3O_8)	1975	1978	1981	1983	1985	1988	1990	1995
			Potential Production Capability						
New Mexico	72.400	6.700	7.450	6.750	4.250	4.250	2.000		
Utah	6.000	900	900	400	400				
Colorado	5.400	1.200	500	500					
Wyoming	60.000	3.500	5.000	4.400	3.400	2.400	2.400	2.000	1.000
Texas	4.000	600	600	600					
Washington	1.000	300	100						
Subtotal	148.800	13.200	14.550	12,650	8.050	6.650	4.400	2.000	1.000
Committed Mills									
New Mexico	8.500		750	750	750	750			
Potential Mills									
New Mexico	71.000		4.000	5.000	5.000	5.000	3.000	3.000	
Wyoming	20.000		1.500	1.500	1.500	1.500	1.500	1.000	
Washington	7.500		600	600	600	600	600		
Total	255.800	13.200	21.400	20.500	15.900	14.500	9.500	6.000	1.000
Miscellaneous Reserves									
New Mexico	16.500								
Wyoming	18.000								
Utah, Colorado & S. Dakota	7.500								
Texas	7.500								
GRAND TOTAL RESERVES	305.300								

Table 1.
United States uranium reserves and production capability

	Reserve (Tons U_3O_8)	1975	1980	1985	1990	1995	2000
				Annual Production Capability			
Denison	160.000	1.800	3.500	3.300	3.000	3.000	3.000
Rio	210.000	2.500	3.000	5.000	5.000	4.000	3.000
Agnew	10.000		500	500	500	500	500
Madawasica	3.000		500	500			
Eldorado	10.000	600	1.000	1.000			
Amok	20.000		2.000	2.000	800		
Gulf	25.000		2.200	2.200			
Brinex	6.000		500	500	500		
TOTAL	444.000	4.900	13.200	15.000	9.800	7.500	6.500

Table 2.
Canadian uranium reserves and production capability

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Velocity and Attenuation in Partially Molten Rocks

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Interpretation of seismic velocity and attenuation in partially molten rocks has been limited, with few exceptions, to models that assume the melt to be distributed either as spheres or as thin films. However, other melt phase geometries, such as interconnected tubes along grain edges, might equally well account for seismic observations if there is a much larger fraction of melt. Seismic velocity and attenuation are estimated in rocks in which the melt phase has the tube geometry, and the results are compared with results expected for the more familiar film model under similar conditions. For a given melt fraction, tubes are found to give moduli intermediate between moduli for rigid spherical inclusions and compliant films. For example, in polycrystalline olivine at 20 kbar the model predicts a decrease in V_s of 10% and a decrease in V_p of 5% at 0.05 melt fraction, without considering inelastic relaxation. Shear attenuation appears to be dominated by viscous flow of melt between the tubes and/or films. For olivine the tube model predicts the increment of relaxation due to melt, $\Delta\mu/\mu$, to be 0.01 at 0.05 melt fraction. Relaxation of the bulk modulus is dominated by flow between melt pockets of different shape, heat flow, and solid-melt phase change. If melt is present, considerable bulk attenuation is expected, although the relaxation may be observable only at long periods, outside the seismic body wave band.

INTRODUCTION

It has been recognized for some time that partially molten rocks can have significantly different acoustic and electrical properties than the same rocks just below the solidus. Inclusions of the liquid melt phase are more compliant in both compression and shear than the solid matrix material. Hence they mechanically soften the rock and decrease wave velocity [*Eshelby*, 1957; *Shimozuru*, 1963; *Walsh*, 1965; *Wu*, 1966; *O'Connell and Budiansky*, 1974; *Birch*, 1969; *Stocker and Gordon*, 1975; *Watt et al.*, 1976]. The time dependence of processes excited by passing waves, such as viscous flow of melt, heat flow, and phase changes, results in dispersion and wave attenuation [*Walsh*, 1969; *Vaisnys*, 1968; *O'Connell and Budiansky*, 1977; *Kjartansson and Nur*, 1980]. In addition, the network of melt phase provides paths of high electrical conductivity [*Presnall et al.*, 1972; *Waff*, 1974; *Shankland and Waff*, 1974, 1977; *Shankland*, 1975]. The strong dependence of seismic and electrical properties on the presence of melt suggests that these may be diagnostic of material properties at depth.

Quantitative interpretation of seismic wave velocity and attenuation in partially melted rocks has been limited, for the most part, to models that assume the melt to be distributed either as spheres or as thin films [*Goetze*, 1977; *Mavko et al.*, 1979]. For example, *Walsh* [1969] modeled the melt phase as a dilute distribution of isolated penny-shaped ellipsoidal films. Under the stress of a passing wave the rock relaxes through simple shear deformation across the film faces. Walsh predicted that the rock behavior with inclusions of a single aspect ratio α is that of a standard linear solid [*Fung*, 1965; *Zener*, 1948] with modulus defect $\Delta M/M$ given by

$$\Delta M/M = \beta/2\alpha \qquad (1a)$$

and frequency of peak attenuation given by

$$f_0 \simeq \alpha\mu/20\eta \qquad (1b)$$

where β is the melt concentration by volume, μ is the shear modulus of the matrix, and η is the melt viscosity. Comparing Walsh's theoretical results with seismic velocity and attenuation data, *Solomon* [1972] inferred a value of 10^8 P, and *Nur* [1971] a range of 10^6–10^{12} P for the viscosity of melt in the low-velocity zone under North America. Similarly, *Spetzler and Anderson* [1968] and *Anderson and Spetzler* [1970] interpreted velocity changes in partially frozen brine in terms of the Walsh model.

Simple shear relaxation of spherical inclusions has been modeled by *MacKenzie* [1950], *Oldroyd* [1956], and *Sato* [1952] and applied to interpretation of molten materials by *Birch* [1969] and *Stocker and Gordon* [1975]. Birch concluded that P and S wave velocity in the low-velocity zone can be explained by assuming about 6–10% melt in the form of spheres.

While the Walsh type simple shear relaxation can at least qualitatively explain the observed drop in velocity when melt appears, *Goetze* [1977] and *O'Connell and Budiansky* [1977] argue that the relaxation is too fast to explain the observed attenuation at seismic frequencies. The melt viscosity must be unreasonably high or the aspect ratio too small for the frequency, given by (1*b*), to lie within the seismic range. The frequency of peak attenuation for spheres, also given by (1*b*) with $\alpha \simeq 1$, lies many orders of magnitude above the seismic range. Hence simple shear relaxation in any geometry may not be important except at laboratory frequencies.

A second postulated mode of viscous fluid relaxation, involving films, occurs when melt flows between films at different orientations or different aspect ratios. This 'melt squirt' was discussed by *Mavko and Nur* [1975] as a mechanism of upper mantle relaxation and much earlier by *Biot* [1962] as a mechanism of wave attenuation and dispersion. *O'Connell and Budiansky* [1977] have quantitatively analyzed the squirt mechanism in considerable detail for the film geometry and argue that it is a more relevant model for wave attenuation because of its longer relaxation time.

For a given volume fraction of melt the thin film geometry is the most efficient softener, causing the greatest decrease in velocity and, depending on frequency, the greatest increase in attenuation. As a result the velocity and attenuation in much of the low-velocity zone, for example, can be explained with less than about 1% melt [*Anderson and Spetzler*, 1970; *O'Connell and Budiansky*, 1977].

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Thermodynamic considerations [*Bulau and Waff*, 1977; *Bulau et al.*, 1979] and experimental results [*Waff and Bulau*, 1977, 1979] suggest that tubes, rather than films, may be the expected equilibrium melt geometry under some conditions. *Frank* [1968] postulated the tube geometry to model melt percolation and to explain certain aspects of heat and mass transport in a convecting upper mantle. *Walker et al.* [1978] refined Frank's tube model to calculate melt mobility and melt-solid segregation. The effect of solid tubular inclusions (with circular cross section) on the effective elastic properties of a composite has been treated by *Wu* [1966], *Boucher* [1974], and *Walpole* [1969].

In the tube model suggested by *Smith* [1964], shown schematically in Figure 1, each tube is roughly triangular in cross section with sharp edges. In the film geometry the flat grain faces are coated. Details of the shape (e.g., tube versus film) depend on the relative solid-solid and solid-melt surface energies, as well as whether or not the system is in equilibrium. The factors affecting shape are discussed by *Smith* [1964], *Stocker and Gordon* [1975], and *Bulau et al.* [1974].

Nonuniqueness in interpretation of seismic velocity and attenuation has been recognized before [*Stocker and Gordon*, 1975; *Goetze*, 1977]. Even within the film model the results depend on the aspect ratio of the film. However, analyses for geometries other than films and sphere have been lacking. In this paper I present new model results for the effects of melt on seismic velocity and attenuation. First, theoretical expressions for effective elastic moduli are derived for the case of melt in the tube geometry. Next, the effects of the melt phase on attenuation and dispersion are explored by comparing the high-frequency (unrelaxed) and the low-frequency (relaxed) states. The model results are plotted and compared with results for the film and sphere models in order to show

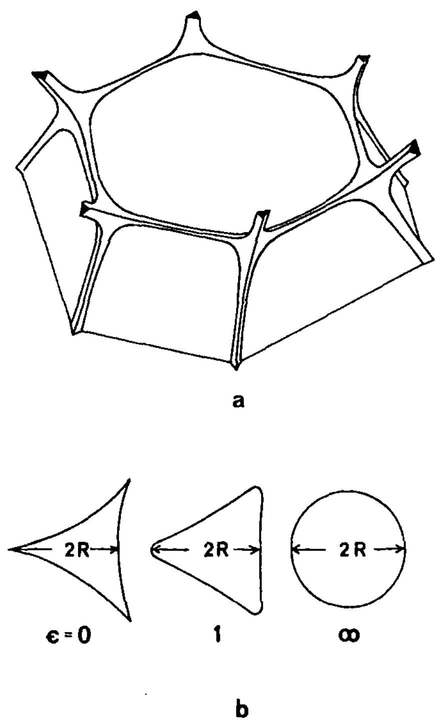

Fig. 1. (*a*) Schematic representation of melt tubes along grain edges [after *Smith*, 1964]. (*b*) Cross sections of model melt tubes for $\epsilon = 0, 1, \infty$.

the effect of melt phase geometry on seismological interpretations. Finally, theoretical results are compared with published laboratory and field observations of velocity and attenuation.

CALCULATION OF ELASTIC MODULI

We approximate the rock in Figure 1*a* as an isotropic elastic solid containing a distribution of randomly oriented tubes of the type shown schematically in Figure 1*b*. For mathematical convenience we assume that each tube segment is long and narrow enough that its deformation is adequately modeled with a two-dimensional cavity. The modeled cross-sectional shape of each tube is given in the x-y plane by the parametric equations

$$x = R\left(\cos\theta + \frac{1}{2+\epsilon}\cos 2\theta\right)$$
$$y = R\left(-\sin\theta + \frac{1}{2+\epsilon}\sin 2\theta\right) \qquad (2)$$

where R and ϵ are constants and the parameter θ varies from 0 to 2π to trace out the entire contour. These shapes are chosen because they somewhat resemble the three-sided cross section in Figure 1*a* and because they are convenient to treat mathematically. The approach is to use the complex variable method of *Muskhelishvili* [1953] and to conformally map the shape (2) into a unit circle. The shape (2) is shown in Figure 1*b* for three values of ϵ. In the limit $\epsilon = 0$ the shape has three cusps and the largest surface to volume ratio. This is the shape used to represent the melt tubes in Figure 1*a* and to calculate results in later sections, though given the degree of approximation of the model, the value of ϵ is somewhat arbitrary. In the limit $\epsilon \rightarrow \infty$ the shape is a circle. By carrying ϵ through the calculations we can see the sensitivity of the results on pore shape. In addition, various results can be checked by substituting $\epsilon \rightarrow \infty$ and comparing with published results for tubes with circular cross section.

In this section we calculate the effective bulk and shear moduli of the partially melted rock in two stages. We first find the effective moduli of a dry porous rock with empty tubes, using the Betti-Rayleigh reciprocity theorem [*Walsh*, 1965; *Jaeger and Cook*, 1969]. The results are then easily extended to the case with melt-filled tubes.

Bulk Modulus

To apply the reciprocity theorem to find the bulk modulus, consider the two sets of tractions shown in Figure 2. The rock with volume V has a distribution of N pores or cavities of the type shown in the figure. The system on the left is loaded by an externally applied hydrostatic stress δP, resulting in the pore wall displacements δU. Because we start by treating empty cavities, the pore faces are stress free. The system on the right has the same uniform stress δP, applied to both the external surface and the pore surfaces. In this case the system behaves like a solid block without pores. Applying the reciprocity theorem, we can write

$$\delta P \frac{\delta P}{K} V = \delta P \frac{\delta P}{K_d'} V - \delta P \sum_{i=1}^{N} \int_i \delta U_n \, dA \qquad (3)$$

where K is the intrinsic bulk modulus of the rock material and K_d' is the effective bulk modulus of the dry porous rock. The integral is taken over the entire pore surface of the ith pore,

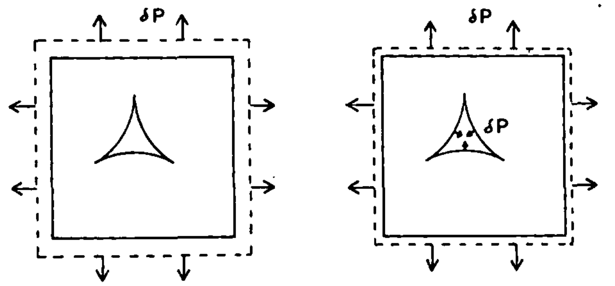

Fig. 2. Applying the reciprocity theorem to a rock under two sets of applied stress to calculate bulk modulus. On the left the pore surfaces are traction free. On the right the stress δP is applied also to the pore, making the rock deform as though nonporous.

and δU_n is the component of displacement normal to the pore wall (defined as positive for pore expansion). Rearranging the equation, we obtain

$$\frac{1}{K_d'} = \frac{1}{K} + \frac{1}{\delta P \cdot V} \sum_{i=1}^{N} \int_i \delta U_n \, dA \tag{4}$$

which gives the effective compressibility (equal to the inverse of the effective bulk modulus) in terms of the pore wall deformation. In the limit $\delta P \rightarrow 0$ the last term in (4) is simply the pressure derivative of porosity.

