UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of PENNSYLVANIA POWER & LIGHT COMPANY and ALLEGHENY ELECTRIC COOPERATIVE INC. (Susquehanna Steam Electric Station, Units 1 and 2)	))))))))))	Docket Nos. 50-387 50-388

AFFIDAVIT OF MORTON I. GOLDMAN
IN SUPPORT OF SUMMARY DISPOSITION
OF CONTENTION 1 (RADON)

Montgomery County)
: ss.
State of Maryland)

MORTON I. GOLDMAN, being duly sworn, deposes and says as follows:

1. I am Senior Vice President, Environmental Systems Group, NUS Corporation, Rockville, Maryland. I have been involved in research and consulting on environmental and radiological matters since 1950. I was consultant to and witness for the applicant in the Perkins proceeding (Duke Power Company (Perkins Nuclear Station Units 1, 2 and 3), Docket Nos. STN 50-488, 50-489 and 50-490) regarding the radon-222

issue. I am also consultant to and witness for the joint applicants in the consolidated radon-222 proceeding before the Appeal Boards (Philadelphia Electric Company (Peach Bottom Atomic Power Station, Units 2 and 3), Docket Nos. 50-277 and 50-278, et al.). A summary of my qualifications and experience is attached as Exhibit "A" hereto. I give this affidavit in support of Applicants' Motion for Summary Disposition of Contention 1 (Radon) in this proceeding. I have personal knowledge of the matters set forth herein and believe them to be true and correct.

2. The purpose of this affidavit is to address the portion of Contention 1 in this proceeding that alleges that the quantity of radon-222 which will be released during the fuel cycle required for the Susquehanna facility has not been, but should be, adequately assessed, and the radiological health effects of this radon should be estimated and these estimates factored into the cost-benefit balance for the operation of the plant. As will be shown below, an adequate assessment of the radon releases attributable to the Susquehanna facility exists, and the health effect of these releases is insignificant and will not alter the cost benefit balance for operation of Susquehanna. Since Contention 1 raises questions as to both the radon-222 source term and the health effects of radon-222 emissions, I will address the two issues separately.

A. Introduction.

3. Radon-222 is one of the products resulting from the radioactive decay of uranium-238, an isotope with a half-life of 4.5 billion years. Uranium-238 decays into radon-222 by a series of intermediate steps. Two of the intermediate precursors of radon-222 are thorium-230, with a half-life of approximately 80,000 years, and radium-226, with a half-life of 1,600 years. Uranium-238, thorium-230 and radium-226 normally exist in non-gaseous states. Radon-222 is a noble (i.e., inert) gas with a short half-life, 3.8 days. Because of its gaseous nature and its lack of chemical activity, radon-222 may diffuse through porous media such as soil and, once in the atmosphere and depending on prevailing weather conditions, it can be transported considerable distances before decaying [1].[1]

4. The potential health hazard of radon-222 lies not so much with radon itself as with its decay products. When radon-222 decays, it produces in quick succession four very short-lived isotopes (polonium-218, lead-214, bismuth-214, and polonium-214) ("the radon daughters") before a relatively more stable isotope (lead-210 with a half-life of 21 years) is reached.[2] The radon daughters are chemically heavy metals that

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1 References cited are listed at the end of this Affidavit.

2 A "decay series" chart for radon is reproduced in Fig. 1 of the Appeal Boards' decision in the consolidated radon proceeding. See Philadelphia Electric Co. et al. (Peach Bottom Atomic Power Station, Units 2 and 3), ALAB-640 (May 13, 1981), slip op. at 11.

become attached to small airborne particles or aeroso[illegible] and are easily deposited in man's respiratory tract, particularly the bronchial epithelium, where they may decay emitting high-energy alpha and beta particles [1,2].

5. Radon-222 is constantly being generated and released to the environment through natural processes. It is estimated that about 100 to 240 million curies ("Ci") of radon-222 emanate each year from the soil in the contiguous U.S., leading to an average outdoor radon concentration between 100 and $200x10^{-12}Ci/m^3$ [3].

6. There are natural sources of other radon isotopes, such as the decay of uranium-235 to radon-219 and thorium-232 to radon-220. These radon isotopes are, however, of lesser importance since their half lives are so short (55 sec. and 4 sec., respectively) that virtually none escapes to the atmosphere [3].

7. In addition to these natural sources, exposure to radon and its progeny may be enhanced by a number of human activities that redistribute the naturally occurring sources of radon. The most significant of these activities are: tillage of soils; mining of coal and its combustion in power generating plants; production, processing and distribution of natural gas; processing of liquified petroleum gas; mining and milling of phosphate ore, use of phosphate products and byproducts, and use of reclaimed phosphate lands for residential and commercial

development; production and use of building materials, such as granite, brick, concrete block and pumice stone; and mining and milling of uranium ore [1, 4].

8. In connection with the fuel cycle of a nuclear power plant, radon-222 is emitted at the "front end" of the cycle as a result of the operations of mining uranium ore and milling the ore to produce uranium fuel. The amount of radon-222 produced during the remainder of the fuel cycle is very small in magnitude and negligible in comparison to the amounts resulting from the mining and milling of uranium [5, 6].

B. Radon emissions from uranium mining.

9. The two most common methods of obtaining uranium in the U.S. are by underground mining and surface ("open-pit") mining. Over the period 1971 to 1979, about 42% of the uranium was produced from underground mining, 52% from surface mining, and 6% from other sources such as heap leaching, mine waters, solution mining, low grade stockpiles, and as a byproduct from the processing of phosphate and copper minerals [11]. See Figure 1.[3] Radon-222 may be released from uranium mines both during the period of active mining and, after mining operations cease, from abandoned mines that have remained unreclaimed. No significant radon emissions result from other production means.

10. During active mining, radon-222 is released to the atmosphere from an underground mine by the forced flow of

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3 Figures and Tables are given at the end of this Affidavit.

air produced by the mine's ventilation system. Radon-222 is released by an open-pit mine during the active mining period as exhalation from the ore, overburden and the walls and floors of the mine pit.

11. After mining operations cease, the amount of radon-222 emitted by underground and open-pit mines depends on whether the mines are reclaimed. Inactive underground mines can be reclaimed by sealing the mine openings with earth and/or concrete plugs [7]. If the mine openings are sealed, essentially no radon will escape to the atmosphere from them. If an abandoned mine remains unreclaimed, however, radon-222 which emanates from the walls of the mine may find its way to the environment outside the mine if natural air circulation is established due to differences in temperature between the mine air and the outside air and differences in elevation between mine openings.

12. Inactive open-pit mines can be reclaimed by backfilling the pit with overburden. An unreclaimed open-pit mine will result in radon emissions comparable to those emitted during the active mining period.

1. Emissions During Active Period of Underground Mines.

13. The most recent data on radon releases from underground mines of which I am aware are contained in a study by Battelle Pacific Northwest Laboratory ("PNL") [8], which reports the result of a comprehensive sampling of 27 mines

accounting for 64% of the uranium produced in the United States in 1978 from underground mining. From the data in the PNL report, the active mining source term for underground mines is computed as approximately 8000 Ci of radon-222 per reference reactor year ("RRY"). This source term was testified to by the Staff in the consolidated radon proceeding and adopted by the Appeal Boards. See ALAB-640, supra, slip op. at 47.[4] I believe it is appropriate to extrapolate the releases from the mines sampled to the industry as a whole because the sampling efforts concentrated on the larger mines which tend to release more radon per ton of ore mined. Hence, the extrapolation if anything would tend to overstate the radon releases from this source category.

2. Emissions from Abandoned, Sealed Underground Mines.

14. Abandoned underground mines can be sealed in ways which are simple and effective in minimizing radon

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4 Here and throughout this Affidavit I have assumed that the reference reactor produces 1000 MWe of electric power, operates at 80% capacity, and requires 245 metric tons ("MT") per RRY of U_3O_8, or 2.71x 105 MT of ore containing 0.1% U_3O_8 at a 90% recovery factor. These assumptions are the ones made in the Perkins proceeding [9] and in the consolidated radon proceeding.

