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APPLICANT'S EXHIBITS

Appl. Exh. 153	Direct Testimony of Richard Codell before the Atomic Safety and Licensing Board Concerning Commission Question 1, presenting an analysis of the risk posed by contamination of the Hudson River, reservoirs and other bodies of water that could be caused by severe accidental radionuclide releases at the Indian Point Nuclear Power Plant. This document consists of 45 consecutively numbered pages and six unnumbered pages containing "exhibits" one through eleven.
Appl. Exh. 154	Richard B. Codell, 1984. Potential Contamination of Surface Water Supplies by Atmospheric Releases from Nuclear Plants, Health Physics, to be published. This document consists of 31 consecutively numbered pages and eight unnumbered pages containing figures one through eight.
Appl. Exh. 155	J. C. Helton, A. B. Muller and A. Bayer, Contamination of Surface Water Bodies after Reactor Accidents by the Erosion of Atmospherically Deposited Radionuclides, Health Physics, to be published. This document consists of 34 consecutively numbered pages and ten unnumbered pages containing Tables one through nine.
Appl. Exh. 156	U.S. Nuclear Regulatory Commission, 1975. Calculation of Reactor Accident Consequences - Appendix VI of Reactor Safety Study, WASH-1400 (NUREG 75/014), Washington, D.C. Five page document consisting of a cover page, title page and pages 8-22, 8-24 and 8-25.

Appl. Exh. 157 Health and Safety Laboratory, U.S. Energy Research and Development Administration, 1977. Final Tabulation of Monthly ^{90}Sr Fallout Data: 1954-1976, HASL-329, New York, New York 10014. Six page document consisting of a cover page and pages i, ii, A-73, A-74, and A-75.

Appl. Exh. 158 Larsen, Richard J., 1983. Worldwide Deposition of ^{90}Sr through 1981, EML-415, Environmental Measurements Laboratory, U.S. Department of Energy, New York, New York 10014. Two page document consisting of a cover page and page 30.

Appl. Exh. 159 U.S. Environmental Protection Agency, 1976, Radiological Quality of the Environment, Office of Radiation Programs, Washington, D.C. 20460. Two page document consisting of a cover page and page 67.

Appl. Exh. 160 Hardy, E. P., Jr. and L. E. Toonkel, 1982, Environmental Measurements Laboratory Environmental Report, EML-405, Environmental Measurements Laboratory, U.S. Department of Energy, New York, New York 10014. Three page document consisting of a cover page and pages II-301 and II-302.

Appl. Exh. 161 U.S. Department of Health, Education, and Welfare, 1960 through 1968, Radiological Health Data, Volumes 1 through 9. This document includes excerpts from a number of reports:

Report April 1960 consists of a cover page and page 38;
" June 1960 " " " " " " " 19;
" Sept. 1960 " " " " " " pages 29 and 30;
" Dec. 1960 " " " " " " pages 19 and 21;
" March 1961 " " " " " " page 131;
" June 1961 " " " " " " " 252;
" Oct. 1961 " " " " " " " 451;

Report Dec. 1961 consists of a cover page and page 531;
" Mar. 1962 " " " " " " " 91;
" Aug. 1962 " " " " " " pages 293 and 294;
" " 1964 " " " " " " page 391;
" Oct. 1964 " " " " " " " 496;
" Dec. 1964 " " " " " " " 608;
" Mar. 1965 " " " " " " " 158;
" July 1965 " " " " " " " 396;
" June 1966 " " " " " " " 357;
" Aug. 1967 " " " " " " pages 450 and 451;
and " Nov. 1968 " " " " " " " 663 and 664;

Appl. Exh. 162 Limerick Generating Station Radiological Environmental Monitoring Program, 1971-1977, Prepared for Philadelphia Electric Company by Radiation Management Corporation May, 1979. This docuemnt consists of a cover page and Table B-1 consisting of 10 unnumbered pages.