The pore wall displacement δU_n resulting from the remotely applied stress δP is derived in the appendix. Substituting (A27), (A28), and (A30) into (4) yields

$$\frac{1}{K_d'} = \frac{1}{K} + \sum_{i=1}^{N} \frac{\pi R_i^2 d_i}{\mu V} \left\{ \frac{2(1-\nu)[(2+\epsilon)^2+2]}{(2+\epsilon)^2} + \frac{(1-2\nu)^2}{2(1+\nu)} \frac{[(2+\epsilon)^2-2]}{(2+\epsilon)^2} \right\} \tag{5}$$

where μ and ν are the intrinsic shear modulus and Poisson's ratio of the solid elastic material. Here d_i is the tube length in the third dimension. Average pore dimensions $\bar{R}$ and $\bar{d}$ can be defined by

$$N\bar{R}^2\bar{d} = \sum_{i=1}^{n} R_i^2 d_i \tag{6}$$

The total volume of N identical pores having dimensions $\bar{R}$ and $\bar{d}$ defined in this way equals the total volume of the original pores having the variable dimensions R_i and d_i if all pores have the same shape parameter ϵ. Hence we can write

$$\frac{1}{K_d'} = \frac{1}{K} + \frac{N\pi\bar{R}^2\bar{d}}{\mu V} \left\{ \frac{2(1-\nu)[(2+\epsilon)^2+2]}{(2+\epsilon)^2} + \frac{(1-2\nu)^2}{2(1+\nu)} \frac{[(2+\epsilon)^2-2]}{(2+\epsilon)^2} \right\} \tag{7}$$

As a test we can examine the limiting case $\epsilon \rightarrow \infty$ which corresponds to tubes of circular cross section. In this case the pore volume is $N\pi\bar{R}^2\bar{d}$, and the expression (7) becomes exactly the same as that given by *Wu* [1966] for the limiting case of a low concentration of needle-shaped cavities (Wu's result with the moduli of the inclusions set equal to zero). The bulk modulus for $\epsilon = 0$ and $\epsilon \rightarrow \infty$ is shown in Table 1. Note that the softening effect for tubes with $\epsilon = 0$ is about twice that for tubes with $\epsilon \rightarrow \infty$.

The bulk modulus given by (5) and (7) assumes small enough pore volume that pore interaction can be neglected in the calculation of δU_n. Results for larger pore volume are estimated by using the self-consistent approximation [*O'Connell and Budiansky*, 1974] which we treat in a later section.

For the same rock with cavities filled with a liquid melt the static or low-frequency bulk modulus K_m' can be obtained by using *Gassmann*'s [1951] relation

$$K_m' = K \frac{K_d' + F}{K + F} \tag{8a}$$

where

$$F = \frac{K_f(K - K_d')}{\beta(K - K_f)} \tag{8b}$$

Here K_d', and K, and K_f are the bulk moduli of the dry porous

TABLE 1. Simplified Forms of Bulk and Shear Modulus for Tubes

	$\epsilon = 0$	$\epsilon \rightarrow \infty$
Bulk modulus, dry	$\frac{1}{K_d'} = \frac{1}{K} + \frac{\beta}{K}\left[\frac{13-4\nu-8\nu^2}{3(1-2\nu)}\right]$	$\frac{1}{K_d'} = \frac{1}{K} + \frac{\beta}{K}\left[\frac{5-4\nu}{3(1-2\nu)}\right]$
Static bulk modulus, saturated	$\frac{1}{K_m'} = \frac{1}{K} + \beta\left\{\frac{KK_f}{K-K_f} + \frac{3(1-2\nu)\beta KV}{2(1+\nu)N\pi R^2 d\,[(13-4\nu-8\nu^2)/4(1+\nu)]}\right\}^{-1}$	$\frac{1}{K_m'} = \frac{1}{K} + \beta\left\{\frac{KK_f}{K-K_f} + \frac{3(1-2\nu)\beta KV}{2(1+\nu)N\pi R^2 d[(5-4\nu)/3(1-2\nu)]}\right\}^{-1}$
Static or dry shear modulus	$\frac{1}{\mu'} = \frac{1}{\mu} + \frac{2\beta}{\mu}\left[\frac{40-26\nu}{15}\right]$	$\frac{1}{\mu'} = \frac{1}{\mu} + \frac{\beta}{\mu}\left[\frac{40-24\nu}{15}\right]$
Unrelaxed saturated shear modulus	$\frac{1}{\mu_u'} = \frac{1}{\mu'} - \frac{\beta}{15\mu}\left[\frac{5-4\nu}{[\mu/K_f(5-4\nu)]+1}\right]$	$\frac{1}{\mu_u'} = \frac{1}{\mu'} - \frac{\beta}{15\mu}\left[\frac{1}{(\mu/K_f)+1}\right]$

rock, of the intrinsic rock material, and of the fluid, respectively, and β is the volume fraction of melt. Substituting for K_d' from (5), we obtain

$$\frac{1}{K_m'} = \frac{1}{K} + \frac{\beta}{K}\left\{\frac{K_f}{K-K_f} + 3(1-2\nu)\beta V\left[2(1+\nu)\pi\sum R_i^2 d_i \cdot \left(\frac{2(1-\nu)[(2+\epsilon)^2+2]}{(2+\epsilon)^2} + \frac{(1-2\nu)^2}{2(1+\nu)}\frac{[(2+\epsilon)^2-2]}{(2+\epsilon)^2}\right)\right]^{-1}\right\}^{-1} \tag{9}$$

This result assumes that the pore pressure is uniform everywhere throughout the rock. Cases where this condition does not hold are discussed in the later section on attenuation. The modulus K_m' is shown in Table 1 for $\epsilon = 0$ and $\epsilon \to \infty$.

Shear Modulus

To estimate the effective shear modulus, we consider the same rock model used for the bulk modulus and once again solve the problem in two steps. First, the reciprocity theorem is used to compute the shear modulus for the corresponding dry rock. Then the effect of liquid melt is included. To apply the reciprocity theorem, consider the two sets of tractions shown in Figure 3*a*. The rock has volume V and a distribution of N randomly oriented pores of the type shown in the figure. The system on the left is loaded by the externally applied principal stresses $\sigma_{xx} = -\delta P$, $\sigma_{yy} = \delta P$, and $\sigma_{zz} = 0$, resulting in the pore wall displacements $\delta\mathbf{U}$. The pore faces are stress free. The system on the right has the same external load plus the tractions

$$\mathbf{T} = \delta P\begin{pmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}\cdot\hat{\mathbf{n}} \tag{10}$$

applied to the internal pore surfaces, where $\hat{\mathbf{n}}$ is the unit normal to the cavity surface (pointing into the cavity) at each point. In this case the system behaves like a solid block without pores. Applying the reciprocity theorem, we can write

$$\frac{1}{\mu'} = \frac{1}{\mu} + \frac{1}{(\delta P)^2 V}\sum_{i=1}^{N}\int_i \delta\mathbf{U}\cdot\mathbf{T}\,dA \tag{11}$$

where the integral is taken over the entire surface of the ith pore.

The orientation of the ith pore relative to the applied principal stresses is specified by the spherical coordinates λ and ξ of the pore axis as shown in Figure 3*b*. To solve for the pore deformation, it is convenient to express the applied stresses in terms of a rotated coordinate system x'-y'-z' such that the z' axis coincides with the pore axis. The primed system is obtained by a rotation through an angle ξ about the z axis followed by a rotation through an angle λ about the y' axis. The remotely applied stress components relative to this system are

$$(\sigma_{ij}') = \delta P\begin{pmatrix} \cos^2\lambda(\sin^2\xi - \cos^2\xi) & 2\sin\xi\cos\xi\cos\lambda & \sin\lambda\cos\lambda(\sin^2\xi-\cos^2\xi) \\ 2\sin\xi\cos\xi\cos\lambda & \cos^2\xi - \sin^2\xi & 2\sin\xi\cos\xi\sin\lambda \\ \sin\lambda\cos\lambda(\sin^2\xi-\cos^2\xi) & 2\sin\xi\cos\xi\sin\lambda & \sin^2\lambda(\sin^2\xi-\cos^2\xi) \end{pmatrix} \tag{12}$$

and the tractions $\mathbf{T}$ appearing in (11) can be written

$$\mathbf{T} = (\sigma_{ij}')\cdot\hat{\mathbf{n}}' \tag{13}$$

where $\hat{\mathbf{n}}'$ is the unit normal vector to the pore surface in the primed system.

An important feature of the calculations is that the integral

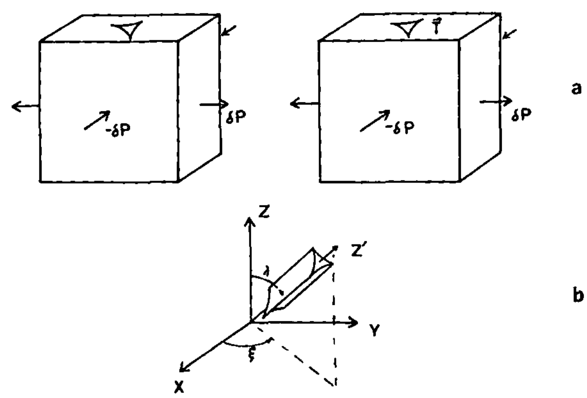

Fig. 3. (*a*) Applying the reciprocity theorem to calculate shear modulus. On the left the pore surfaces are traction free. On the right the tractions T are applied to the cavity, making the rock deform as though nonporous. (*b*) Orientation of the ith pore in terms of spherical coordinates.

that appears in (11),

$$W = \int_i \mathbf{T}\cdot\delta\mathbf{U}\,dA \tag{14}$$

which represents the additional strain energy due to introducing each pore, is invariant under rotations about the z' axis. This follows from the symmetry of the pore. We can therefore freely rotate the coordinates to facilitate evaluating the pore strain energy (14).

The displacement field is found in the appendix. Substituting (A38)–(A40), (A45), and (A49) into (14) yields

$$\int_i \mathbf{T}\cdot\delta\mathbf{U}\,dA = \frac{\pi R_i^2 d_i}{\mu}\left\{2\tau^2 + \sigma_0^2\left[\frac{2(1-\nu)[(2+\epsilon)^2+2]}{(2+\epsilon)^2} + \frac{2(1+\nu)[2+\epsilon)^2-2]}{(2+\epsilon)^2}\right] + 4S^2(1-\nu)\right\} \tag{15}$$

For large N the summation over all pores can be replaced with an integral over the range of orientations λ and ξ [*Walsh*, 1966]. In each increment of solid angle, $d\Omega = \sin\lambda\,d\lambda\,d\xi$, the number of pores is $N\,d\Omega/4\pi$, assuming an isotropic distribution of pore orientations. Integrating and substituting into (11) give the effective dry rock shear modulus, valid for small concentrations of tubes:

$$\frac{1}{\mu'} - \frac{1}{\mu} = \frac{N\pi\bar{R}^2\bar{d}}{\mu V}\left\{\frac{4}{5} + \frac{1}{15}\left[\frac{2(1-\nu)[(2+\epsilon)^2+2]}{(2+\epsilon)^2} + \frac{2(1+\nu)[(2+\epsilon)^2-2]}{(2+\epsilon)^2}\right] + \tfrac{8}{5}(1-\nu)\right\} \tag{16}$$

Expressions for the cases $\epsilon = 0$ and $\epsilon \to \infty$ are summarized in Table 1. Again the softening effect of tubes with $\epsilon = 0$ is about twice that for $\epsilon \to \infty$. Once again the limiting case $\epsilon \to \infty$ agrees with *Wu*'s [1966] result for low concentrations of needle-shaped cavities.

For the same rock filled with a liquid melt the modulus is frequency dependent. At sufficiently low frequencies the increment of pore pressure induced by the applied stress is zero everywhere throughout the rock, and the saturated rock shear modulus is equal to the dry rock shear modulus given in (16). At very high frequencies the applied stress changes faster than the fluid can flow to equalize the pore pressure. In this case the pores are effectively isolated from each other with respect to flow. The pore pressure is a function of pore orientation relative to the applied stresses and is generally not equal to zero. The nonzero fluid pressure resists distortion of the rock, and the effective shear modulus with isolated pores, denoted here as μ_u' is larger than the low-frequency modulus in (16). We solve for μ_u' as follows.

Consider again the tractions shown in Figure 3*a*, with the exception that pore pressure δP_{pi} are now applied to the rock on the left, resulting in slightly different pore wall displacement $\delta\mathbf{U}$. As before, the system on the right behaves as a solid block. Applying the reciprocity theorem, we can write

$$\frac{1}{\mu_u'} \doteq \frac{1}{\mu} + \frac{1}{(\delta P)^2 V} \sum_{i=1}^{N} \int_i \delta\mathbf{U} \cdot \mathbf{T}\, dA - \frac{1}{(\delta P)^2 V} \sum_{i=1}^{N} \delta P_{pi} \int_i \delta U_n'\, ds \tag{17}$$

where the integral in each summation is over the entire surface of the *i*th pore. The quantity

$$\Delta V_i = \int_i \delta U_n'\, ds \tag{18}$$

where $\delta U_n'$ is the normal component of pore wall displacement, gives the volume change of each pore in the rock on the right side of Figure 3*a*. Because the rock on the right deforms as a uniform solid block, ΔV_i is simply proportional to the hydrostatic component of the applied stress (which is zero). Hence ΔV_i is identically zero, and (17) reduces to a form similar to (11).