It should be noted, however, that other (lower) RRY figures have been postulated, depending among other things on the definition of RRY that is adopted. For instance, the NRC Staff in NUREG-0706 [2] and other fuel cycle studies [35, 36] assumes 182 MT U_3O_8 per RRY. Use of such a definition would, of course, result in decreased radon emissions per RRY.

releases. The hoisting and ventilation shafts of the mines can be sealed by filling them with overburden, waste rock or soil; additional sealing may be provided by placing a concrete plug in the collar of the shafts [7]. Since there is currently no Federal control upon the reclamation of underground mines, the decision to seal a mine depends upon the requirements of the State in which the mine is located, and the operator's judgment as to the potential for future extension of mining activities as the value of residual ores of lower grades increases. In an informal survey conducted by members of my staff in 1979 of five mining companies in Colorado, Wyoming and New Mexico, it was learned that none of them had closed underground mines recently; several have committed to their State agencies to seal shafts with concrete and/or earth plugs, or plan to do so in future mine closures.

15. Assuming proper sealing, the radon emission rates from mine shafts will be negligible, and the only measurable radon releases associated with a sealed underground mine will come from waste rock remaining on the surface after the mine is abandoned. The waste rock pile is estimated to release radon at the rate of approximately 10 Ci/year per RRY.

3. Emissions From Unsealed Underground Mines.

16. During normal operation of an underground mine, the radon removed by the mechanical ventilation system balances that emanated from the mine walls, thus maintaining a

reasonably constant concentration of radon in the mine air. When the mine is closed and mechanical ventilation ceases, radon continues to emanate from the mine walls; the only mechanism for the removal of the radon from the mine air to the outside atmosphere is whatever natural circulation air flow may be established. The driving forces for this flow are primarily the temperature difference between the mine air and the outside air, and secondarily the difference in elevation between the mine and the surface. Resistance to the flow is created by mine drifts, bulkheads, dead-end rooms, flooding, the size of and the distance between vents, possible blockages due to collapses, etc. Natural circulation air flow, to the extent it exists, is quite variable in magnitude and may reverse direction as frequently as twice a day in a mine having several openings.

17. A draft EPA report has considered radon exhalation from unsealed underground uranium mines, using a model which represents the average of some 2,100 inactive mines [10]. The model mine was assumed to have ended operation by 1977 and to have produced 3.02×10^4 MT of ore and 9.68×10^3 MT of waste. As a "first approximation," the analysis assumed that all radon released into mine air would be exhausted by natural ventilation before significant decay occurred and resulted in a calculated release of 12.3 Ci/yr. No ore grade was specified. If it is assumed for this model mine that the ore grade was midway between the average grade bought by the AEC in 1960

(0.43%), and that processed by uranium mills in 1977 (0.15%) [11], the average mine ore grade would be 0.29%. At this ore grade, the model mine would have produced 87.6 MT U_3O_8. Further assuming an average recovery of 95% for this ore grade (see Figure 2, infra), the mine would have produced 87.6 x 0.95/245 = 0.34 RRY, and would have a radon emission rate of 36.2 Ci/yr per RRY.[5]

18. Considering the relatively small amount of information in this area, the most conservative approach would be to assume, as did EPA, that the radon emitted by an abandoned, unsealed underground mine would equal that removed by the ventilation system during normal operation; that is, all the radon emanated by the mine walls would be released to the atmosphere as if the fans were in operation. I would, however, expect that the value obtained using this approach would be greatly in excess of the amount of radon actually released. Such factors as blockages of the vents, collapses of mine drifts, flooding, etc. would significantly reduce radon emissions. Indeed, the Appeal Boards in the consolidated radon proceeding rejected this assumption as "unwarranted" and instead adopted an upper limit, "worst-case" estimate of 80

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5 An NRC Staff witness at the consolidated radon proceeding hearings testified that measurements taken at a "worst case" abandoned mine in McKinley County, New Mexico, showed radon emissions in the order of 70-80 Ci/year per RRY. Another, more typical abandoned mine in the same area released radon at a rate of 1.2 Ci/year per RRY [12].

Ci/RRY per year. ALAB-640, supra, slip op. at 27. I agree that the Appeal Boards' estimate represents a realistic upper limit to the radon releases from abandoned, unsealed underground mines. Another 10 Ci/year per RRY would be added, as in the case of sealed mines, to account for releases from waste rock remaining on the surface when the mine was abandoned. The upper-limit radon release from unsealed underground mines would therefore be approximately 90 Ci/year per RRY. This upper-limit estimate is extremely conservative on the high side.

4. Emissions During Active Period of Open-Pit Mines.

19. Another report by PNL [13] provides information on radon exhalation rates from open-pit mines and contains analyses of current and projected mining methods and practices, which are then used to develop mine models and radon releases both for the period of active mining and for the period after the mines are shut down. According to the report, the radon releases from an open-pit mine during the active mining period are approximately 945 Ci/RRY.[6] A more recent report by Argonne National Laboratory ("ANL") [14] provides results of extended radon measurements at both active and inactive pits of a

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6 The PNL report estimated 630 Ci/RRY as the radon emissions due to active open-pit mines. However, since the RRY assumed by PNL was 182 MT instead of the 271/MT assumed here, the PNL value must be scaled upwards by a factor of 271/182, giving an emission estimate of 945 Ci/RRY. The Staff and the Appeal Boards rounded off this figure to 1000 Ci/RRY. See ALAB-640, supra, slip op. at 34-35.

uranium mine operation. These results indicate substantially lower radon release rates than the estimates presented in the earlier PNL report. For example, PNL computed a mean specific radon flux of 0.29 pCi/cm^2-sec-% U_3O_8 [(1.02 pCi/m^2-sec)/(pCi Ra-226/g ore)] with one-sigma confidence limit of 0.19-0.46 pCi/cm^2-sec-% U_3O_8 [(0.67-1.6 pCi/m^2-sec)/(pCi Ra-226/g ore)] for "22 measurements in the pit and on ore and subore piles." The ANL investigation, on the other hand, reports a mean specific radon flux of "0.017 with a range of 0.004 to 1.027 (pCi/m^2-sec)/(pCi Ra-226/g ore)" as measured in the active mine pit, or about 1.7% of the PNL value.

20. The ANL report proceeds to adopt a "more representative estimate of specific flux, 0.072 (pCi/m^2-sec)/(pCi Ra-226/g)" by dividing the average value for radon flux measured over 5 months in the ore zone of the <u>inactive</u> pit, by the average of measured radium content of the ore zone in the <u>active</u> pit. Even this "more representative" value is only 7.2% of that used by PNL as the basis for the 945 Ci/RRY value.

21. In view of ANL's measurements, I believe that a rounded-off 1000 Ci/RRY estimate of radon releases from active open-pit mines is high and quite conservative.

5. Radon Emissions From Reclaimed Open-Pit Mines.

22. A model of a reclaimed open-pit mine reflecting current conditions is a compromise between complete reclamation

(anticipated for present and future mining operations) and no reclamation (the case in many mining operations in the past). The PNL report [13] developed a model of such a partially reclaimed open-pit mine, based on average statistics for eight major open-pit uranium mines in the Casper, Wyoming area. The model recognized the current practice of sequential development of individual pits, with worked-out pits being backfilled using overburden from new pits. Radon emissions were calculated assuming the final pit, overburden and sub-ore piles were not reclaimed, and that overburden was so mixed with sub-ore in the relocation and backfilling operation as to raise the effective uranium content of the backfill material by a factor of five (from 4 ppm to 20 ppm uranium oxide ("U_3O_8")). For such a mine, 85% of the mine volume would be refilled with overburden containing 20 ppm U_3O_8. The balance of the overburden, approximately 15%, would remain as a pile on the surface. Another surface pile containing 150 ppm U_3O_8 would remain as a sub-ore pile awaiting possible commercial use in the future.

23. For this partially-reclaimed model open-pit mine, radon emanations would result from overburden fill in six pits, sub-ore and overburden exposed in the last unfilled pit, and sub-ore and overburden dump piles. The combined long-term radon releases from these sources would be about 40 Ci/year per RRY. Because this partially-reclaimed mine represents conditions leading to higher radon releases than those that will result from completely reclaimed mines, and in view of the

lower release rates measured by ANL as discussed above, I believe that the estimate of radon emissions from reclaimed open-pit mines arrived at using this mine as a model is conservatively high.