Appl. Exh. 163 U.S. Environmental Protection Agency, 1976 through 1982, *Environmental Radiation Data*, Reports 6, 10, 15, 18, 23-24, 25-26, and 29, Office of Radiation Programs, P.O. Box 3009, Montgomery, Alabama 36193. Report 6 consists of a cover page and four unnumbered pages; Report 10 consists of a cover page and four pages numbered 19-22; Report 15 consists of a cover page and four pages numbered 18-21; Report 18 consists of a cover page and four pages numbered 18-21; Report 23-24 consists of a cover page and four pages numbered 25, 26, 28, and 29; Report 25-26 consists of a cover page and four pages numbered 33, 35, 36 and 37; Report 29 consists of a cover page and four pages numbered 21, 23, 24, and 25.

Appl. Exh. 164	Menzel, Ronald G., 1975, "Land Surface Erosion and Rainfall as Sources of Strontium-90 in Streams," Journal of Environmental Quality, Vol. 3, No. 3. This document consists of five pages, numbered 219-223.
Appl. Exh. 165	U.S. Geological Survey, 1982, Water Resources Data for Pennsylvania Water Year 1982 Volume 1 - Delaware River Basin and Volume 2 - Susquehanna and Potomac River Basins, Water Resources Division, P.O. Box 1107, Harrisburg, Pennsylvania 17108. The excerpt from Vol. 1 includes a cover page and pages 94 and 141; the excerpt from Vol. 2 includes a cover page and page 144.
Appl. Exh. 166	City of Philadelphia Water Department, 1982. How Water in Philadelphia is Teated and Distributed, 1180 Municipal Services Building, Philadelphia, Pa. 19107. This document consists of pages one through seven, an unnumbered page containing a map entitled "Philadelphia Water Facilities Water Pressure Districts", pages 10 through 15, and a closure page.
Appl. Exh. 167	U.S. Nuclear Regulatory Commission, 1977. Calculations of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10CFR50, Appendix I, NRC Regulatory Guide 1.109. This document consists of a cover page, pages iii through vi and pages 1.109-1 through 1.109-80.
Appl. Exh. 168	Simpson, D. B., and B. L. McGill, 1980. User's Manual for LADTAPII - A Computer Program for Calculating Radiation Exposure to Man from Routine Releases of Nuclear Reactor Liquid Effluents, Oak Ridge National Laboratory, NUREG/CR-1276. This document consists of pages iii, v, vii, ix, and pages one through 21.

Appl. Exh. 169	Aptowicz, Bruce S., 1984. Letter to Robert E. Martin, USNRC, dated April 23, 1984 and private communication, S. Gibbon, PECO and B. Aptowicz, City of Philadelphia, May 25, 1984. The April 23, 1984 letter consists of two consecutively numbered pages.
Appl. Exh. 170	Philadelphia Water Department, 1982. Table of pumping, treatment and consumption rates for FY '82. This document consists of two consecutively numbered pages.
Appl. Exh. 171	Commonwealth of Pennsylvania Disaster Operations Plan, Annex E, Fixed Nuclear Facility Incidents, February 1984. One page numbered E-12-42.
Appl. Exh. 172	Straub, C.P., 1964 Low-Level Radioactive Wastes, Their Handling, Treatment and Disposal, Division of Technical Information, United States Atomic Energy Commission. This document consists of a cover page and pages 155-202.
Appl. Exh. 173	Hardy, E.P., Jr., 1981, Environmental Measurements Laboratory Environmental Report, EML-390, Environmental Measurements Laboratory, U.S. Department of Energy, New York, New York 10014. This document consists of a cover page, pages C-102 through C-115, an unnumbered page and pages C-64 through C-79.

COMMISSION

Docket No. 50-352/353 Exhibit No. 153
In the matter of PECO - Limerick 1 & 2
Staff ✓ IDENTIFIED ✓
Applicant ✓ RECEIVED —
Intervenor REJECTED —
Cont'g Off'r
Contractor DATE 6/19/84
Other Witness
Reporter Mary Simon

(III.D) #6

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of		
CONSOLIDATED EDISON COMPANY OF NEW YORK (Indian Point, Unit 2)	)	Docket Nos. 50-247-SP 50-286-SP
POWER AUTHORITY OF THE STATE OF NEW YORK (Indian Point, Unit 3)	)	

DIRECT TESTIMONY OF RICHARD CODELL
CONCERNING COMMISSION QUESTION 1

Q1 Please state your name and business address for the record.