The pore wall displacement in this case is also evaluated in the appendix. Substituting (A67) and (A70) into (11) and integrating over all pore orientations yield

$$\frac{1}{\mu_u'} = \frac{1}{\mu'} + \frac{N\pi \bar{R}^2 \bar{d}}{15\mu V} \left\{ \frac{2(1-\nu)[(2+\epsilon)^2+2] - (1-2\nu)[(2+\epsilon)^2-2]}{-2(1-\nu)[(2+\epsilon)^2+2] + \mu[(2+\epsilon)^2-2][(1/K)-(1/K_f)-[(1-2\nu)^2/2\mu(1+\nu)]]} \right\} \cdot \left\{ \frac{2(1-\nu)[(2+\epsilon)^2+2] - (1-2\nu)[(2+\epsilon)^2-2]}{(2+\epsilon)^2} \right\} \tag{19}$$

where μ' is the low-frequency modulus given by (16). Simplified forms for μ_u' are given in Table 1 for $\epsilon = 0$ and $\epsilon \to \infty$. As a check, the case $\epsilon \to \infty$ agrees with *Wu*'s [1966] result for low concentrations of saturated isolated needle-shaped cavities (computed by setting the inclusion shear modulus equal to zero in Wu's result).

Self-Consistent Approximation

As stated, the expressions (5), (7), and (9) for effective bulk modulus and expressions (16) and (19) for effective shear modulus were derived by assuming no pore interaction in the elastic calculation. The self-consistent scheme [*Hill*, 1965; *Budiansky*, 1965; *Walpole*, 1969; *O'Connell and Budiansky*, 1974] provides one way of approximating the interaction and extending the results to slightly larger melt fractions.

To find the self-consistent moduli, we use the same isolated pore solutions derived in the appendix for the displacement of the cavity walls, except that the pore is now considered to lie in a solid elastic material having the yet-unsolved-for effective moduli. Hence the self-consistent dry rock moduli are found by replacing μ and ν with the effective values μ' and ν' on the right sides of (7) and (16) and solving these together with the usual relation for linear isotropic elastic materials:

$$\nu_d' = \frac{3K_d' - 2\mu'}{2(3K_d' + \mu')} \tag{20}$$

The very low frequency self-consistent bulk modulus for the melt-filled case is obtained from the self-consistent dry modulus by using Gassmann's relation. The low-frequency melt-filled shear modulus is the same as the dry rock modulus.

Finally, the high-frequency self-consistent bulk and shear moduli for the melt-filled case are found as follows. On the right side of (19) K, ν, and μ (including values of μ implicit in the term $1/\mu'$) are replaced by their effective values of K_m', ν_m', and μ_u'. On the right side of (7), μ and ν are replaced by the effective μ_u' and ν_m', and the self-consistent form of (7) is then substituted into Gassmann's relation. These two equations are then solved simultaneously with

$$\nu_m' = \frac{3K_m' - 2\mu'}{2(3K_d' + \mu')} \tag{21}$$

CALCULATION OF ATTENUATION

A number of mechanisms have been proposed to account for wave attenuation in rocks at elevated temperatures [*Jackson and Anderson*, 1970; *Johnston et al.*, 1979; *Mavko et al.*, 1979]. In this paper we focus on losses associated with the liquid melt phase. In particular, we consider stress-induced viscous fluid motion, heat flow, and phase changes. Other mechanisms, including dislocation motion and atomic diffusion, dissipate wave energy in the solid phase at temperatures both above and below the solidus and must be superimposed. However, the various sources of attenuation may not be simply additive [*Stocker and Gordon*, 1975; *O'Connell and Budiansky*, 1977]. For example, grain boundary relaxation may dissipate wave energy below the solidus. If, however, melt appears as films on grain boundaries, grain boundary relaxation is replaced by viscous shear, not added to it. For tubes the interaction should be much smaller, and we assume that the attenuation calculated here represents the difference in attenuation just above and just below the solidus.

The attenuation is most easily estimated from the modulus defect [*Fung*, 1965; *Kjartansson*, 1979]. Consider, for example, a material whose relaxation can be approximated as a single decaying exponential, resembling a standard linear solid [*Zener*, 1948]. In this case the maximum attenuation is given in terms of the modulus defect as

$$Q_{\max}^{-1} = \frac{1}{2} \frac{M_u - M_R}{(M_u M_R)^{1/2}} \tag{22}$$

and occurs at a frequency ω_0. Here M_u, the 'unrelaxed modulus,' is the modulus at frequencies much higher than ω_0, and M_R, the 'relaxed modulus,' is the modulus at frequencies much lower than ω_0. The peak frequency ω_0 depends on the physical mechanism of relaxation and is almost always a strong function of grain and pore geometry.

Rocks are, without exception, characterized by distributions of grain and pore dimensions and shapes. Furthermore, some relaxation mechanisms (e.g., some of those controlled by diffusion) cause attenuation to be spread out over a much broader range of frequencies than is the attenuation of a standard linear solid [*Kjartansson and Nur,* 1980]. We would expect, then, that a continuous distribution of simple relaxation peaks over a range of frequencies ω_0 would be required to describe the attenuation.

In the case where the distribution causes Q to be constant, or nearly constant, between frequencies ω_1 and ω_2 the attenuation can be related to the moduli M_1 at ω_1 and M_2 at ω_2 with the dispersion relation [*Kjartansson,* 1979]

$$(M_2/M_1) = (\omega_2/\omega_1)^{2\gamma} \tag{23}$$

where

$$\gamma = \frac{1}{\pi} \tan^{-1} \frac{1}{Q}$$

For large Q, (23) can be approximated as

$$Q^{-1} = \frac{\pi}{2 \ln (\omega_1/\omega_2)} \frac{M_1 - M_2}{M_2} \tag{24}$$

If we interpret M_1 as being approximately equal to the unrelaxed modulus and M_2 as the relaxed modulus, then (24) takes on roughly the same form as (22) except for the factor which depends on the spread of relaxation frequencies. This spread is the most poorly determined quantity in any relaxation model, but fortunately, the logarithmic dependence is weak. For example, when ω_1 and ω_2 are separated by 6 orders of magnitude, (24) becomes

$$Q^{-1} \simeq \frac{1}{8} \frac{M_1 - M_2}{M_2} \tag{25}$$

which differs by only a factor of 4 from the single relaxation peak result in (22).

In the following discussion of attenuation we estimate separately the modulus defect and frequency dependence. We first identify the various relaxed and unrelaxed states of the partially melted rock and estimate the corresponding effective moduli, using the results of the previous sections. While we can estimate these moduli fairly accurately, a detailed calculation of the frequency dependence depends on many more assumptions about the unknown distributions of pore sizes and shapes and about the manner in which pores interconnect. Because of this uncertainty we estimate the magnitude of attenuation by using (23) and (24) and simply assuming that Q is approximately constant over a range of frequencies. In most of the figures we plot $(M_u - M_R)/2M_u$, because it is independent of assumptions about the frequency dependence and because it is an estimate of the upper bound on the attenuation resulting from the mechanisms considered.

Bulk Attenuation

Consider again the rock model represented in Figure 1*b*. If uniform pressure is suddenly applied, an increase in pore pressure is induced that is nearly uniform throughout the rock, except for localized gradients that tend to force a small amount of melt out of the sharp tips of the triangular tubes.

At the same time, increased adiabatic temperatures are induced, generally different in the solid and melt phases because of their different thermodynamic constants [*Kjartansson and Nur,* 1980]. Neglecting the minor fluid motion and considering times much shorter than the time for substantial heat flow between solid and liquid, we take for the unrelaxed modulus K_u the expression (9) with adiabatic values for K, K_f, and ν substituted on the right side. Tabulated values for the elastic moduli of individual phases are usually appropriate for isothermal conditions, but we can solve for the adiabatic values by using the relations [*Landau and Lifshitz,* 1970]

$$\begin{aligned} \frac{1}{K_{ad}} &= \frac{1}{K_T} - \frac{T\alpha^2}{\rho c_p} \\ \mu_{ad} &= \mu_T \\ \nu_{ad} &= \frac{\nu_T + E_T T\alpha^2/9\rho c_p}{1 - E_T T\alpha^2/9\rho c_p} \end{aligned} \tag{26}$$

where c_p is the specific heat, T is the absolute temperature, α is the volume coefficient of thermal expansion, and subscripts *ad* and T refer to adiabatic and isothermal conditions, respectively.

On a longer time scale, relaxation occurs as heat flows between the solid and liquid. One possible intermediate relaxed state occurs when the local adiabatic temperature gradients are relaxed. A second relaxed state will occur when the induced solid-melt phase change is complete and the local temperature gradients resulting from the release or absorption of latent heat of fusion are relaxed. These effects are discussed in detail by *Savage* [1965], *Vaisnys* [1968], and *Kjartansson and Nur* [1980].

With phase changes, the net relaxed volume change resulting from an applied compression (and therefore the effective bulk modulus) depends on the elastic compressibilities of the solid and liquid and thermal expansions resulting from the temperature increase. The temperature increase associated with phase change depends on the Clausius-Clapyron equation, which dictates the change in temperature that results from the change in pressure for a solid and melt in equilibrium. In addition, a very large effect is the volume change that accompanies the melting (or solidification) of material.

Kjartansson and Nur [1980] have computed the equilibrium relaxed properties of partially melted olivine (fayalite) and pyroxene, including the effect of the phase change, using thermodynamic data from *Carmichael et al.* [1977]. Their calculations assume that the induced pore pressure is equal to the applied pressure, which is appropriate for very thin films of melt. For the present geometry the induced pressure is less than the applied.

We obtain a rough estimate of the relaxed bulk modulus K_R' with phase change for the tube geometry, using expression (9) with adiabatic moduli specified for the solid and an effective melt modulus K_f' defined to include the effect of the volume decrease at phase change. For a given melt fraction β we estimate K_f' from Kjartansson and Nur's values for relaxed moduli K_R', using

$$\frac{1}{K_R'} = \frac{1-\beta}{K_{ad}} + \frac{\beta}{K_f'} \tag{27}$$

where K_{ad} is the adiabatic solid modulus. The expression (27) is simply the effective compressibility for a composite with induced pore pressure equal to the applied pressure, the case treated by Kjartansson and Nur.

We assume that the time constant for relaxation is governed by both the phase change reaction kinetics [*Vaisnys*, 1968] and the thermal diffusion time, given by

$$t_T \simeq l^2/\kappa \tag{28}$$

where l is a characteristic diffusion length and κ is the diffusivity; κ is typically of the order of 10^{-2} s cm^{-2} [*Carmichael et al.*, 1977]. Length scales range from the pore radius R for equilibration of the thinnest tubes up to the grain diameter for equilibration of the larger tubes. Neither of these dimensions is well determined for the upper mantle, but a reasonable range of $0.001 < l < 1$ cm, for example, corresponds to relaxation times of $10^{-4} < t_T < 10^2$ s. In contrast, *Vaisnys* [1968] suggests that the relaxation time, if it is based on the reaction kinetics, is of the order of 500 s. In a given system the slower process would determine the overall relaxation time.

Shear Attenuation

Consider now the rock represented in Figure 3. If pure shear stress is suddenly applied, the instantaneous induced change in pore pressure is not uniform throughout the rock but rather depends on the orientation of each pore relative to the applied principal stresses. In addition, within each pore, minor pressure gradients and viscous shear stresses appear near the sharp crack tips.

Neglecting the latter, we take as the unrelaxed state the condition where the pore pressure is uniform within each pore but different from one pore to the next. The unrelaxed shear modulus is μ_u', given by (19) with adiabatic moduli substituted on the right side.

Relaxation occurs as melt flows from one pore to another, from high pore pressure to low pore pressure. The final state, if pores are randomly and isotropically distributed, has uniform pore pressure equal to the pore pressure that existed before the shear stress was applied. Hence the relaxed modulus is given simply by (16) with isothermal moduli substituted on the right side.

An intermediate relaxed state is possible. If squirt is sufficiently slow, the local compression and dilation of unrelaxed pores might lead to localized thermal relaxation and phase change, even though the average microscopic stress field has no hydrostatic component.

The relaxation time for flow between tubes is estimated as follows. During relaxation a volume of liquid Δv_0 is transferred from a pore with initially high pore pressure Δp_0 to one with initially low pore pressure $-\Delta p_0$, where Δp_0 is the increment of pore pressure change induced by the applied shear stress. When relaxation is complete, the increment of induced pore pressure has decayed to zero. Hence we estimate the pore pressure at any point during relaxation as

$$\Delta p = \Delta p_0 \, \Delta v/\Delta v_0 \tag{29}$$

where Δv is the portion of excess pore fluid remaining in the pore. The total volume flow rate out of a circular pipe with radius r under pressure gradient $\partial P/\partial x$ [*Batchelor*, 1967] is

$$\frac{\partial \Delta v}{\partial t} = -\frac{\pi r^4}{8\eta}\frac{\partial p}{\partial x} \tag{30}$$

where η is the liquid viscosity. For the triangular tube with length d the pressure gradient is approximately $\partial P/\partial x = \Delta p/d$. Assuming an equivalent circular tube with radius roughly $r \simeq 2R/3$, the volumetric flow rate out of the tube is

$$\frac{\partial \Delta v}{\partial t} = -\frac{\pi}{8\eta}\left(\frac{2R}{3}\right)^4 \frac{\Delta p_0}{d}\frac{\Delta v}{\Delta v_0} \tag{31}$$

Then Δv decays exponentially with time constant

$$t_v' = 81\eta d \Delta v_0/2\pi R^4 \Delta p_0 \tag{32}$$

The ratio $\Delta v_0/\Delta p_0$ can be estimated from (A69) and (A70) to be of the order of $\pi R^2 d/K_f$. Hence

$$t_v \simeq (40\eta/K_f)(d/R)^2 \tag{33}$$

K_f is typically 0.6×10^{12} dyn/cm^2, and η is probably less than 10^6 P. Again, the important dimensions are poorly determined, but $d \sim 1$ cm, and $0.001 < R < 0.1$ cm corresponds to relaxation times $10^{-2} < t < 10^2$ s. Lower viscosities and shorter tube lengths decrease the relaxation time. In comparison, *O'Connell and Budiansky* [1977] estimate the relaxation time for flow between films of aspect ratio α as

$$t_f \simeq 2\pi\eta/K\alpha^3 \tag{34}$$

On the average the ratio of pore length to width will tend to decrease as the melt fraction increases, causing relaxation times to shorten. *Frank* [1968] modeled grains as truncated octahedra of diameter a (between square faces) as follows. Each of the 36 grain edges is shared by three grains, so that the total edge length per unit volume of material is $6(2)^{1/2}/a^2$. If the average tube diameter along all of the edges is $\bar{R}$, then the melt fraction of the tubes is

$$\beta \simeq 3\pi 2^{1/2}(\bar{R}/a)^2 \tag{35}$$

If the distance of flow for squirt is $d \simeq a$, then

$$(d/R)^2 \simeq 3\pi 2^{1/2}/\beta \tag{36}$$

Therefore as β increases, there is a tendency for t_v, given by (33), to decrease. However, to estimate the actual relaxation times, we would need to know the distribution of tube diameters R rather than the average $\bar{R}$. For some tubes, d/R might be significantly smaller than $\bar{d}/\bar{R}$. Similarly, we need to know what fraction of the melt is in the tubes and what fraction is in the tetrahedral regions where tubes intersect [*Bulau and Waff*, 1979]. For example, if only 10% of the melt is in tubes, then (36) is modified as

$$(d/R)^2 \simeq 30\pi 2^{1/2}/\beta \tag{37}$$

The distribution of tube diameters and the fraction of melt in tubes versus tetrahedra probably have very little effect on the estimate of moduli versus melt fraction. These factors do, however, complicate our estimation of relaxation time.