6. Radon Emissions From Unreclaimed Open-Pit Mines.

24. The Battelle model mine can also be utilized to compute the long-term radon releases assuming no reclamation whatsoever (i.e., no refilling of the worked-out mine pits). The model unreclaimed open-pit mine would release radon from [illegible]rburden and sub-ore exposed in seven unfilled pits, [illegible] overburden piles, and a sub-ore pile. Such an unreclaimed open-pit mine would release radon at the rate of approximately 80 Ci/year per RRY about half of which would come from the seven unfilled pits. Again, use of the ANL data [14] for the pits' contribution would lead to significantly lower release estimates, about 40 Ci/year-RRY.

25. Another estimate of radon releases from abandoned, unreclaimed open-pit mines can be obtained from a model established by EPA based on annual ore and waste production statistics for an estimated 944 surface mines [10]. The model mine was assumed to have ended operations in 1977. The total waste and ore removed from the pit would be 1.18×10^6 MT and 4.75×10^5 MT, respectively, with an amount of sub-ore equal to that of the ore. The sub-ore was assumed to be placed in a uniform layer on top of the overburden pile, which would

maximize the radon emissions from that source. The pit and waste pile were calculated to emit about 145 mCi/day, or about 53 Ci/yr. The ore grade was not specified.

26. To estimate the radon emitted per RRY for the EPA model mine, I again assumed the ore grade to be 0.29%, midway between the average grade bought by the AEC in 1960 and that processed by uranium mills in 1977. At this average ore grade, the model mine would have produced 138 MT U_3O_8. Assuming an average recovery of 95% for this ore grade would result in the mine having produced 138 x .95/245 = 0.53 RRY, and the radon emission would equal 100 Ci/year per RRY.

27. In summary, two radon release estimates from abandoned unreclaimed open-pit mines, one based on current large scale mine development methods and conservative specific radon flux values, the other based on the average of more than 900 small surface mines reflecting no reclamation whatsoever, yield radon emissions per RRY which are consistent with each other. Therefore, I believe appropriate upper bounds for radon releases from open-pit mines are 40 Ci/year per RRY from reclaimed mines and 100 Ci/year per RRY from unreclaimed mines. The latter value was adopted by the Appeal Boards in the consolidated radon proceeding. See ALAB-640, _supra_, slip op. at 39.

7. <u>Combined radon released from uranium mining</u>

28. Over the period 1971-1979 inclusive, production figures indicate that 42% of the uranium produced in the United

States came from underground mines, 52% from open-pit mines, and 6% from other sources [11]. Since the upper-limit radon releases during the active mining period are, respectively, 8000 Ci/RRY for underground mines, 1000 Ci/RRY for open-pit mines and zero from other sources, the combined, upper-limit release from active mines using the average production figures given above is approximately 3,880 Ci/RRY. Similarly, since the upper-limit long term release from underground mines is 90 Ci/yr-RRY, that from open-pit mines is 100 Ci/yr-RRY and that from other sources is zero, the combined, upper limit long-term radon release from mining is approximately 90 Ci/yr-RRY.

C. Radon releases from uranium milling

29. Uranium leaves the mine in the form of crude ore containing uranium oxide (U_3O_8) and other uranium compounds, all generically referred to as U_3O_8. The crude ore is delivered to a mill where it undergoes a series of mechanical and chemical processes to separate the U_3O_8 from the other materials contained in the ore. Radon may be released at various points in the milling process, from the initial stockpiling of the ore to await processing to the crushing, roasting, grinding, and chemical treatment of the ore [15].

30. After the U_3O_8 is separated out at the mill, the residual materials ("mill tailings") are a mixture of solids and solutions varying in chemical and physical composition depending on the nature of the ore and the milling process

used. These mill tailings contain 5 to 10% of the uranium in the ore (which is not recovered during milling) and virtually all the thorium-230 and radium-226 contained in the ore [16].

31. The mill tailings are usually disposed of in a tailings pond. Because the tailings contain thorium and radium and some residual uranium, they continue to emit radon for thousands of years. Some of the radon emitted by the dry portion of the tailings will diffuse to the surface of the tailings pile, and if the pile is not treated to minimize radon releases, will escape to the atmosphere.

1. <u>Releases during active milling period</u>

32. In <u>Perkins</u>, the NRC Staff estimate of radon released during the active milling period amounted to 750 Ci/RRY [17]. Using the model mill parameters presented more recently in the Final Generic Statement on Uranium Milling [18] and realistic values for tailings depth and diffusion coefficients (see paras. 46-49 below), I calculate an active milling period radon release of about 890 Ci/RRY.

2. <u>Releases prior to stabilization</u>

33. In <u>Perkins</u>, the Staff assumed that a period of five years would be required after mill operations cease for the tailings to dry sufficiently to permit stabilization, and estimated 350 Ci of radon per RRY to be released during that time [19]. With the mill and tailings parameters used above for the active milling period, I also calculate a total radon

release over the 5 year period of about 350 Ci/RRY, including the contribution from ore and tailings locally dispersed over the active milling period. The total radon emissions attributable to uranium milling prior to tailings stabilization are therefore 890+350=1240 Ci/RRY. Based on a slightly different assumption as to the diffusion coefficient, the Appeal Boards estimated a radon release rate of 1400 Ci/RRY from mill tailings prior to stabilization. ALAB-640, supra, slip op. at 53-54. The difference between my computed value and that arrived at by the Appeal Boards is not significant.

3. Long term radon releases from mill tailings

A. Releases from stabilized tailings piles

34. The Uranium Mill Tailings Radiation Control Act of 1978 (P.L. 95-604, 92 Stat. 3021) ("the Act") gives authority to the NRC to license and regulate uranium mill tailings, and requires reclamation and state or federal ownership of tailings and their disposal sites.

35. Under the Act, any licensee authorized to operate a uranium mill is required to maintain the mill tailings in such a manner as will protect the public health, safety and the environment. The same requirement will apply to the Federal and State agencies upon transfer of control of the tailings to them after mill operations end.

36. Implementation of the reclamation provisions of the Act will require long-term stabilization of the mill tailings piles. Such stabilization can be achieved by below-grade disposal or by covering the tailings above ground with sufficient amount of covering material. Even a minimum amount of cover (e.g., three feet of well-compacted earth) will reduce radon emissions by a factor of at least two from what they would be from an unstabilized pile.

37. Technical capability exists for isolating large volumes of tailings for long periods of time. The tailings isolation can be carried out by straightforward earth moving operations, for which there is more than sufficient experience in the industry. Adequate economic resources to meet the cost of stabilizing mill tailings piles are assured by the Act's authorization to the NRC to require prospective mill operators to provide adequate financial sureties to guarantee that there will be funds available to cover the cost of mill tailings reclamation and stabilization.

38. Properly stabilized tailings should remain stable for many thousands of years without reliance on institutional controls and without need for active maintenance. Stabilized piles with a minimum amount of cover (e.g., three feet of well-compacted earth) will emit radon at a rate of no more than 40 Ci/year per RRY.

39. The potential for maintaining a cover for tailings over long periods of time under conditions in which erosion is a factor is evidenced by the earth structures, or

mounds, built by pre-Columbian Indians in North America to serve as burial mounds or foundations for structures such as temples. These mounds can be found in many locations east of the Mississippi River; some of them are 2,000 to 3,000 years old. The climatic conditions in the regions where mounds are more prevalent are significantly wetter than those of the more arid western regions, particularly in the southeast and along the Ohio and Mississippi River valleys. These areas have been subject to the severe erosive forces of rainfall and flooding which are common in those regions, yet the mounds have survived the effects of those erosive forces.

40. The potential for wind erosion is higher in many parts of the uranium producing areas in the West than it is for the eastern half of the United States. Nevertheless, recognition of a potential for wind erosion permits its control by providing rip-rap (large blocks of rock), flat slopes and/or asphaltic layers as protection on upwind faces. Considering the limited technology available to the early mound builders, the fact that their structures have survived natural forces for many centuries indicates that contemporary engineers should be able to do just as well in keeping stabilized tailings intact for very long periods of time. The survival of the ancient structures also indicates that mill tailings piles can be maintained in a stabilized condition with a minimum of administrative controls.