A1 My name is Richard Codell, and I am employed by the Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Q2 Please identify your position with the NRC and describe your responsibilities in that position.

A2 I am a Senior Hydraulic Engineer in the Hydrologic and Geotechnical Engineering Branch, Division of Engineering, Office of Nuclear Reactor Regulation.

My primary responsibilities include, among other things, the reviews, evaluations, and assessments of:

- The safety of nuclear power plants and other nuclear facilities, from natural or man-made external flooding;

- The hydrologic aspects of the reliability of safety-related water supplies for nuclear plants
- The potential for and consequences of contamination of the hydrosphere from nuclear accidents.

Q3 Please describe your education and professional qualifications.

A3 A copy of my professional qualifications is attached to this testimony.

Q4 What is the purpose of this testimony?

A4 The purpose of this testimony is to present the Staff's review of the liquid pathway analyses in the Indian Point Probabilistic Safety Study (IPPSS), and to describe the Staff's independent analysis of the risk posed by contamination of the Hudson River, reservoirs, or other bodies of water that could be caused by severe accidental radionuclide releases from the Indian Point nuclear power plant.

Q5 What are "Liquid pathways"?

A5 The liquid pathways are routes by which people can be exposed to radiation released by a nuclear power plant via surface and ground water. Exposures involving surface water can come from drinking or swimming in contaminated water, direct radiation from contaminated shoreline sediments, and ingestion of contaminated seafood. Ground water, which can serve as a source of drinking water, can also be contaminated. In addition, radionuclides released to ground water can migrate to surface water.

Q6 How might liquid pathways be contaminated from accidents at nuclear plants?

A6 There are three possible ways in which radionuclides could be released to the hydrosphere as a result of accidents (Ref. 1).

1. Direct release to surface water - some relatively small accidental releases could occur through faulty routing of radionuclide streams through the circulating water system, the service water system, or the storm drainage system. Accidents of this type do not involve releases approaching the severity of core-melt accident releases, and would not be significant contributors to risk.* Releases of radionuclides from core-melt accidents directly to surface water, while possible, would be much less likely than other liquid pathways considered by the staff, and are not expected to be serious contributors to risk.
2. Releases to the ground - core-melt accidents involving basemat penetration could release radioactivity to the ground in the form of core debris, or in some cases, highly contaminated water from inside the containment building. Such releases could affect ground-water supplies or could migrate to surface water.
3. Airborne releases - some core-melt accidents could release radionuclides to the air in the form of gases or aerosols (Ref. 2). These radionuclides would be deposited on the land and water surface by such natural processes as settling and rainfall. Some of the radionuclides would fall directly on water surfaces. The rest would fall

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* In this testimony, risk is defined as the consequence of an event in terms of person-rems times the probability of the event in terms of reciprocal reactor-years.

on land, but a portion of that could be carried to surface water by rainfall runoff or after first infiltrating to ground water.

Q7 What are the major differences in the risk from the "liquid pathways" and (traditional) airborne exposure pathways?

A7 Probably the most significant difference between them is that much of the risk immediately following the airborne releases might be difficult to avoid (e.g., inhalation), while the risk from the liquid pathway could be virtually eliminated by avoiding contaminated water, seafood, and other uses, such as swimming or shoreline recreation.

The immediate consequences from airborne exposure pathways would be difficult to avoid except by prompt evacuation of the affected population because radioactive gases and particulates would be carried at the speed of the wind, and could reach people in a matter of minutes to hours after release. There would generally be much longer delays associated with the liquid pathway, which would allow time for the monitoring and avoidance of the contaminated water.

Q8 What kinds of risks are posed, therefore, by the liquid pathway?

A8 It is not likely that waterborne radionuclides would pose a risk in terms of early fatalities or even early injury because the doses would be below the threshold levels necessary to cause immediate health effects (as identified in Dr. Acharya's testimony, Section III.C), and could be interdicted at any level deemed necessary. It is much more likely that contamination of the liquid pathway would cause economic losses because of cleanup and treatment costs and temporary loss of the use of affected water. There could be latent health effects caused by the accumulation of low level doses, at or below protective actions levels.