MODEL RESULTS

Effective bulk and shear moduli calculated for olivine (fayalite) and pyroxene at 20 kbar are shown in Figure 4 as a function of melt fraction. The similarity of results for the two minerals suggests that the results may apply as least qualitatively to a range of compositions. Thermal and phase change calculations were taken from *Kjartansson and Nur* [1980], and material parameters were taken from *Carmichael et al.* [1977]. Curves labeled 'tubes' show the results of this study (for $\varepsilon =$

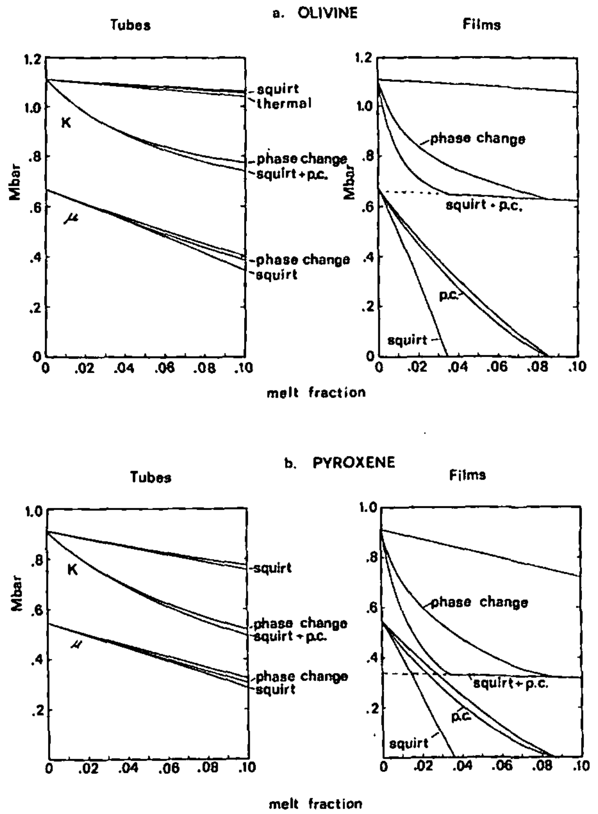

Fig. 4. Computed effective moduli as a function of volume melt fraction, assuming (left) all tubes and (right) all films. The dashed curve is the result from *Kjartansson and Nur* [1980] (see text). (*a*) Olivine: P = 20 kbar, $T \simeq$ 1600°K. (*b*) Pyroxene: P = 20 kbar, $T \simeq$ 1900°K.

0). For comparison, curves labeled 'films' are shown that assume that the melt exists as penny-shaped ellipsoidal films having a distribution of aspect ratios α uniform in ln α between 10^{-1} and 10^{-4}. This is the case computed by O'Connell and Budiansky. For films the expressions of O'Connell and Budiansky were modified (see appendix) to treat more correctly the case of nonzero melt fraction. All of the curves in Figure 4 incorporate the self-consistent approximation.

Comparing tubes and films, the upper unrelaxed bulk moduli curves are approximately the same, because the adiabatic compressibilities of solid and melt are within a factor of 2. Hence the difference in pore stiffness is not very important. The other bulk modulus curves represent the various possible relaxed states. Note that there is a small bulk relaxation due to squirt. Although squirt should not affect isolated tubes in pure compression, their compression does depend on the effective shear modulus of the matrix. Hence at larger melt concentrations we observe the effect of coupling between bulk and shear incorporated in the self-consistent approximation. For all geometries a small bulk relaxation results from the relaxation of adiabatic temperature gradients (curve labeled 'thermal').

The largest single effect for the bulk modulus is the induced solid-melt phase change. Recall that in this case the melt looks effectively very compressible. By our model the difference between unrelaxed and (phase change) relaxed moduli at small melt fraction goes continuously to zero at zero melt fraction, where the results of Kjartansson and Nur show a discontinuous drop in relaxed modulus at the onset of melt. This difference is produced by Kjartansson and Nur's assumption that the composite has zero shear stiffness. Their results are shown as dashed curves in Figure 4. Note that our results converge with theirs at melt fractions large enough that $\mu' \rightarrow 0$. The curves labeled 'squirt + p.c.' (phase change) show an effect physically similar to the 'squirt' only curve except that the relaxation is magnified because the melt is now effectively very compliant.

The sets of shear moduli curves show the upper unrelaxed moduli and various relaxed states. The greatest effect in shear is relaxation due to squirt. However, the effect of phase charge without squirt is also distinguishable.

In most cases the effects of melt are magnified in the film geometry.

Figure 5 shows normalized P and S wave velocities predicted for olivine at 20 kbar if melt is in the form of tubes (ϵ = 0) only. The upper curves represent the unrelaxed or high-frequency values. The spread in velocities represents the dispersion resulting from the various relaxation mechanisms shown in Figure 4. Note that if squirt alone occurs, there is a large S dispersion and a small P dispersion. The effect of phase change is to introduce additional P relaxation with no further change in S.

In the plot of modulus defect, $\Delta M/2M$ (where $M = K + 4\mu/3$) and $\Delta\mu/2\mu$, note that without phase change, squirt causes S wave attenuation to be approximately 3 times the P wave at-

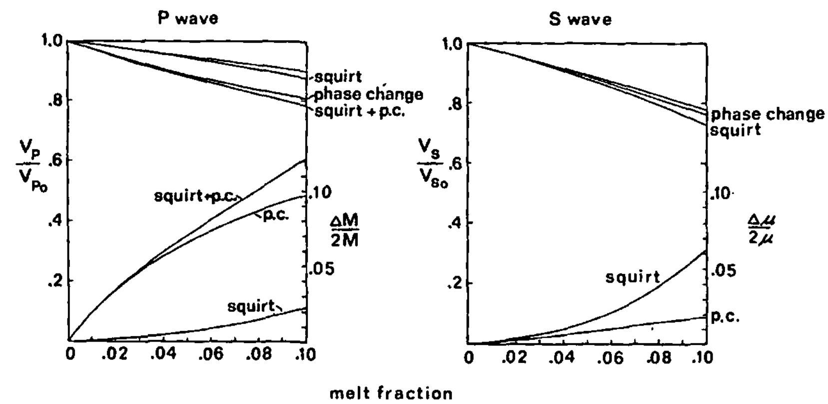

Fig. 5. Computed P and S wave velocity and attenuation versus volume fraction melt for olivine at 20 kbar, 1600°K, assuming that melt is in the form of tubes only (ϵ = 0). Different curves show the effects of the various relaxation mechanisms.

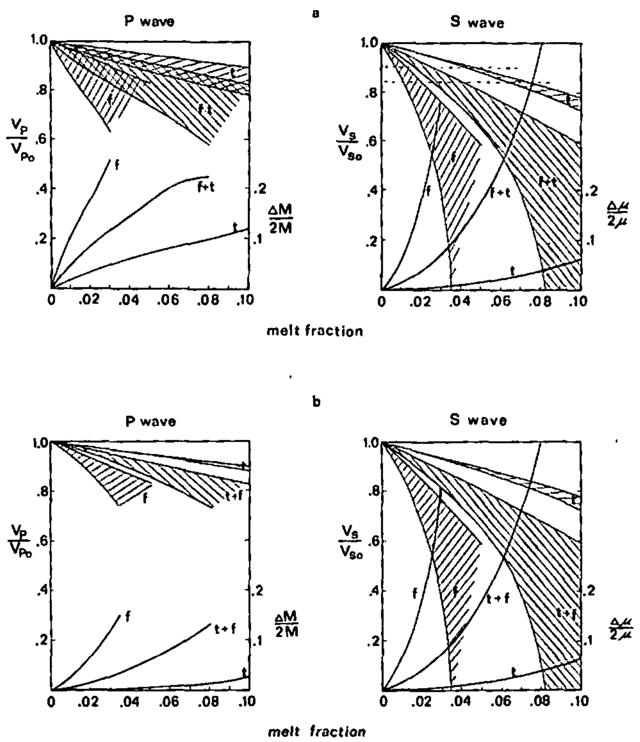

Fig. 6. Computed P wave velocity and attenuation for olivine at 20 kbar, 1600°K, comparing three different melt geometries: t, tubes only ($\epsilon = 0$); f, films only, uniform in ln (aspect ratio) between 10^{-1} and 10^{-4}; and t + f, mixture of tubes plus films where at any melt fraction 30% is in the form of films. The shaded regions show the range of dispersion. (*a*) Relaxation due to phase change plus squirt. (*b*) Relaxation due to squirt only.

tenuation. If phase change is important, then the situation is reversed. Recall that these values can be transformed into $1/Q$ if we estimate the frequency spread of relaxation. For a single relaxation time the curves represent $1/Q$. For a spread of 6 orders of magnitude the values $1/Q$ would be approximately one quarter of the plotted values.

Figure 6 shows normalized P and S wave velocity dispersion and attenuation for olivine at 20 kbar. Three sets of calculations are compared. One assumes that the melt is in the form of tubes ($\epsilon = 0$) only; the second, films only (in the same uniform distribution of aspect ratios as in Figure 4); and the third, a mixture of tubes and films, where at any melt fraction, 30% by volume of melt is in films. The shaded regions define the total range of dispersion, that is, the difference between the high-frequency (unrelaxed) and low-frequency (relaxed) velocities. The modulus defects are also plotted.

In Figure 6*a* it is assumed that both phase change and squirt relaxation occur. This gives the largest possible relaxation for the various mechanisms discussed in this paper. In all cases the dispersion and attenuation are predicted to be comparable and sometimes greater for P waves as compared to S waves. This difference is caused by the phase change and illustrates that it is primarily a mechanism of local compression.

Figure 6*b* is similar to Figure 6*a* except that phase change is neglected so that the relaxation is produced by squirt only. This would be the case if, for example, squirt were dominant in the seismic body wave band and phase change were important only at longer periods. Now S wave attenuation is predicted to be 2 or 3 times the P wave attenuation.

The interpretation of the curves for P and S wave velocity dispersion and attenuation for pyroxene (Figure 7) is the same as for the case of olivine in Figure 6.

Velocity and attenuation in partially melted copper-lead alloys were measured in the laboratory by *Stocker and Gordon* [1975], in extensional resonance at about 100 kHz. The results are shown in Figure 8. The vertical velocity axis is normalized to the velocity with no melt. The horizontal scale is melt fraction by volume. This alloy was chosen because it is known to have a nonwetting melt that tends toward the tube geometry.

In Figure 8*a* the circles are data points. The curves are based on theoretical low-frequency results for several melt geometries, using the material properties given in Table 2. (It is assumed that viscous flow is relaxed and phase changes are unimportant for these conditions.) The upper curve is for spherical inclusions of melt as presented by *Stocker and Gordon* [1975], using *Oldroyd*'s [1956] theory. The lower two curves are for triangular tubes ($\epsilon = 0$), and the middle curve is for tubes with circular cross section ($\epsilon \rightarrow \infty$). All curves incorporate the self-consistent approximation except the one labeled NI (noninteracting), which is included for comparison. Comparing the self-consistent curves, the triangular tubes are more than twice as compliant as spheres or circular tubes; that is, for a given velocity it takes twice as much melt in the circular geometry to explain the observations. The difference be-

TABLE 2. Material Parameters for Copper and Lead

	K_{ad}, Mbar	ν_{ad}	ρ, g/cm^3	η, dyn s cm^{-2}
Copper				
Solid	1.300	0.355	8.792	
Lead				
Solid	0.360	0.459	11.07	
Liquid	0.337		10.68	0.025

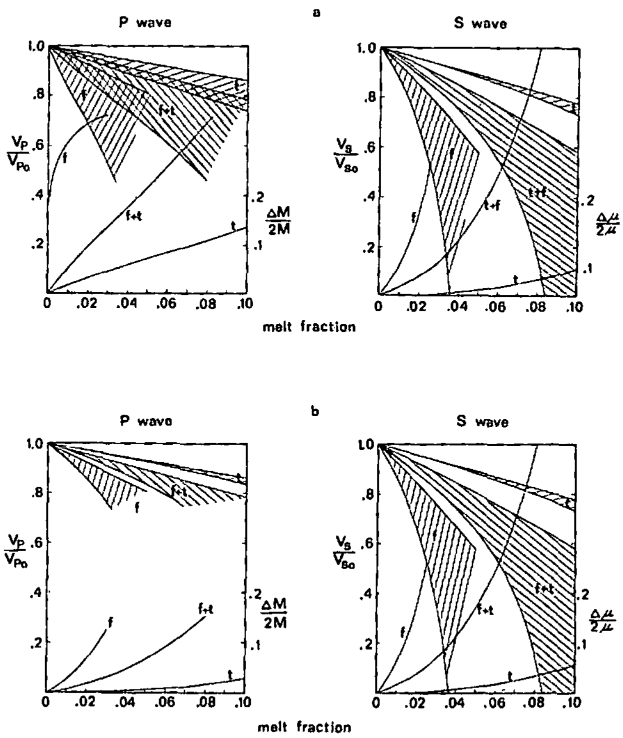

Fig. 7. Same as in Figure 6 but for pyroxene.