B. Emissions from unstabilized piles

41. Even though I expect that tailings piles will be stabilized in accordance with the requirements of the Act will remain in stabilized condition for many thousands of years, I have attempted to calculate the radon emissions for a scenario in which erosion eventually removes all the stabilizing cover from a tailings pile without dispersing the pile itself.

42. There are a number of variables that enter into such a calculation. They include:

a. the radium concentration, which is related to the ore grade;

b. the porosity and bulk density of the tails;

c. the diffusion coefficient for radon through the mass of tailings which, in turn, is related to porosity and moisture content;

d. the emanating power of the tailings particles;

e. the volume of tailings per unit of U_3O_8 recovered, which is related to ore grade and milling recovery fraction; and

f. the area-depth product for the tailings pile. Depending upon the particular choice of variables, radon emission rates per annual fuel requirement can be calculated to vary over more than one order of magnitude.

43. Radon flux varies directly with the radium concentration and, in a somewhat more complex fashion, with the bulk diffusion coefficient and the tailings depth [21]. The radium concentration, in turn, is directly related to the grade

of the uranium processed. Average values for the porosity and bulk density of the tailings are well established, as is the value for the emanating power of the tailings particles. Thus, the major variables in the radon releases from mill tailings piles are the ore grade, the bulk diffusion coefficient, and the depth of the tailings pile. The effect of each of these variables will be examined separately below.

44. The ore grade is a variable because the U_3O_8 recovery efficiency changes somewhat as a function of ore grade, thereby increasing the volume (and hence the area-depth product) of tailings required per RRY produced. To determine the significance of this effect, data on uranium ore grade processed and the percent of contained U_3O_8 recovered from the ore were examined, as presented in Reference [11]. These data, covering the period from 1966 to 1979, are plotted in Figure 2; the linear equation best fitting those points was calculated using the method of least-squares and is also presented in Figure 2. Based on this equation, the recovery fraction for an ore grade of 0.10% can be seen to be 90.3%. While no data have been published on the recovery fraction for ore grades below 0.1%, I believe the linear equation would provide a reasonable approximation of the recovery fraction for grades down to at least .07% (the average grade of ore currently included in the Department of Energy's "$50 uranium reserve" category) [11]. At the .07% grade, the percentage recovery rate would be about 89%.[7]

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7 It is anticipated that by the year 2000 the grade of ore that will be processed will still be no less than 0.08% [22].

45. The tailings surface area per RRY can be calculated as a function of ore grade and depth of the tailings pile [23]. The results of that computation are presented in Figure 3, from which it can be seen that, for a given tailings depth, halving the ore grade increases the area by a factor only slightly greater than 2. In other words, the difference in the recovery percentage over the range from 0.2% to 0.07% U_3O_8 ore is not a significant factor in the volume of tailings or, consequently, in the surface area per RRY for a given depth of tails.

46. Once the tailings surface area per RRY is known, one can compute the radon exhalation per RRY as a function of ore grade, depth of tails, and bulk diffusion coefficient of radon through tailings [21, 23]. The diffusion coefficient I have used, 0.019 cm^2/sec, is based on the experimental measurement of radon flux from acid-leached tailings by ANL [24] which provided an average flux value of 0.64 (pCi/m^2 sec)/(pCi Ra-226/g). ANL also measured an average flux value from carbonate-leached tailings of 0.30 (pCi/m^2)/(pCi Ra-226/g), less than half that for the acid leached tails. The carbonate-leached tailings diffusion coefficient was not used in my calculations because it is less conservative and because only a minority of mills (about 20%) utilize such a process.[8]

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8 The choice of diffusion coefficient is important in the estimation of radon releases from uncovered tailings. For instance, Reference [2] assumes a diffusion coefficient of 0.047 cm^2/sec for its model mill, a value apparently based on (continued next page)

47. The results of my calculations are presented in Figure 4 as a function of tailings depth for two ore grades, 0.07% and 0.2%. As noted above, the .07% value was chosen as the ore grade included in current $50 uranium reserves. From these results it can be noted that the effect of ore grade on exhalation rate per RRY is minor, as also reflected in the earlier surface area per RRY computations.

48. The average effective depth of existing inactive tailings piles is about 4.8 m [25]. However, the average effective depth of existing active piles is between 12 and 13 m and can be reasonably expected to go as high as 15 m [26]. Therefore, the appropriate depth to use in the radon release computations is 12 to 13 m.

49. A limited survey performed by members of my staff in late 1979 of active mills which were operating prior to January 1, 1975 obtained data for 14 mills which indicate an average pile depth of about 42 feet, or 13 meters, with a maximum depth in the range of about 43 meters. These results confirm the average depth estimate of about 12-13 meters. If the average depth value of 12.5 meters is used, the radon exhalation rate per RRY from dry uncovered tailings is about 75-80 Ci/yr.

(Continued)
theoretical analyses instead of experimental data. See Reference [2] at G-13. Utilizing a 0.047 cm^2/sec diffusion coefficient would result in nearly doubling (to 130-140 Ci/yr per RRY) the radon emissions from the average tailings pile.

50. On the basis of the foregoing analysis, I conclude that 1) differences in ore grade make an almost negligible incremental contribution to radon exhalation per RRY; 2) assumptions as to the bulk diffusion coefficient may change the estimate of radon exhalation by a factor of two for a given depth of tails; 3) the major determinant of radon exhalation per RRY is the surface area-to-volume relationship, or the average depth to which the tailings are accumulated; and 4) a conservative estimate of the radon exhalation rate, which takes into account current practice in tailings depth and utilizes an experimentally determined radon diffusion coefficient, is 75-80 Ci/yr per RRY (See Figure 4). If the higher value of diffusion coefficient assumed in Reference [2] is utilized, the radon emission rate attributable to unstabilized piles is approximately 140 Ci/yr for RRY. This is the value adopted by the Appeal Boards in the consolidated radon proceeding. ALAB-640, supra, slip op. at 59.

4. Dispersion of de-stabilized tailings piles

51. Assuming the stabilizing cover of a mill tailings pile is lost, I have analyzed the possible effect of erosion followed by migration of the tailings on the radon releases emitted by the pile. To do so, I have studied the extent of tails migration that has taken place on existing inactive tailings piles, and evaluated the radon emissions resulting from that migration.

52. To determine the spread of radioactive materials for this testimony, I examined a report by EPA [27], which presents the results of surveys at 20 inactive sites in the western United States. The results of these surveys are presented in the EPA report on maps delineating plant areas as contour lines of gamma exposure rates which are related to surface contamination by radium-226.

53. For each of the 20 sites, the EPA report presents contours which define areas of contamination extending down to background levels. For 15 out of the 20 sites, the contours were closed within the confines of the surveyed area. For four of the remaining five sites, contours were not constructed or were not closed for lack of sufficient data (Monument Valley, Arizona; Grand Junction, and Durango, Colorado), or due to extensive downwind contamination by a roaster (calciner) plume (Naturita, Colorado). For the fifth site (Lowman, Idaho) no source information (i.e., tailings quantity or radioactivity content) was presented. For these reasons, I did not use these remaining five sites in my calculations. In a number of the other 15 sites the contours enclose the inactive mill area, haul roads and evaporation pond sites as well as the tailings pile. Measured contamination levels reflect, in these instances, sources other than dispersed tailings and therefore provide a conservative (high) estimate of tailings dispersion. In two cases (Maybell, Colorado and Converse Co., Wyoming), the sites include

extensive mine waste dumps and overburden piles in addition to an open pit mine, hence the emissions at those sites are not representative of those from a tailings pile and were not used in my analysis of tailings dispersion.

54. In my analysis, dispersed contamination was calculated by a series of integrations: first, between the tailings pile equivalent radius and the equivalent radius of the first survey contour; successive integrations were made between the first and second survey contour radii, and between the second and third (background) contour radii.