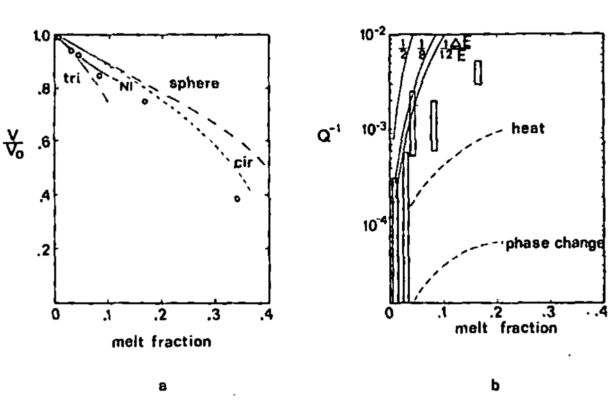

Fig. 8. Comparison of computed velocity and attenuation with observations from *Stocker and Gordon* [1975] for a copper-lead alloy. (*a*) Velocity normalized to the value without melt. Circles are data. Curves are computed for the following geometries: sphere, spherical inclusions; cir, circular tubes; tri and NI, triangular tubes. All computations are self-consistent except for the curve NI (noninteracting). (*b*) Attenuation. Boxes are data. The dashed curves were computed by *Stocker and Gordon* [1975]. The solid curves were computed for three different spreads in relaxation time (see text).

tween the two triangle curves is entirely a result of the method of mathematically treating elastic interactions of the inclusions. At low melt fractions (<5%) the curves converge, as is expected, and fit the data quite well, much better than the sphere or circular tube geometries. Hence it seems that the shape ($\epsilon = 0$) is a good model for the melt geometry. At larger melt fractions the self-consistent and noninteracting results diverge. Probably, the best fit is some average of the noninteracting and self-consistent values.

Attenuation is plotted in Figure 8*b*. The boxes show the values observed by *Stocker and Gordon* [1975]. The curves show upper bounds predicted by several models. The curves for heat flow and phase change were taken from *Stocker and Gordon* [1975] and are too low to account for the observed attenuation except at the lowest melt fractions.

The curves for $\frac{1}{2}$, $\frac{1}{8}$, and $\frac{1}{12}$ $\Delta E/E$ correspond to a single relaxation time and spreads of relaxation times approximately equal to 6 orders and 9 orders of magnitude (see (24)), respectively. The relaxation times, using Table 2 and (33), are of the order of

$$t = 3 \cdot 10^{-12}(d/R)^2 \tag{38}$$

This would equal the experimental frequency if $R/d \simeq 5 \times 10^{-4}$. Such a thin tube might be reasonable at very small melt fractions where the curves agree with the observations. At larger melt fractions (~0.10) the theoretical curves predict a maximum attenuation an order of magnitude or more larger than that observed. The results could explain the observations if, for example, the attenuation outside the frequency band of constant Q falls off as $1/\omega$ and the largest relaxation time were about one decade shorter (10^{-6} s) than the experimental period (10^{-5} s). Again, using (33), this could require $R/d \simeq 10^{-3}$ for the thinnest tubes. A two-decade difference between the longest relaxation time (10^{-7} s) and the experimental period would require $R/d \simeq 0.005$.

The tube geometry explains very well the velocity data and provides a plausible explanation for the observed attenuation in the copper-lead alloy. *Stocker and Gordon* [1975] also measured velocity and attenuation in a partially melted copper-silver alloy, which tends toward the film geometry. *O'Connell and Budiansky* [1977] have shown that those results are consistent with theoretical predictions for melt squirt in the film geometry.

Discussion and Conclusions

We have discussed calculations for velocity and attenuation in partially melted rocks. In particular, new results for the tube geometry have been presented and compared with results expected for the more familiar film model under similar conditions. Our motivation was not to demonstrate that any one model is best but rather to show the range of behavior that is possible. In fact, over a range of conditions from crustal magma bodies to ocean ridges to the asthenosphere it is possible that a variety of melt geometries exist. It is also possible that the geometry depends on the amount of melt present.

From Figures 7 and 8 it is clear that the greatest reduction in velocity and increase in attenuation is expected where melt is in the film geometry; the least where in the tube geometry; and almost any intermediate values when mixtures of tubes and films. If melt is present, a finite bulk attenuation arising from thermal relaxation, melt squirt, or phase change is expected. The phase change seems to be quite large for the olivine and pyroxene examples calculated here.

Since bulk attenuation is seldom required to explain P and S (body wave) attenuation, the model results suggest several alternative constraints on melt in the upper mantle:

1. If bulk attenuation from melt is important at body wave frequencies, then the spatial distribution of melt must be very restricted. For example, partial melt in the mantle low-velocity zone would have to be in thin layers. Alternatively, melt might exist only in laterally restricted regions, such as under ridges or trenches (E. Kjartansson, personal communication, 1979).

2. If bulk attenuation from melt is important at body wave frequencies, then melt can be widely distributed but only in minute fractions by volume except in spatially restricted regions.

3. Bulk relaxation due to melt may not be important at body wave frequencies. The larger relaxation time suggested by *Vaisnys* [1968] would imply that bulk attenuation associated with phase change would be observed only with longer-period surface waves and free oscillations.

We have suggested that in many cases dispersion and attenuation can be easily estimated from the spread of relaxation times and modulus defect by using (23) and (24). Figure 9 illustrates the results of this technique relative to more extensive viscoelastic calculations done by *O'Connell and Budiansky* [1977]. The plotted points are normalized S wave velocity and Q for melt in the film geometry as computed by *O'Connell and Budiansky* [1977, Figure 8]. For the three melt fractions shown (0.6%, 1.8%, and 3%) a distribution of aspect ratios is assumed to be uniform in $\ln \alpha$ between 10^{-4} and 10^{-1}, as in Figures 4, 6, and 7. The results represent relaxation due to squirt only.

Our predicted Q (assuming frequency-independent Q), is shown by the pairs of dashed lines. The upper line in each pair was found from the plotted value of $\Delta\mu/2\mu$ in Figure 6*b* and the simplified expression (24) using $\omega_1/\omega_2 = 10^9$. The lower line in each pair is calculated from the more exact expression (23) using the unrelaxed and relaxed moduli for squirt only in Figure 4. Our predicted velocity dispersion is calculated using (23) to interpolate between the unrelaxed and relaxed moduli and using the constant Q value also calculated

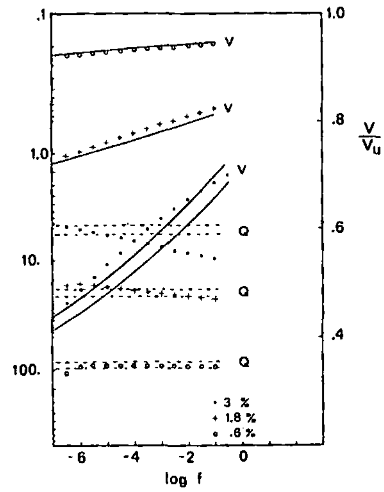

Fig. 9. Comparison of computed dispersion using the simple constant Q assumption versus the more detailed viscoelastic calculations of *O'Connell and Budiansky* [1977].

from (23). For the two smaller melt fractions (0.6% and 1.8%) the low-frequency velocity at 10^{-7} Hz was taken from Figure 6*b*. For the largest melt fraction (3%) the lower-velocity curve was calculated using the relaxed velocity from Figure 6*b*, at 10^{-8} Hz. The lower frequency was used because O'Connell and Budiansky's 3% Q has not yet rolled off at 10^{-7} Hz. A better fit is obtained by using our estimated constant Q and simply extrapolating upward from O'Connell and Budiansky's lowest velocity. Hence the constant Q approximation seems to provide reasonable back-of-the-envelope estimates comparable to the results of more complicated calculations.

A sample interpretation of the upper mantle low-velocity zone can be made from Figure 6. Typical values under the western United States [*Goetze*, 1977] are a shear velocity drop of 10–16% and peak attenuation of $1/Q = 0.04$–0.06. These ranges are shown by the horizontal dashed lines in Figure 6, and it appears that a continuous range of interpretations is possible between ~1% for films only to ~8% for tubes only. An independent constraint comes from upper mantle electrical conductivity. *Gough* [1974] models geomagnetic deep sounding data under the western United States with a value of 0.5 mho/m. This value suggests a minimum melt fraction of the order of 5% at 100-km depth [*Shankland and Waff*, 1977, Figure 7]. From Figure 6 it is clear that the seismic observations are consistent with melt fractions greater than 5% only if the melt is in the form of tubes or tubes mixed with films. The model with films alone lowers the velocity too much.

APPENDIX

Plane Strain Tube Deformation

In this section the deformation of a tube under remotely applied stress is found. The method of solution is that given in detail by *Savin* [1961] for polygonal-shaped cavities.

The problem is most conveniently posed by using the complex variable notation of *Muskhelishvili* [1953]. Stress solutions of two-dimensional problems (plane stress and plane strain) in the theory of linear isotropic elasticity can be expressed in terms of two analytic functions $\phi_1(z)$ and $\psi_1(z)$ of the complex variable $z = x + iy$:

$$\sigma_{xx} + \sigma_{yy} = 2[\phi_1'(z) + \overline{\phi_1'(z)}] \tag{A1}$$

$$\sigma_{yy} - \sigma_{xx} + 2i\sigma_{xy} = 2[\bar{z}\phi_1''(z) + \psi_1'(z)] \tag{A2}$$

where the overbar refers to the complex conjugate.

For the case of an infinite body loaded uniformly at infinity and having a cavity surrounding the origin, each of the potentials can be expanded as

$$\begin{aligned}\phi_1(z) &= \phi^0(z) + \phi^*(z)\\ \psi_1(z) &= \psi^0(z) + \psi^*(z)\end{aligned} \tag{A3}$$

where ϕ^0 and ψ^0 give the solution in a body without a cavity under identical remote loading and ϕ^* and ψ^* give the superimposed perturbations due to introducing the cavity.

If the remote loading takes the form of a uniaxial tensile stress P acting along an axis forming an angle α with the x axis, the corresponding potentials of the uniform solutions are [*Savin*, 1961]

$$\begin{aligned}\phi^0(z) &= Pz/4\\ \psi^0(z) &= -Pze^{-i2\alpha}/2\end{aligned} \tag{A4}$$

The corresponding uniform stress components relative to the x-y axes are

$$\begin{aligned}\sigma_{xx} &= P\cos^2\alpha\\ \sigma_{yy} &= P\sin^2\alpha\\ \sigma_{xy} &= P\sin\alpha\cos\alpha\end{aligned} \tag{A5}$$

The problem of introducing the cavity into the uniform stress field can be thought of as follows. Before introducing the cavity the stress is uniform throughout the body. The traction $\mathbf{T}$ on any surface normal to the x-y plane specified by outward unit normal $\hat{\mathbf{n}}$ is given by Cauchy's formula [*Fung*, 1965]:

$$\mathbf{T} = \begin{pmatrix}\sigma_{xx} & \sigma_{xy}\\ \sigma_{yx} & \sigma_{yy}\end{pmatrix}\cdot\hat{\mathbf{n}} \tag{A6}$$

where σ_{xx}, σ_{xy}, and σ_{yy} are given by (A5). Imagine now cutting and removing material to form the desired cavity but simultaneously applying precisely the tractions given by (A6) to the newly formed surfaces. At this point the elastic field outside the cavity is exactly the uniform field that existed before making the cuts. The final desired state of traction free cavity surfaces is achieved by relaxing these tractions, the equivalent of superimposing the additional tractions $-\mathbf{T}$. Hence the problem reduces to finding the potentials $\phi^*(z)$ and $\psi^*(z)$ that correspond to an infinite body with a cavity loaded by tractions $-\mathbf{T}$ and having zero stresses at infinity.

The stress boundary conditions in the form of tractions $-\mathbf{T}$ with components $-X$ and $-Y$ acting on the surface of the cavity can be related to the potentials at the surface by [*Savin*, 1961]

$$\phi^*(z) + z\overline{\phi^{*\prime}(z)} + \overline{\psi^*(z)} = -i\int_0^s (X + iY)\,ds \tag{A7}$$

where s is the distance along the surface in the z plane. In the cutting process described above, a similar condition holds between the potentials of the uniform part of the solution and the tractions $+\mathbf{T}$ given by (A6) that were applied to the cavity:

$$\phi^0(z) + z\overline{\phi^{0\prime}(z)} + \overline{\psi^0(z)} = +i\int_0^s (X + iY)\,ds \tag{A8}$$

Hence at the surface of the cavity only we have, equating (A7) and (A8),

$$\phi^*(z) + z\overline{\phi^{*\prime}(z)} + \overline{\psi^*(z)} = -[\phi^0(z) + z\overline{\phi^{0\prime}(z)} + \overline{\psi^0(z)}] \tag{A9}$$

It is convenient to treat irregularly shaped cavities such as those in Figure 1*b* by conformally mapping the outside of the complex z plane into the inside of a unit circle in the complex ζ plane by means of a function $z = \omega(\zeta)$, which we choose here as

$$z = R\left(\frac{1}{\zeta} + \frac{1}{2+\epsilon}\zeta^2\right) \tag{A10}$$

where R and ϵ are real constants. Accordingly, the values of $\zeta = \rho e^{i\theta}$ on the unit circle ($\rho = 1$) generate the parameteric equations for the tube when they are substituted into (A10):

$$\begin{aligned} x &= R\left(\cos\theta + \frac{1}{2+\epsilon}\cos 2\theta\right) \\ y &= R\left(-\sin\theta + \frac{1}{2+\epsilon}\sin 2\theta\right) \end{aligned} \tag{A11}$$

Muskhelishvili [1953] gives the more general form

$$z = R\left(\frac{1}{\zeta} + \frac{1}{m}\zeta^n\right) \tag{A12}$$

which if $m = 1/n$, maps the unit circle $|\zeta| = 1$ into a symmetric figure in the z plane with $n + 1$ cusps. *Savin* [1961] treats the special case $z = R\cdot(1/\zeta + \zeta^2/3)$, which corresponds to $\epsilon = 1$ in (A10).

By using the mapping (A10) and the uniform solutions (A4) the potentials (A3) for the total problem can be transformed to the ζ plane:

$$\begin{aligned} \phi_1[\omega(\zeta)] &= \frac{P}{4}\omega(\zeta) + \phi^*[\omega(\zeta)] \\ \psi_1[\omega(\zeta)] &= \frac{-P}{2}e^{-i2\alpha}\omega(\zeta) + \psi^*[\omega(\zeta)] \end{aligned} \tag{A13}$$

Including the notation

$$\begin{aligned} \phi(\zeta) &= \phi_1[\omega(\zeta)] \qquad \psi(\zeta) = \psi_1[\omega(\zeta)] \\ \phi_0(\zeta) &= \phi^*[\omega(\zeta)] \qquad \psi_0(\zeta) = \psi^*[\omega(\zeta)] \end{aligned} \tag{A14}$$

the problem now reduces to finding the functions $\phi(\zeta)$ and $\psi(\zeta)$ in the interior of the unit circle. Similarly, the boundary condition (A9) can be transformed using the mapping (A10) and the uniform field potentials (A4) to read

$$\phi_0(\sigma) + \frac{\omega(\sigma)}{\overline{\omega'(\sigma)}}\overline{\phi_0'(\sigma)} + \overline{\psi_0(\sigma)} = \frac{-P}{2}[\omega(\sigma) - e^{+i2\alpha}\overline{\omega(\sigma)}] \tag{A15}$$

where $\sigma = e^{i\theta}$ denotes the values of ζ on the unit circle.

Two functional equations for $\phi_0(\zeta)$ and $\psi_0(\zeta)$ can be obtained by multiplying (A15) and the complex conjugate of (A15) by

$$\frac{1}{2\pi i}\frac{d\sigma}{\sigma - \zeta} \tag{A16}$$

where ζ is a point inside the unit circle, and integrating each equation about the unit circle [*Muskhelishvili*, 1953, pp. 303–308; *Savin*, 1961]:

$$\phi_0(\zeta) + \frac{1}{2\pi i}\int_\gamma \frac{\omega(\sigma)}{\overline{\omega'(\sigma)}}\overline{\phi_0'(\sigma)}\frac{d\sigma}{\sigma - \zeta} + \beta = \frac{-P}{4\pi i}\int_\gamma [\omega(\sigma) - e^{i2\alpha}\overline{\omega(\sigma)}]\frac{d\sigma}{\sigma - \zeta} \tag{A17}$$

$$\psi_0(\zeta) + \frac{1}{2\pi i}\int_\gamma \frac{\overline{\omega(\sigma)}}{\omega'(\sigma)}\phi_0'(\sigma)\frac{d\sigma}{\sigma - \zeta} = \frac{-P}{4\pi i}\int_\gamma [\overline{\omega(\sigma)} - e^{-i2\alpha}\omega(\sigma)]\frac{d\sigma}{\sigma - \zeta} \tag{A18}$$

where β is an undetermined constant.

If we assume a solution in the form

$$\phi_0(\zeta) = a_1\zeta + a_2\zeta^2 + a_3\zeta^3 + \cdots \tag{A19}$$

substitute into (A17), and equate coefficients of identical powers of ζ, we obtain

$$\phi_0(\zeta) = \frac{PR}{2}\left[e^{i2\alpha}\zeta - \frac{z}{2+\epsilon}\zeta^2\right] \tag{A20}$$

Substituting (A20) into (A18), we obtain

$$\begin{aligned} \psi_0(\zeta) = \frac{PR}{2}\Bigg[&\frac{e^{i2\alpha}}{2+\epsilon} - \frac{2\zeta}{(2+\epsilon)^2} \\ &+ \frac{e^{i2\alpha}\{[(2+\epsilon)^2 + 2]/(2+\epsilon)^2\}\zeta^3}{1 - [2/(2+\epsilon)]\zeta^3} \\ &- \frac{[2/(2+\epsilon)]\{[(2+\epsilon)^2 + 2]/(2+\epsilon)^2\}\zeta^4}{1 + [2/(2+\epsilon)]\zeta^3} \\ &- \zeta + \frac{e^{-i2\alpha}\zeta^2}{2+\epsilon}\Bigg] \end{aligned} \tag{A21}$$

Finally, substituting (A20) and (A21) into (A13), we obtain

$$\phi(\zeta) = \frac{PR}{4}\left[\frac{1}{\zeta} + 2e^{i2\alpha}\zeta - \frac{1}{2+\epsilon}\zeta^2\right] \tag{A22}$$

$$\psi(\zeta) = PR\left[\frac{-e^{-i2\alpha}}{2\zeta} + \frac{(2+\epsilon)e^{i2\alpha} - [2 + (2+\epsilon)^2]\zeta + (2+\epsilon)^2 e^{i2\alpha}\zeta^3}{2(2+\epsilon)^2 - 4(2+\epsilon)\zeta^3}\right] \tag{A23}$$

Hydrostatic Stress

The normal component of pore wall displacement δU_n of each pore resulting from the remotely applied hydrostatic stress δP can be found as the superposition of two problems. The first is the plane strain deformation δU_{1n} resulting from remotely applied stresses $\sigma_{xx} = \delta P$, $\sigma_{yy} = \delta P$, and $\sigma_{zz} = 2\nu\delta P$. Here the z axis is chosen to coincide with the pore axis. The second problem is the deformation δU_{2n} resulting from uniaxial applied stress $\sigma_{zz} = (1 - 2\nu)\delta P$.

The displacement field $\delta \mathbf{U}_1 = (u, v)$ for the plane strain problem can be expressed in terms of the analytic functions $\phi_1(z)$ and $\psi_1(z)$ of the complex variable $z = x + iy$ found in the preceding section.

The outward normal component of displacement δU_{1n} can be written in terms of the Cartesian components as

$$\delta U_{1n} = (u, v)\cdot\frac{(dy, -dx)}{(dx^2 + dy^2)^{1/2}} \tag{A24}$$

where $ds = (dx, dy)$ is the increment of pore contour Γ in the x-y plane. It follows that

$$\int_\Gamma \delta U_{1n}\, ds = \mathrm{Im} \int_\Gamma \overline{(u+iv)}\, dz \tag{A25}$$

where $ds = |ds|$ and Im refers to the imaginary part. Introducing the transformation (A10) into (A25) gives

$$\int_\Gamma \delta U_{1n}\, ds = \frac{1}{2\mu}\,\mathrm{Im} \int \Big\{ (3-4\nu)\, \overline{\phi_1[\omega(\zeta)]} - \frac{\overline{\omega(\zeta)}}{\overline{\omega'(\zeta)}} \cdot \overline{\phi_1'[\omega(\zeta)]} - \overline{\psi_1[\omega(\zeta)]} \Big\}\, \omega'(\zeta)\, d\zeta \tag{A26}$$

The functions $\phi(\zeta) = \phi_1[\omega(\zeta)]$ and $\psi(\zeta) = \psi_1[\omega(\zeta)]$ are given by (A22) and (A23) for the case of a body with a single cavity loaded at infinity by a uniaxial stress P acting along an axis in the x-y plane forming an angle α with the x axis. For the plane strain part of the hydrostatic problem we superimpose the solution for stress δP and $\alpha = 0$ with that for stress δP and $\alpha = \pi/2$. Finally, evaluating (A26) gives

$$\int_\Gamma \delta U_{1n}\, ds = \delta P\, \frac{2\pi R^2(1-2\nu)}{\mu}\, \frac{[(2+\epsilon)^2+2]}{(2+\epsilon)^2} \tag{A27}$$

The uniaxial loading problem with stress $\sigma_{zz} = \delta P(1-2\nu)$ results in the axial strain $\epsilon_{zz} = \delta P(1-2\nu)/E$ and lateral strains from the Poisson effect $\epsilon_{xx} = \epsilon_{yy} = -\nu\epsilon_{zz}$. Here E is the intrinsic Young's modulus for the rock material. Hence we can write the change in cross-sectional area of the pore as

$$dA = \int \delta U_{2n}\, ds = (\epsilon_{xx} + \epsilon_{yy})A = \frac{-2\nu(1-2\nu)\delta P}{E}\, A \tag{A28}$$

where

$$A = \frac{\pi R^2[(2+\epsilon)^2 - 2]}{(2+\epsilon)^2} \tag{A29}$$

is the unstrained cross-sectional area of the pore obtained by integrating the area enclosed by the curve (2). The contribution to the strain energy integral from the pore ends can be approximated by assuming a finite pore length d and finding the pore axial length change

$$\int_{\mathrm{ends}} \delta U_{n2}\, ds = \epsilon_{zz} A d = \frac{\delta P(1-2\nu)Ad}{E} \tag{A30}$$

Substituting the contributions (A27), (A28), and (A30) into (4) gives the effective bulk modulus.

Pure Shear Applied Stress: Empty Pores

The pore wall displacement $\delta \mathbf{U}$ from the remotely applied stress (12) is found as the superposition of three separate problems. Accordingly, we write the applied stress (12) as the sum

$$(\sigma_{ij}') = \delta P \begin{pmatrix} \sigma_{xx}' & \sigma_{yx}' & 0 \\ \sigma_{yx}' & \sigma_{yy}' & 0 \\ 0 & 0 & \nu(\sigma_{xx}' + \sigma_{yy}') \end{pmatrix} + \delta P \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \sigma_{zz}' - \nu(\sigma_{xx}' + \sigma_{yy}') \end{pmatrix} + \delta P \begin{pmatrix} 0 & 0 & \sigma_{xz}' \\ 0 & 0 & \sigma_{yz}' \\ \sigma_{zx}' & \sigma_{zy}' & 0 \end{pmatrix} \tag{A31}$$

The first term on the right side of the expression gives the uniform applied stress field corresponding to plane strain deformation; the second term is uniaxial stress; the last term corresponds to antiplane deformation.

The rotational symmetry of the strain energy (26) allows the plane strain problem to be replaced by the two-dimensional hydrostatic (H) and deviatoric (D) components in the principal stress coordinate system

$$(\sigma_{ij}')_H + (\sigma_{ij}')_D = \begin{pmatrix} \sigma_0 & 0 & 0 \\ 0 & \sigma_0 & 0 \\ 0 & 0 & 2\nu\sigma_0 \end{pmatrix} + \begin{pmatrix} S & 0 & 0 \\ 0 & -S & 0 \\ 0 & 0 & 0 \end{pmatrix} \tag{A32}$$

where

$$\sigma_0 = (\sigma_{xx}' + \sigma_{yy}')/2 = -\sin^2\lambda(\sin^2\xi - \cos^2\xi)\delta P/2 \tag{A33}$$

$$S^2 = [(\sigma_{xx}' - \sigma_{yy}')^2/4 + \sigma_{xy}'^2]\delta P^2 = [\tfrac{1}{4}(\cos^2\lambda + 1)^2(\sin^2\xi - \cos^2\xi)^2 + 4\sin^2\xi\cos^2\xi\cos^2\lambda]\delta P^2$$

Similarly, the antiplane problem can be replaced by the rotated antiplane (A) stresses:

$$(\sigma_{ij}')_A = \begin{pmatrix} 0 & 0 & \tau \\ 0 & 0 & 0 \\ \tau & 0 & 0 \end{pmatrix} \tag{A34}$$

where

$$\tau^2 = \sigma_{xz}{}^2 + \sigma_{yz}{}^2 = \delta P^2 \sin^2\lambda[\cos^2\lambda(\sin^2\xi - \cos^2\xi)^2 + 4\sin^2\xi\cos^2\xi] \tag{A35}$$

With the problem thus divided, the pore energy can be written as

$$\int \mathbf{T}\cdot\delta\mathbf{U}\, dA = \int (\mathbf{T}_A + \mathbf{T}_H + \mathbf{T}_D + \mathbf{T}_{AX}) \cdot (\delta\mathbf{U}_A + \delta\mathbf{U}_H + \delta\mathbf{U}_D + \delta\mathbf{U}_{AX})\, dA \tag{A36}$$

where the subscripts A, H, D, and AX refer to the tractions and corresponding displacements in the antiplane, hydrostatic plane strain, deviatoric plane strain, and uniaxial problems, respectively. By symmetry, several of the cross products in the integrand integrate to zero, yielding

$$\int \mathbf{T}\cdot\delta\mathbf{U}\, dA = d_i \int_\Gamma \mathbf{T}_H\delta\mathbf{U}_H\, ds + d_i \int_\Gamma \mathbf{T}_H\delta\mathbf{U}_{AX}\, ds + \int_{\mathrm{ends}} \mathbf{T}_A\delta\mathbf{U}_{AX}\, dA + d_i \int_\Gamma \mathbf{T}_D\delta\mathbf{U}_D\, ds + d_i \int_\Gamma \mathbf{T}_A\delta\mathbf{U}_A\, ds \tag{A37}$$

Each of these five integrals is now treated separately.