55. The results of my calculations are presented in Table 1 for each of the 13 piles evaluated, and the totals of pile inventory and dispersed radium-226 for all of those piles. A total of 56.1 curies of radium-226 are calculated to have been dispersed out of a total inventory of about 10,140 curies estimated to be in the piles, or about 0.55% of the inventory on average. These 56.1 dispersed curies of radium-226 are calculated to release 743 Ci of radon-222 per year.

56. The EPA [25] has estimated that all inactive mill tailings piles in the United States contain a total of 15,450 Ci of radium-226. Assuming that all inactive piles disperse at the average rate found for the 13 piles évaluated, the total radon-222 released by dispersed tailings would be (15,450 x 743)/10,140 = 1,130 Ci/yr. Since the EPA estimates that the total radon emission from these inactive tailings piles is 6×10^4 Ci/yr, it follows that the total amount of

radon emitted by the dispersed tailings is about 1.9% of the radon released by the piles themselves.

57. In considering the rate at which dispersion occurred at these inactive sites, I examined the data covering the period of operation of each of them. Assuming the dispersion occurred between the mid-life of each facility and the measurement period (1974) for the data in Reference [27], I have calculated the mean dispersion period for these 13 facilities to have been 15.3 years. Thus, the mean fraction dispersed per year would be (0.55%/15.3) or 0.036% per year. This would imply complete dispersal in about 2700 years if the erosion rates were to remain the same. However, I would expect erosion rates to decrease with time as the more readily eroded material (i.e., finer particles, more steeply sloped material) is removed.

58. On the basis of these calculations, the dispersion of unstabilized tailings would not appear to result in a significant addition to tailings radon exhalation over any reasonable near term period. For example, assuming erosion to continue at the same rate for 200 years would increase the current estimate of radon releases from the inactive tailings piles by only 25%. This very slow rate of dispersion indicates that there should be ample opportunity for taking remedial action to correct the effects of erosion or other destabilizing agents.

59. In the unlikely event that tailings piles became completely dispersed, the tailings would not remain exposed on

the surface releasing radon to the atmosphere for long periods of time, but instead would either be carried by surface waters to the ocean or would be covered or deposited upon by other soil materials, thus minimizing radon releases.

5. Summary

60. Based on the foregoing, I can summarize my testimony on the radon emissions associated with milling of uranium as follows:

1. Radon releases during the period of active operation of a mill are approximately 890 Ci/RRY.

2. Radon releases during the five years after the mill closes and prior to tailings stabilization are approximately 350 Ci/RRY.

3. Long term stabilization of mill tailings piles is achievable by simple earth moving and placing operations well within current state of the art. Stabilized mill tailings piles should remain in that condition for many thousands of years and, as long as stabilization is maintained, will emit radon at rates no greater than 40 Ci/yr per RRY.

4. Radon releases from an undispersed tailings pile after loss of its stabilizing cover depend on the depth of the tailings pile and are expected to be in the range of 75-80 Ci/year per RRY for current pile depths (12-13 meters).

5. Estimates based on data for inactive tailings piles indicate that, should stabilized tailings piles become uncovered, tailings dispersal will be slow, requiring several

centuries for a significant increase in radon emissions over those from the uncovered piles alone, and thus providing ample time to take remedial action.

D. Summary of radon source terms

61. Each of the Susquehanna units has a 1085 MWe (gross) capacity. Unit 1 is expected to operate for 30 years, from 1983 to 2013. Unit 2 is expected to operate for 29 years, from 1984 to 2013.[9] Since the annual fuel requirement for a reference reactor is defined as the amount of ore necessary to produce fuel for a 1000 MWe plant operating at 80% capacity for a year [36], it follows that the Susquehanna units will require a total of 64 RRYs during their lifetime. Therefore, the upper-limit radon source terms associated with the Susquehanna facility are as follows:

Short-term[10] mining releases: 3,880 Ci/RRY x 64 RRY = 248,320 Ci

Long-term mining releases: 90 Ci/yr-RRY x 64 RRY = 5,760 Ci/yr

Short-term milling releases: 1240 Ci/RRY x 64 RRY = 79,360 Ci

Long-term milling releases: 80 Ci/yr-RRY x 64 RRY = 5,120 Ci/yr.

Total upper-limit radon releases associated with the Susquehanna facility:

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9 The operating license application for Susquehanna Units 1 and 2 seeks a 40 year license from November 1973. Current projections indicate that Unit 1 will start commercial operations in 1983 and Unit 2 will do so in 1984.

10 In this context, "short-term" refers to releases occurring over a period of time that may range from a few years to a few decades; "long-term" refers to releases that (theoretically, at least) continue indefinitely into the future.

Short term: 327,680 Ci

Long term: 10,880 Ci/yr.

62. As noted above, I regard these upper-limit estimates to be extremely conservative on the high side, particularly with respect to long-term releases. A set of radon release values representing more realistic conditions can be obtained assuming reclamation of inactive mines and stabilization of mill tailings piles. Under those conditions, the radon source terms associated with the Susquehanna facility would be as follows:

Short-term mining releases:	248,320 Ci
Long-term mining releases (reclamation assumed):	25 Ci/yr-RRY x 64 RRY = 1,600 Ci/yr
Short-term milling releases:	79,360 Ci
Long-term milling releases (stabilization assumed):	40 Ci/yr-RRY x 64 RRY = 2,560 Ci/yr.

Total radon releases associated with the Susquehanna plant assuming reclamation of mines and stabilization of mill tailings piles:

Short term: 327,680 Ci

Long term: 4,160 Ci/yr.

E. <u>Significance of Radon Releases</u>.

63. The significance of the radon releases associated with the Susquehanna facility can be best appreciated by estimating the increase in radioactive dose that the average

person will receive as a result of the operation of the Susquehanna facility over the dose that this person would receive from other sources of radon.

64. The most significant of the doses resulting from radon releases is that to the bronchial epithelial tissues of the lung which arises predominantly from the decay of the short-lived daughters. The concentrations of these daughters relative to that of the parent Rn-222 (and, hence, the dose per unit parent concentration) is a function of a number of factors, prominent among which are the degree of ventilation of the air volume being considered and the dustiness of the atmosphere. For the assessments in the Final GEIS, the NRC Staff has used a bronchial epithelial (lung) dose/exposure ratio of 0.625 mrem/yr per pCi Rn-222/m^3 [28].

65. Both outdoor and indoor radon concentrations are highly variable and site-dependent. The measured concentrations of radon-222 in open air in western areas of the U.S. have ranged between 60 pCi/m^3 to 2000 pCi/m^3 [2], giving a range of lung doses between 39.5 and 1,350 mrem/year; NCRP [3] selected 150 pCi/m^3 as the "standard concentration" for outdoor air, giving (from the Staff dose/exposure ratio) a lung dose equivalent of 94 mrem/year from natural sources.

66. The indoor radon concentrations depend, among other things, on the materials used in building construction, the degree of ventilation in the building, and the location within the structure [29, 2]. The geometric mean indoor radon

concentration has been reported at 4.6 times the outdoor radon level [30]. Thus, an estimate of the average lung dose from indoor radon exposures would be 4.6 x 150 pCi/m^3 x 0.625 mrem/yr-pCi/m^3, or 430 mrem/yr. Energy conservation practices, which I anticipate will continue to be implemented, will cause the amount of ventilation in a building to decrease from typical past values of 2-5 air changes per hour to 0.1 - 0.9 air changes per hour. Utilization of energy conservation practices and the resulting reduced ventilation could increase the radon dose commitment inside a building by an order of a magnitude [29, 31].

67. From the analyses of U.S. population dose commitments from mill radon emissions in the Final GEIS [32], an average individual bronchial epithelial dose per Ci Rn-222 released can be calculated to be 3×10^{-7} mrem/Ci Rn-222 released.[11] Assuming, very conservatively, that all of the "short-term" radon associated with the total operation of the Susquehanna facility is released in only one year, the resulting average individual bronchial epithelial dose would increase by less than 0.1 mrem in that year. Similar , the upper limit "long-term" release of 10,880 Ci/year would increase the average individual lung dose by 0.003 mrem/year.