The contributions from the plane strain and axial deformations are found as in the calculations of bulk modulus. By simply replacing δP in (A27) with σ_0 and noting that $|\mathbf{T}_H| = \sigma_0$ we obtain

$$d_i \int_\Gamma \mathbf{T}_H\delta\mathbf{U}_H\, ds = \frac{\sigma_0{}^2\pi R^2 d_i(1-\nu)2[(2+\epsilon)^2+2]}{\mu(2+\epsilon)^2} \tag{A38}$$

The uniaxial stress $\sigma_{zz}' = -2\sigma_0(1+\nu)$ causes the lateral strains $\epsilon_{xx}' = \epsilon_{yy}' = 2\sigma_0\nu/E$ from the Poisson effect, and we can immediately write, analogous to (A28),

$$d_i \int_\Gamma \mathbf{T}_H \delta \mathbf{U}_{Ax}\, ds = \frac{2\sigma_0^2 \nu d_i \pi R^2}{\mu} \frac{[(2+\epsilon)^2 - 2]}{(2+\epsilon)^2} \tag{A39}$$

The contributions from the pore ends are found from the axial strain as in (A30), leading to

$$\int_{\text{ends}} \mathbf{T}_{Ax} \delta \mathbf{U}_{Ax}\, dA = \frac{2\sigma_0^2 d_i \pi R^2 [(2+\epsilon)^2 - 2]}{\mu(2+\epsilon)^2} \tag{A40}$$

The plane strain deviatoric contribution is found by referring again to the complex notation. The energy integral can be expanded as

$$d_i \int_\Gamma \mathbf{T}_D \delta \mathbf{U}_D\, ds = d_i \int_\Gamma (u, v) \cdot \begin{pmatrix} S & 0 \\ 0 & -S \end{pmatrix} \cdot \begin{pmatrix} -dy \\ dx \end{pmatrix} \tag{A41}$$

where u and v are the x and y components of $\delta\mathbf{U}$ and the inward unit normal to the pore contour $dz = dx + i\, dy$ is

$$\hat{n}' = \frac{1}{(dx^2 + dy^2)^{1/2}} \begin{pmatrix} -dy \\ dx \end{pmatrix} \tag{A42}$$

It follows that

$$d_i \int_\Gamma \mathbf{T}_D \delta \mathbf{U}_D\, ds = \operatorname{Im} \frac{S}{2\mu} \int_\Gamma [(3-4\nu)\phi_1(z) - \overline{z\phi_1'(z)} - \overline{\psi_1(z)}]\, dz \tag{A43}$$

Transforming to the ζ plane using (A10), this becomes

$$\operatorname{Im} \frac{S}{2\mu} \int_\gamma \left\{ (3-4\nu)\phi_1[\omega(\zeta)] - \frac{\omega}{\bar{\omega}'} \overline{\phi_1[\omega(\zeta)]} - \overline{\psi_1[\omega(\zeta)]} \right\} \omega'\, d\zeta \tag{A44}$$

For the plane strain deviatoric problem we take $\phi(\zeta)$ and $\psi(\zeta)$ from (A22) and (A23) and superimpose the solution for S at α with that for $-S$ at $\alpha + \pi/2$. Integrating around the unit circle γ, we obtain

$$d_i \int_\Gamma \mathbf{T}_D \delta \mathbf{U}_D\, ds = \frac{4(1-\nu) S^2 R^2 \pi}{\mu} \tag{A45}$$

The antiplane problem is solved by using a slightly different complex notation. The antiplane displacement δU_A is nonzero only in the z' direction and can always be written as the real part of an analytic function $\phi(z)$. It follows that the stresses can be written as

$$\sigma_{xz} + i\sigma_{yz} = \mu\, \partial\phi/\partial z \tag{A46}$$

The energy integral can be written as

$$d_i \int_\Gamma \mathbf{T}_A \delta \mathbf{U}_A\, ds = d_i \int_\Gamma \delta U(\sigma_{xz}\, dy - \sigma_{yz}\, dx) \tag{A47}$$

It follows that

$$d_i \int_\Gamma \mathbf{T}_A \delta \mathbf{U}_A\, ds = \operatorname{Im} \frac{\mu}{2} \int \frac{\partial\phi}{\partial z} (\phi + \bar{\phi})\, dz \tag{A48}$$

The function ϕ is found in the next section. Transforming to the ζ plane using (A10) and integrating around the unit circle, we obtain

$$d_i \int_\Gamma \mathbf{T}_A \delta \mathbf{U}_A\, ds = \frac{\tau^2 R^2 2\pi}{\mu} \tag{A49}$$

Substituting the contributions (A38)–(A40), (A45), and (A49) into (14) gives the dry rock strain energy needed to find the effective shear modulus (16).

Antiplane Deformation

In this section the antiplane solution is found for an infinite body with a tube loaded by a uniform simple shear field at infinity. Choose Cartesian coordinates such that all antiplane displacements U are in the z direction. Then U is a harmonic function and can be considered the real part of an analytic function $\phi(z)$ of the complex variable $z = z + iy$. It follows that the only nonzero stresses can be written as

$$\sigma_{xz} - i\sigma_{yz} = \mu\, \partial\phi/\partial z \tag{A50}$$

For the case of a body loaded uniformly at infinity and containing a cavity the solution can be expanded as

$$\phi(z) = \phi^0(z) + \phi^*(z) \tag{A51}$$

where ϕ^0 is the solution for a uniform body without a cavity under identical loading and ϕ^* is the perturbation due to introducing the cavity.

In the case of simple shear loading the uniform field is

$$\phi^0(z) = (\tau/\mu) z e^{-i\alpha} \tag{A52}$$

The corresponding stresses are

$$\sigma_{xz} + i\sigma_{yz} = \tau \cos\alpha + i\tau \sin\alpha \tag{A53}$$

Here α gives the angle between the normal to the plane of maximum shear stress and the x axis.

The stress boundary conditions in the form of tractions $\mathbf{T}$ acting on the surface of the cavity can be related to the potential function at the surface by

$$\int_0^s |\mathbf{T}|\, ds = \frac{\mu}{2} [\phi(z) - \bar{\phi}(z)] \tag{A54}$$

where s is the distance along the cavity contour in the z plane. A similar condition applies to both the uniform solution ϕ^0 and the perturbing solution ϕ^*. We can now write

$$\frac{\mu}{2} [\phi^0(z) - \overline{\phi^0(z)}] = \frac{-\mu}{2} [\phi^*(z) - \overline{\phi^*(z)}] \tag{A55}$$

for z on the contour of the cavity. Using the mapping (A10) and introducing the notation $\phi_0(\zeta) = \phi^*[\omega(\zeta)]$, this becomes

$$\phi_0(\sigma) - \overline{\phi_0(\sigma)} = \frac{-\tau}{\mu} [\omega(\sigma) e^{-i\alpha} - \overline{\omega(\sigma)} e^{i\alpha}] \tag{A56}$$

where σ denotes values of ζ on the unit circle. A functional equation for $\phi_0(\zeta)$ is obtained by multiplying both sides of (A56) by

$$\frac{1}{2\pi i} \frac{d\sigma}{\sigma - \zeta} \tag{A57}$$

where ζ is a point inside the unit circle, and integrating around the unit circle

$$\frac{1}{2\pi i} \int_\gamma \frac{\phi_0(\sigma) - \overline{\phi_0(\sigma)}}{\sigma - \zeta} d\sigma = \frac{-\tau}{2\pi i \mu} \int_\gamma [\omega(\sigma) e^{-i\alpha} - \overline{\omega(\sigma)} e^{i\alpha}] \frac{d\sigma}{\sigma - \zeta} \tag{A58}$$

If we assume a solution of the form

$$\phi_0(\zeta) = a_1 \zeta + a_2 \zeta^2 + \cdots \tag{A59}$$

integrate, and equate like powers of ζ, we find

$$\phi_0(\zeta) = \frac{\tau R}{\mu}\left[e^{i\alpha}\zeta - \frac{e^{-i\alpha}}{2+\epsilon}\zeta^2\right] \quad \text{(A60)}$$

The total solution is that

$$\phi[\omega(\zeta)] = \frac{\tau R}{\mu}\left[\frac{e^{-i\alpha}}{\zeta} + e^{i\alpha}\zeta\right] \quad \text{(A61)}$$

Pure Shear Loading With Pore Pressure

To evaluate the pore wall displacements $\delta \mathbf{U}$ of the ith pore, consider the stress shown in Figure 3a. The desired set of boundary conditions for the ith pore consists of the remotely applied stress σ_{ij}' given by (12) plus the normal stress $-\delta P_{pi}$ (stress defined as positive in tension) applied to the walls of the pore. This can be expanded as the superposition of two problems. The first has the hydrostatic stress $-\delta P_{pi}$ applied remotely as well as at the pore walls. The resulting deformation is that of a solid block under pure hydrostatic stress. The second problem has the stress

$$\begin{pmatrix} \sigma_{11}' + \delta P_{pi} & \sigma_{12}' & \sigma_{13}' \\ \sigma_{21}' & \sigma_{22}' + \delta P_{pi} & \sigma_{23}' \\ \sigma_{31}' & \sigma_{32}' & \sigma_{33}' + \delta P_{pi} \end{pmatrix} \quad \text{(A62)}$$

applied remotely while the pore walls are stress free. This problem resembles the dry rock calculation above and can be once again decomposed into plane strain, uniaxial, and antiplane problems, as in (A31). It can be immediately seen that the pore pressure affects only the terms in (A37) involving plane strain hydrostatic and uniaxial displacements. These are evaluated as follows.

$$\int_{\text{ends}} \mathbf{T}_{AX}\delta\mathbf{U}_{AX}\, ds = \{[-2\sigma_0(1+\nu) + \delta P_p(1-2\nu)]/E - \delta P_p/3K\}\, dA \quad \text{(A66)}$$

Substituting (A45), (A49), (A63), (A65), and (A66) into (14) gives

$$\int \mathbf{T}\delta\mathbf{U}\, ds = \frac{\pi R^2 d_i}{\mu}\Bigg\{2\tau^2 + 4S^2(1-\nu) + \sigma_0^2\left[\frac{2(1-\nu)[(2+\epsilon)^2+2]}{(2+\epsilon)^2} + \frac{2(1+\nu)[(2+\epsilon)^2-2]}{(2+\epsilon)^2}\right] + \delta P_p\sigma_0\,\frac{2(1-\nu)[(2+\epsilon)^2+2]}{(2+\epsilon)^2} - \frac{(1-2\nu)[(2+\epsilon)^2-2]}{(2+\epsilon)^2}\Bigg\} \quad \text{(A67)}$$

The induced pore pressure δP_{pi} is given by

$$\delta P_{pi} = -K_f(\Delta V_p/V_p) \quad \text{(A68)}$$

where $\Delta V_p/V_p$ is the pore volumetric strains. The volumetric strain is the sum of the pore cross-sectional area strain in the x'-y' plane plus the pore axial strain in the z direction,

$$\Delta V_p/V_p = (\Delta A/A) + \epsilon_{zz}' \quad \text{(A69)}$$

which are contained in the expressions (A63), (A65), and (A66). Eliminating $\Delta V_p/V_p$ from (A68) and (A69) and using (A63) and (A66), we obtain the induced pressure in the ith pore due to the plane hydrostatic stress σ_0.

$$\delta P_{pi} = \sigma_0\left\{\frac{2(1-\nu)[(2+\epsilon)^2+2] - (1-2\nu)[(2+\epsilon)^2-2]}{-2(1-\nu)[(2+\epsilon)^2+2] + \mu[(2+\epsilon)^2-2]\{(1/K) - (1/K_f) - [(1-2\nu)^2/2\mu(1+\nu)]\}}\right\} \quad \text{(A70)}$$

The plane strain hydrostatic displacement is found just as in (A27) with σ_0 replaced by $\sigma_0 + \delta P_{pi}$. Adding the solid block area change $dA = -2\delta PA/3K$, we obtain

$$d_i\int_\Gamma \mathbf{T}_H\delta\mathbf{U}_H = -d_i\sigma_0\,\frac{2}{3}\,\frac{\delta P_{pi}}{K}A + \pi d_i\sigma_0 R^2\,\frac{(\sigma_0+\delta P_p)}{\mu}\,2(1-\nu)\,\frac{[(2+\epsilon)^2+2]}{(2+\epsilon)^2} \quad \text{(A63)}$$

The uniaxial stress component of (A62) is

$$\sigma_{AX} = (\sigma_{33}' + \delta P_{pi}) - \nu[(\sigma_{11}' + \delta P_{pi}) + (\sigma_{22}' + \delta P_{pi})] = 2\sigma_0(1+\nu) + \delta P_{pi}(1-2\nu) \quad \text{(A64)}$$

The resulting area change from the Poisson effect is $dA = -2\nu A\sigma_{AX}/E$. Hence

$$d_i\int_\Gamma \mathbf{T}_H\delta\mathbf{U}_{AX}\, ds = -2\nu d_i\sigma_0\,\frac{[-2\sigma_0(1+\nu) + \delta P_{pi}(1-2\nu)]}{E}\cdot \pi R^2\,\frac{[(2+\epsilon)^2-2]}{(2+\epsilon)^2} \quad \text{(A65)}$$

The pore shortening from the same uniaxial stress is $\sigma_{AX}d/E$ and from the superimposed solid block problem is $-\delta P/3K$. Hence

Modified Forms of Self-Consistent Moduli for Films

O'Connell and Budiansky give the following self-consistent expressions for effective bulk modulus K_f' and shear modulus μ_f' for isolated saturated thin (penny shaped) films of aspect ratio α.

$$K' = K\left[1 - \frac{16}{9}\,\frac{(1-\nu'^2)}{(1-2\nu')}D\epsilon\right] \quad \text{(A71)}$$

$$\mu' = \mu\left[1 - \frac{32}{45}(1-\nu')\left(D + \frac{3}{2-\nu'}\right)\epsilon\right] \quad \text{(A72)}$$

where

$$D = \left[1 + \frac{4}{3\pi\alpha}\,\frac{(1-\nu'^2)}{(1-2\nu')}\,\frac{K_f}{K'}\right]^{-1} \quad \text{(A73)}$$

The crack density parameter ϵ is defined as $\epsilon = (\Sigma a_i^3)/V$, where a_i is the radius of the ith crack and V is the total rock volume containing the N cracks.

These results are strictly valid only in the limiting case of zero crack porosity. This can be seen by examining the results when the crack density ϵ becomes large enough that $\mu' = 0$, that is, $\epsilon = 45/32$ and $\nu' = 0.5$. In this case, (A71) and (A73) reduce to

$$\frac{1}{K'} = \frac{1}{K} + \frac{\beta}{K_f} \tag{A74}$$

where β is the porosity given by $\beta = 4\pi(\Sigma\alpha_i a_i^3)/3V$. The correct limit is

$$\frac{1}{K'} = \frac{1-\beta}{K} + \frac{\beta}{K_f} \tag{A75}$$

which agrees with (A74) only when $\beta \ll 1$.