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11 The Final GEIS analysis results gave a U.S. population lung dose in 1978 of 66.3 person (organ) mrem per Ci radon-222 released from mill sites. Since the 1978 population used in the analysis was 218 million people, the <u>per capita</u> dose was $66.3/218 \times 10^6 = 3 \times 10^{-7}$ mrem.

68. Thus, the yearly lung dose commitment received by the average individual in the U.S. from upper limit "long-term" radon releases attributable to the Susquehanna facility would be approximately 0.005% of the dose received from just breathing average outdoor air. Alternatively, the total yearly dose that an average individual would receive as an upper limit attributable to the Susquehanna plant would be equivalent to that which he would receive by spending less than four additional minutes a year indoors.[12]

69. Even the upper limit radon releases attributable to the Susquehanna facility are, therefore, a very small fraction of the naturally-occurring radon releases to which the public is subjected constantly, and the fluctuations in radon releases in natural background are in themselves greater than the contribution attributable to the Susquehanna facility. Thus, I believe that the increase in the radon releases that

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12 Other sources of radon also contribute amounts comparable to those that would be attributable to the Susquehanna facility. For instance, I have calculated that the radon releases from the ash pile produced by burning coal to produce 800 MWe-year (1 RRY equivalent) would be 2 to 15 Ci/yr-RRY [33]. In the case of the Susquehanna facility, the radon releases from coal units equivalent in energy output to Susquehanna's nuclear units would be 132 to 990 Ci/yr.

would be produced by operation of the Susquehanna facility would be undetectable and such releases would have insignificant impact on the health and safety of the public [34].

Morton I. Goldman
Morton I. Goldman

Sworn to and subscribed before me this 7th day of August, 1981.

Dorothy L. Martin
Notary Public

MY COMMISSION EXPIRES JULY 1, 1982

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16. Id., pp. G-6, G-7.

17. Ref. 9, supra, 8 NRC at 92.

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FIGURE 1

U.S. URANIUM PRODUCTION HISTORY

1971 -1979

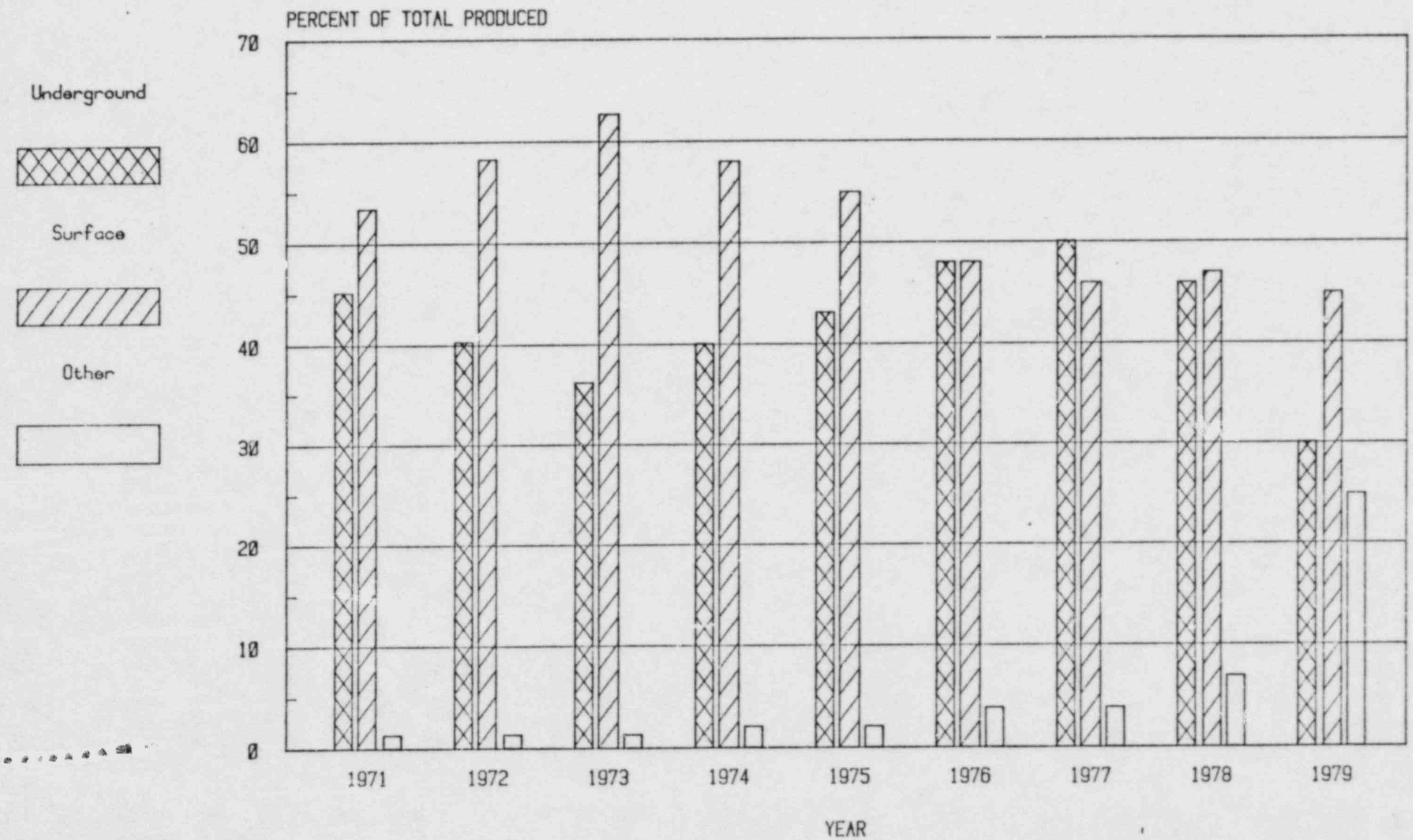


FIGURE 2

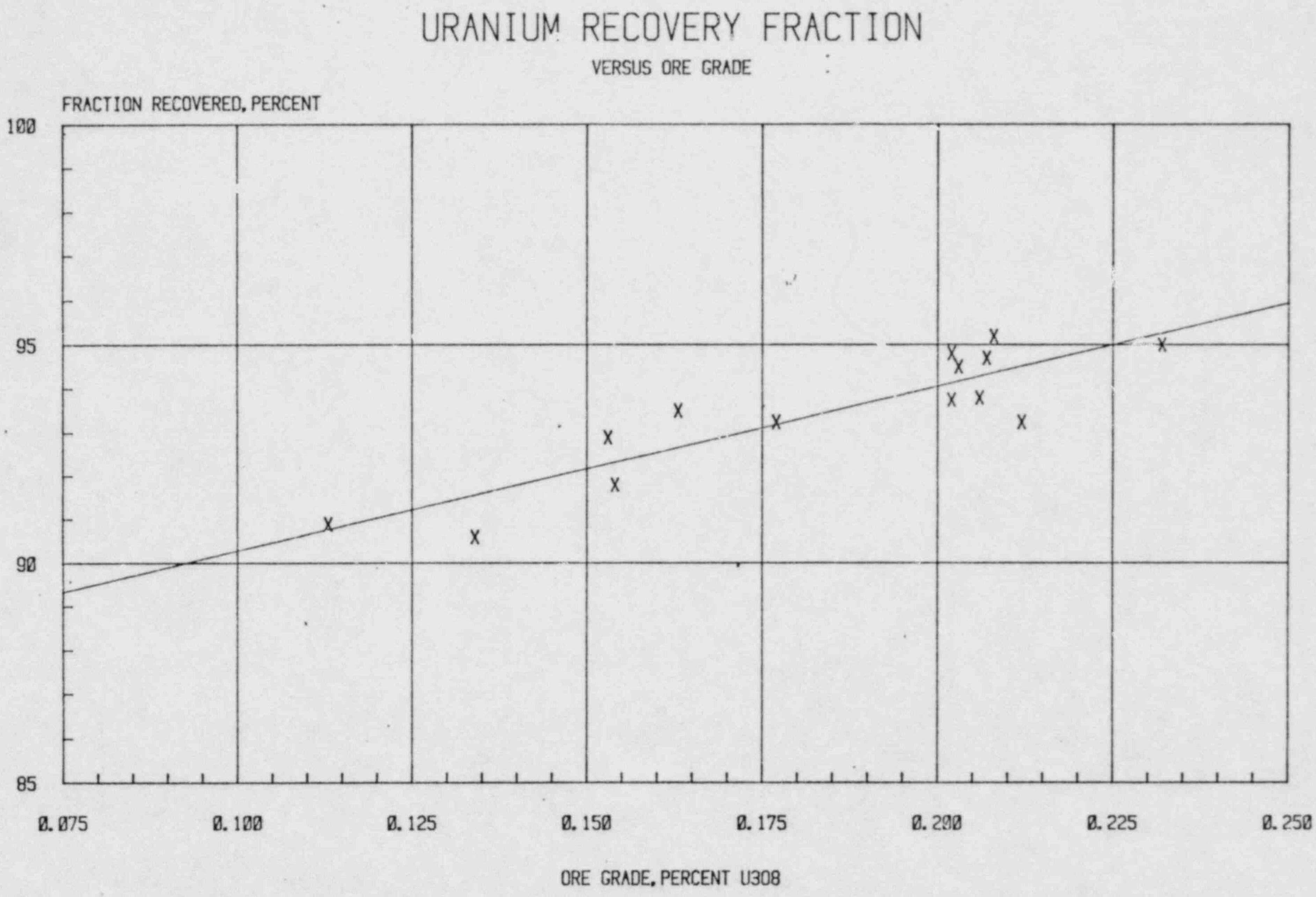
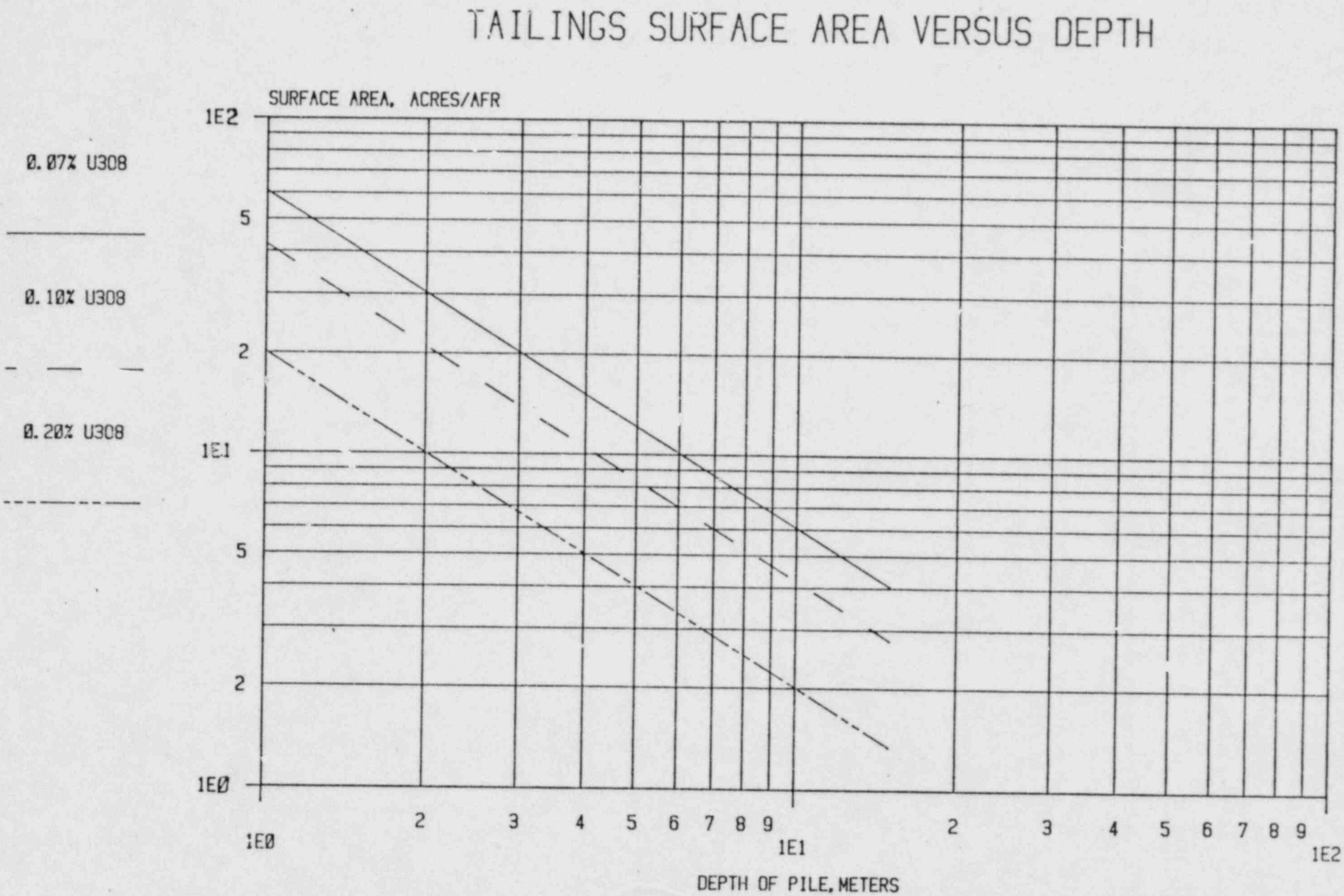

URANIUM RECOVERY FRACTION
VERSUS ORE GRADE
FRACTION RECOVERED, PERCENT
100
95
90
85
0.075
0.100
0.125
0.150
0.175
0.200
0.225
0.250
ORE GRADE, PERCENT U308

FIGURE 3



TAILINGS SURFACE AREA VERSUS DEPTH
SURFACE AREA, ACRES/AFR
Ø.Ø7% U3O8
Ø.1Ø% U3O8
Ø.2Ø% U3O8
1E2
5
2
1E1
5
2
1EØ
2
3
4
5
6
7
8
9
1EØ
1E1
2
3
4
5
6
7
8
9
1E2
DEPTH OF PILE, METERS