A second important limiting case is where $K_f = K$, which should yield the result $K' = K$. However, (A71) and (A73) reduce to

$$K' = K - \frac{\beta K}{1 + (3\pi\alpha/4)(1-2\nu')/(1-\nu'^2)}$$

which is correct only if $\beta \to 0$.

A modified set of self-consistent moduli for nonzero film porosity were derived by using the reciprocity theorem in order to calculate the examples in Figures 4, 6, and 7. These are exactly the same as (A71) and (A72) except that the parameter D is now redefined as

$$D\epsilon = \frac{1}{V_0}\frac{K-K_f}{K}\sum_{i=1}^{N}\frac{a_i^3}{1 + (4/3\pi\alpha)[(1-\nu'^2)/(1-2\nu')](K_f/K')} \tag{A76}$$

In this case, K' in the limit as $\mu' \to 0$ reduces to (A75), and the $K' \to K$ in the limit $K_f \to K$.

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REFERENCES

Anderson, D. L., and H. Spetzler, Partial melting and the low-velocity zone, *Phys. Earth Planet. Interiors, 4*, 62–64, 1970.

Batchelor, G. K., *An Introduction to Fluid Dynamics*, Cambridge University Press, New York, 1967.

Biot, M. A., Generalized theory of acoustic propagation in porous dissipative media, *J. Acoust. Soc. Amer., 34*, 1254–1264, 1962.

Birch, F., Density and composition of the upper mantle: First approximation as an olivine layer, in *The Earth's Crust and Upper Mantle, Geophys. Monogr. Ser.*, vol. 13, edited by P. J. Hart, pp. 18–36, AGU, Washington, D. C., 1969.

Boucher, S., On the effective moduli of isotropic two-phase elastic composites, *J. Compos. Mater., 8*, 82–89, 1974.

Budiansky, B., On the elastic moduli of some heterogeneous materials, *J. Mech. Phys. Solids, 13*, 223–227, 1965.

Bulau, J. R., and H. S. Waff, Thermodynamic considerations of liquid distribution in partial melts, *Eos Trans. AGU, 58*(6), 535, 1977.

Bulau, J. R., H. S. Waff, and J. A. Tyburczy, Mechanical and thermodynamic constraints on fluid distribution in partial melts, *J. Geophys. Res., 84*, 6102–6108, 1979.

Carmichael, I. S. E., J. Nicholls, F. J. Spera, B. J. Wood, and S. A. Nelson, High-temperature properties of silicate liquids: Applications to the equilibration and ascent of basic magma, *Phil. Trans. Roy. Soc. London, Ser. A, 286*, 373–431, 1977.

Eshelby, J. D., The determinations of the elastic field of an ellipsoidal inclusion, and related problems, *Proc. Roy. Soc. London, Ser. A, 241*, 376, 1957.

Frank, F. C., Two-component flow model for convection in the earth's upper mantle, *Nature, 220*, 350–353, 1968.

Fung, Y. C., *Foundations of Solid Mechanics*, Prentice-Hall, Englewood Cliffs, N. J., 1965.

Gassmann, G. Uber die Elastizitat poroser Medien, *Vierteljahresschr., Naturforsch. Ges. Zuerich, 96*(1), 1–21, 1951.

Goetze, C., A brief summary of our present day understanding of the effect of volatiles and partial melt on the mechanical properties of the upper mantle, in *High-Pressure Research*, edited by M. H. Manghnani and S.-I. Akimoto, Academic, New York, 1977.

Gough, D. I., Electrical conductivity under western North America in relation to heat flow, seismology and structure, *J. Geomagn. Geoelec., 26*, 105–123, 1974.

Hill, R., A self-consistent mechanics of composite materials, *J. Mech. Phys. Solids, 13*, 213–222, 1965.

Jackson, D. D., and D. L. Anderson, Physical mechanisms of seismic wave attenuation, *Rev. Geophys. Space Phys., 8*, 1–63, 1970.

Jaeger, J. C., and N. G. W. Cook, *Fundamentals of Rock Mechanics*, Methuen, London, 1969.

Johnston, D., N. Toksoz, and A. Timur, Attenuation of seismic waves in dry and saturated rocks, II, Mechanisms, *Geophysics, 44*, 691–711, 1979.

Kjartansson, E., Constant Q wave propagation and attenuation, *J. Geophys. Res., 84*(B9), 4737–4748, 1979.

Kjartansson, E., and A. Nur, Attenuation due to thermal relaxation in porous rocks, submitted to *J. Geophys. Res.*, 1980.

Landau, L. D., and E. M. Lifshitz, *Theory of Elasticity*, Pergamon, New York, 1970.

MacKenzie, J. K., The elastic constants of a solid containing spherical holes, *Proc. Phys. Soc. London, Sect. B, 63*, 2–11, 1950.

Mavko, G. M., and A. Nur, Melt squirt in the asthenosphere, *J. Geophys. Res., 80*, 1444–1447, 1975.

Mavko, G. M., E. Kjartansson, and K. Winkler, Seismic wave attenuation in rocks, *Rev. Geophys. Space Phys., 17*(6), 1155–1164, 1979.

Muskhelishvili, N. I., *Some Basic Problems of the Mathematical Theory of Elasticity*, edited by J. R. M. Radok, Noordhoff, Groningen, Holland, 1953.

Nur, A., Viscous phase in rocks and the low-velocity zone, *J. Geophys. Res., 76*(5), 1270–1277, 1971.

O'Connell, R. J., and B. Budiansky, Seismic velocities in dry and saturated cracked solids, *J. Geophys. Res., 79*(35), 5412–5426, 1974.

O'Connell, R. J., and B. Budiansky, Viscoelastic properties of fluid-saturated cracked solids, *J. Geophys. Res., 82*, 5719–5735, 1977.

Oldroyd, J. G., The effect of small viscous inclusions on the mechanical properties of an elastic solid, in *Deformation and Flow of Solids, IUTAM Colloquium, Madrid (1955)*, edited by R. Granmel, Springer, New York, 1956.

Presnall, D. C., C. L. Simmons, and H. Porath, Changes in electrical conductivity of a synthetic basalt during melting, *J. Geophys. Res., 77*(29), 5665–5672, 1972.

Sato, Y., Velocity of elastic wave propagated in media with small holes, *Bull. Earthquake Res. Inst. Tokyo Univ., 30*, 179–190, 1952.

Savage, J. C., Attenuation of elastic waves in granular mediums, *J. Geophys. Res., 70*, 3935–3942, 1965.

Savin, G. N., *Stress Concentrations Around Holes*, Pergamon, New York, 1961.

Shankland, T. J., Electrical conduction in rocks and minerals: Parameters for interpretation, *Phys. Earth Planet. Interiors, 10*, 209–219, 1975.

Shankland, T. J., and H. S. Waff, Conductivity in fluid-bearing rocks, *J. Geophys. Res., 79*(32), 4863–4868, 1974.

Shankland, T. J., and H. S. Waff, Partial melting and electrical conductivity anomalies in the upper mantle, *J. Geophys. Res., 82*(33), 5409–5417, 1977.

Shimozuru, D., On the possibility of the existence of the molten portion in the upper mantle of the earth, *J. Phys. Earth, 11*(2), 49–55, 1963.

Smith, C. S., Some elementary principles of polycrystalline microstructure, *Met. Rev., 9*, 1–48, 1964.

Solomon, S. C., Seismic wave attenuation and partial melting in the upper mantle of North America, *J. Geophys. Res., 77*, 1483–1502, 1972.

Spetzler, H., and D. L. Anderson, The effect of temperature and partial melting on velocity and attenuation in simple binary system, *J. Geophys. Res., 73*(18), 6051–6060, 1968.

Stocker, R. L., and R. B. Gordon, Velocity and internal friction in partial melts, *J. Geophys. Res., 80*(35), 4828–4836, 1975.

Vaisnys, J. R., Propagation of acoustic waves through a system under-

going phase transformations, *J. Geophys. Res.*, *73*(24), 7675–7683, 1968.
Waff, H. S., Theoretical considerations of electrical conductivity in a partially molten mantle and implications for geothermometry, *J. Geophys. Res.*, *79*(26), 4003–4010, 1974.
Waff, H. S., and J. R. Bulau, Fluid distribution in partially molten "pyrolite," *Eos Trans. AGU*, *58*(6), 535, 1977.
Waff, H. S., and J. R. Bulau, Equilibrium fluid distribution in an ultramafic partial melt under hydrostatic stress, *J. Geophys. Res.*, *84*(B11), 6109–6114, 1979.
Walker, D., E. M. Stolper, and J. F. Hays, A numerical treatment of melt/solid segregation: Size of the eucrite parent body and stability of the terrestrial low-velocity zone, *J. Geophys. Res.*, *83*(B12), 6005–6013, 1978.
Walpole, L. J., On the overall elastic moduli of composite materials, *J. Mech. Phys. Solids*, *17*, 235–251, 1969.
Walsh, J. B., The effect of cracks on the compressibility of rock, *J. Geophys. Res.*, *70*(2), 381–389, 1965.
Walsh, J. B., Seismic wave attenuation in rock due to friction, *J. Geophys. Res.*, *71*(10), 2591–2599, 1966.
Walsh, J. B., New analysis of attenuation in partially melted rock, *J. Geophys. Res.*, *74*(17), 4333–4337, 1969.
Watt, J. P., G. F. Davies, and R. J. O'Connell, The elastic properties of composite materials, *Rev. Geophys. Space Phys.*, *14*(4), 541–564, 1976.
Wu, T. T., The effect of inclusion shape on the elastic moduli of a two-phase material, *Int. J. Solids Struct.*, *2*, 1–8, 1966.
Zener, C. M., *Elasticity and Anelasticity of Metals*, University of Chicago Press, Chicago, Ill., 1948.

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THE VARIATION OF MECHANICAL AND TRANSPORT PROPERTIES OF CRACKED ROCK WITH PRESSURE

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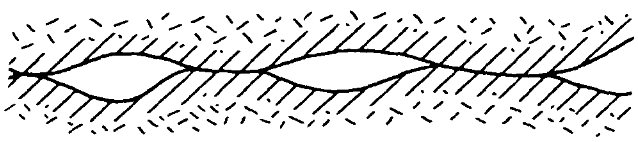
The variation of the mechanical and transport properties of cracked rock with pressure are accurately described and their interrelationships developed and understood by using the "Bed-of-Nails" model (Gangi, 1975, 1978). A number of different models were treated (by considering the asperities on cracks to be described as hemispheres, cones, wedges, etc.) and it was shown that they are mechanically equivalent to the simpler "Bed-of-Nails" model which treats the asperities as distributions of rods. The same model was used by Kragelskii (1965) to obtain an analytic model for the true area of contact between rough faces to characterize friction.

The rationale for the model is illustrated in Figure 1. Figure 1A shows (schematically) a "natural" crack. This "crack" was generated by making a hairline fracture in the unfractured medium and then translating the lower half of the rock to right (by about one-half the dominant wavelength of the hairline fracture) and introducing some deformation to the contact areas of the crack. This is similar to how open cracks are formed in rocks in nature; that is, the rock is fractured in extension and shear displacements prevent the crack from closing up completely when the rock is pressurized. Of course, if there is no or little shear displacement along the crack, the crack will mate very well and will close up, almost completely, when the rock is pressurized.



A) Natural Crack (stylized)

B) Mechanically and Hydraulically Equivalent Crack (schematic)

Figure 1.

The mechanical properties of this crack can be determined by using complex mathematical techniques, such as Muskhelishvili's method of Singular Integral Equations (see Mavko and Nur, 1978), but the essential properties can be determined using a much simpler method which treats the problem as a statistical one, which it inherently is. The model chosen by the author (Gangi, 1975, 1978) is the "Bed-of-Nails" model which is illustrated in Figure 1B. That is, the distribution of asperities is treated as a distribution of rods; these are much simpler to analyze.

Earlier, Greenwood and Williamson (1966) used distributions of hemi-spheres of different heights to characterize the closing or "approach" (and therefore, the modulus) of cracks under pressure. They assumed gaussian and exponential distributions for the heights of the hemispherical asperities. Walsh and Grosenbaugh (1979) used the Greenwood and Williamson theory to predict the stiffness of a crack (i.e., the joint stiffness or modulus) is proportional to the (normal) stress (see their Figure 7). Walsh and Grosenbaugh used the exponential distribution for the asperity heights. We find the same mechanical behavior with the simpler "Bed-of-Nails" model if the power of the power-law asperity-height distribution function (Gangi, 1975, 1978),

$$N(h) = N_T(1-h/w_o)^{n-1}, \qquad (1)$$

is very large; that is, if (n-1) is very much greater than one. This distribution function holds when there are very few tall asperities and most asperities have heights that are a small fraction of the maximum crack width, w_o.

In equation 1, N(h) is the number of asperities that have heights lying between h and w_o. The quantity N_T is the total number of rods on the crack face used to represent the asperities. That is, all the rods (as well as all asperities) have heights lying between zero and w_o, the latter being the width when there is no stress acting across the crack (here we are referring to the equivalent crack shown in Figure 1B).

We find that some cracked rocks have crack moduli which definitely do not vary linearly with pressure as predicted by the Greenwood and Williamson model. These distinctly different moduli variations with pressure are easily accomodated by the simple "Bed-of-Nails" model by allowing different values for n ($1 \leq n \leq \infty$) in equation 1. The resulting asperity-height distribution functions are illustrated in Figure 2. These functions were chosen simply because they allow us to determine the variation of the crack width with pressure (or crack modulus) while at the same time being general enough so that they can represent reality.

For power-law asperity-height distribution functions (equation 1), the width (w) of the equivalent crack varies with normal stress, P, (Gangi, 1978) as

$$w/w_o = 1-(P/P_1)^{1/n} \qquad (2)$$

where

$P_1 = EN_o w_o^2 b/n$

E = the rod's Young's Modulus