FIGURE 4

RADON EXHALATION PER AFR VS. DEPTH

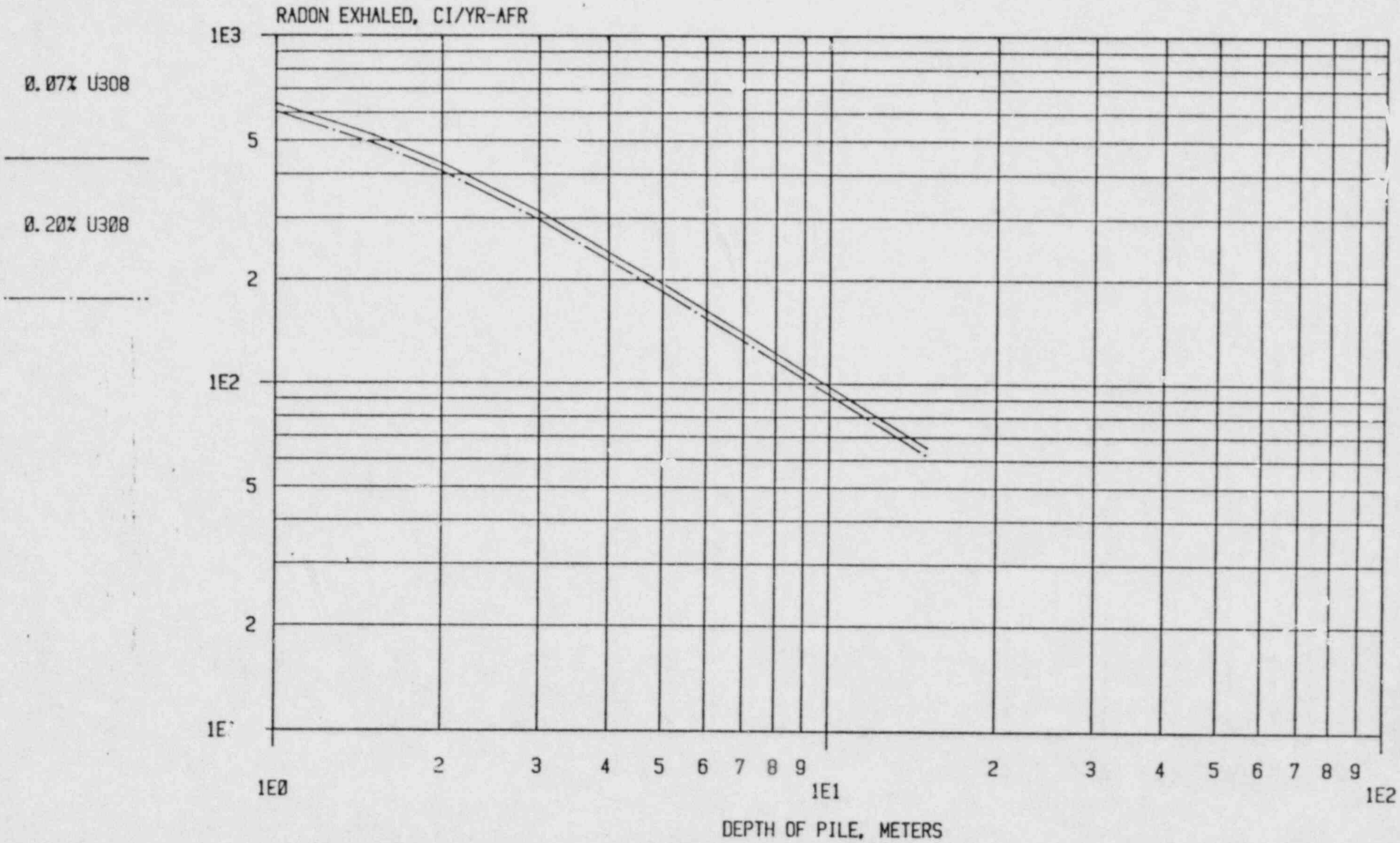


TABLE 1

TAILINGS DISPERSION FROM INACTIVE PILES[1]

Site	Tailings Pile		Dispersed Ra-226: R_t to R_1		Dispersed Ra-226: R_t to R_2		Dispersed Ra-226: R_t to Background		Fraction of Activity Dispersed
	Area, ac.	Ci	Area, ac.	Ci	Area, ac.	Ci	Area, ac.	Ci	
Arizona									
Tuba City	27	670	128	14.7	169	15.0	202	15.0	0.0224
Colorado									
Gunnison	30	206	12	0.12	26	0.23	68	0.26	0.00126
Slick Rock (UC)	19	70	3	0.045	41	0.33	81	0.36	0.00514
Slick Rock (NC)	7	30	--	--	12	0.13	33	0.19	0.00633
Rifle (Old)	20	320	17	0.32	44	0.52	243	0.66	0.00206
Rifle (New)	21	2130	114	17.4	169	17.8	312	17.9	0.0084
New Mexico									
Ambrosia Lake	104	1520	210	7.41	390	8.78	617	8.97	0.00590
Shiprock	118	984[2]	--	--	126	0.75	229	1.03	0.00105
Texas									
Falls City	142	1020	139	2.45	256	3.34	411	3.47	0.00340
Ray Point	48	230	19	0.19	39	0.34	94	0.38	0.00165
Utah									
Salt Lake City	94	1380	114	2.36	198	3.00	510	3.24	0.00235
Green River	9	20	--	--	44	2.06	153	2.32	0.116
Mexican Hat	77	1560	--	--	127	1.53	457	2.35	0.00151
TOTAL		10,140						56.1	0.00553

(1) from ORP/LV-75-5
(2) from EPA-520/1-76-001

R_t = Equivalent Radius of Tailings Pile
R_1 = Equivalent Radius to 40 μr/hr contour
R_2 = Equivalent Radius to 10 μr/hr contour

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Massachusetts Institute of Technology, Sc. D., 1960
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New York University, B. S., Civil Engineering, 1948

REGISTRATION

Professional Engineer: New York (1955), District of Columbia (1965), Maryland (1972), Arizona (1974), California (19

EXPERIENCE

NUS CORPORATION, 1961–Present
U.S. Public Health Service
Division of Radiological Health, 1950–1961
Nuclear Installations Consultant, 1959–1961
M.I.T. Nuclear Engineering Department, 1956–1959
Reactor Safeguards Committee, Secretary
Radioactive Waste Disposal Project, Pr ct Leader
ORNL Waste Disposal Research Activity, Soil and Engineering Section, Chief, 1954–1956
Sanitary Engineering Center, Radiological Health Training Section, 1950–1954
M.I.T. Sanitary Engineering Department, Radioactivity Research Laboratory, Research Assistant, 1949–1950
New York University, Sanitary Engineering Research Laboratory, Research a Teaching Assistant, 1948–1949

NUS — As Senior Vice President, Environmental Systems Group, has responsibility for managing all activities in site evaluation and selection, safety analyses, waste management system evaluations, environmental assessments and impact evaluations for nuclear and fossil-fueled power plants, industrial facilities, and aerospace nuclear activities. In 1968, served as U.S. representative to and chairman of an IAEA expert panel on Radioactive Waste Management at Nuclear Power Plants, resulting in IAEA Safety Series No. 28 of that title. From 1972 to 1975, served as consultant to and witness for the Consolidated Utility Group in the AEC/NRC rulemaking hearing on "as low as practicable" radioactive waste discharge s ndards.

Other activities include Chairman, Atomic Industrial Forum ommittee on Environmental Aspects of Uranium Mining and Milling; member of AIF Co e on Environment Steering Group; Vice-Chairman, Nuclear Effects Task Committee nental Engineering Division, ASCE; member, Committee on Nuclear Standards, ASCE; , Standards Committees ANS-2 "Site Evaluation" and ANS-18 "Environmental Impact Evaluation."

Previously was Technical Director of NUS. As such, was responsible for auditing the quality, scope, and depth of the Corporation's technical capabilities; guiding the continuing development of those capabilities; serving as the senior corporate spokesman on all environmental and nuclear safety issues; and providing senior level consulting and project supervision for selected clients. In the latter capacity, served as consultant to and witness for utilities and utility groups in individual and generic proceedings involving energy/environmental activities including the GESMO proceedings.

4/80 ESG

EXHIBIT A

United States Public Health Service — Provided technical consultation and assistance to state and federal agencies on health and safety problems of nuclear installations, including Peach Bottom, Humboldt Bay, Yankee, Elk River, Pathfinder, CVTR, PM-3A, and Indian Point plants. Served as member of working group responsible for Radioactivity Section of USPHS Drinking Water Standards (1960). During M.I.T. assignment, directed research on fixation of high-activity fission-product waste which led to successful development of low solubility vitreous fusion for several waste compositions. Supervised research on disposal of radioactive wastes at ORNL and effect of waste solutions on soil chemistry and structure. Conducted original research at N.Y.U. and M.I.T. on removal of radionuclides from water by standard water treatment techniques.

MEMBERSHIPS

American Society of Civil Engineers
American Nuclear Society
Air Pollution Control Association
American Association for the Advancement of Science
American Academy of Environmental Engineering, Diplomate

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of PENNSYLVANIA POWER & LIGHT COMPANY and ALLEGHENY ELECTRIC COOPERATIVE, INC. (Susquehanna Steam Electric Station, Units 1 and 2)	))))))))))	Docket Nos. 50-387 50-388

CERTIFICATE OF SERVICE

This is to certify that copies of the foregoing "Applicants' Motion for Summary Disposition of Contention 1 (Radon)", "Applicants' Memorandum in Support of Motion For Summary Disposition of Contention 1 (Radon)", "Applicants' Statement of Material Facts As To Which There Is No Genuine Issue To Be Heard (Contention 1 (Radon))", and "Affidavit of Morton I. Goldman in Support of Summary Disposition of Contention 1 (Radon)", were served by deposit in the U. S. Mail First Class, postage prepaid, this 7th day of August, 1981 to all those on the attached Service List.

Jay E. Silberg

Dated: August 7, 1981

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In the Matter of PENNSYLVANIA POWER & LIGHT COMPANY AND ALLEGHENY ELECTRIC COOPERATIVE, INC. (Susquehanna Steam Electric Station, Units 1 and 2)	Docket Nos. 50-387 50-388

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