Q9 What is the licensees' appraisal of the risk for the liquid pathway releases associated with basemat penetration at Indian Point?

A9 The licensees considered two paths by which radioactive core material could reach ground water. First, molton core debris could penetrate the basemat to the ground beneath the plant (Ref. 1, Ref. 3). Second, highly contaminated liquid "sump" water could escape through the failed basemat. In the former case, the heat of the molton debris would drive ground water away, effectively isolating most of the radionuclides from coming in contact with water for perhaps a year. When liquid water could finally contact the debris, leaching of radionuclides would begin. The leached radionuclides would be carried by ground water in the direction of the Hudson River. The speed of ground-water movement toward the Hudson River has not been determined, but the licensee has estimated that the ground water travel time would range between 19 and 1900 days with 95% confidence and have an expected value of 190 days (Ref. 4). On the basis of available data from the site and values of hydrologic coefficients for similar materials reported in the literature, I consider this to be a reasonable range. The speed of transport of the most hazardous radionuclides would be slower than the movement of the ground water itself because of "sorption," which is the physical or chemical interaction of the radionuclide with the soil or rock substrate. The licensees have estimated that, because of sorption, most of the radionuclides assumed to be released to the ground water would decay before reaching the Hudson River.

Radionuclides released from the reactor from a sump water release case would potentially be in the dissolved form, and therefore readily available to be transported through ground water to the Hudson River. Additionally, the estimated one-year cooling-down period associated with the debris leaching case would not apply. The fraction of high consequence radionuclides which could reach the Hudson River from the sump water would, therefore, be substantially greater than that from the debris leaching case. The probability of sump-water release with basemat penetration would be considerably lower than that of basemat penetration alone, however, because the sump water would act to cool the core debris. The probability of any basemat failure is estimated by the staff to be 4.11×10^{-4} per year for Unit 2 and 2.37×10^{-4} per year for Unit 3 before engineering fixes (Release Category H as defined in the testimony of Dr. Meyer, Sect. III.B). The probability of a basemat failure with sump-water release is estimated to be about 2.9×10^{-5} per year for Unit 2 and 1.9×10^{-5} per year for Unit 3.

The licensees have performed a deterministic liquid pathway dose assessment for postulated core melt releases at the Indian Point site. The analysis considered normal uses of the Hudson River and the beaches in the lower bay. Commercial and recreational fish catches were considered to be taken as usual. There is presently a ban on shellfish harvesting in the Hudson River. This ban was arbitrarily considered to still be in effect for two years following the release. The licensees' estimate of the maximum dose rate to an individual was calculated to be 6 rem per year to the gastrointestinal tract for the sump water release case (Ref. 4). The population dose calculated over all time for this type of release was estimated to be 76,000 person-rem with present-day use of the river, and potentally, if the shellfish fishery were reopened, 150,000 person-rem whole body dose and up to 490,000 person-rem to bone. Doses resulting from the release of molten core debris (i.e., leaching) were estimated to be much smaller: an estimated maximum organ dose rate of 0.1 rem/yr and 1900 person-rem population dose to bone with present-day river use. These dose rates are based on the assumption of no interdiction (other than the shellfishing ban).

The maximum individual doses in either case would be too small to evidence themselves in early health effects as defined by Dr. Acharya's testimony, Section III-C, but population doses associated with groundwater releases could be translated to latent health effects. The licensees' analyses did not take mitigation into account, nor did they consider the probabilities of accidents which would lead to ground-water releases. These doses and health effects could, of course, be reduced by several means, such as interception or isolation of the contaminated ground water or by denying people use of the river. The economic cost of such measures has not been quantified, however.

Q10 Do you agree with the licensees' estimates of doses from basemat penetrations involving releases to the ground water?

A10 I have some reservations about the coefficients used in the surface-water and ground-water models. For example, there is reason to believe that retardation by the highly fractured limestone beneath the plant of key radionuclides such as Cs-137 and Sr-90 might have been overestimated. Bioaccumulation factors for fish and shellfish might have been underestimated. The licensees' model also does not treat the contamination of sediments and their transport to New York Harbor and beaches along the Hudson River realistically, so exposure to sediment such as direct shine might have been underestimated. Futhermore, I believe that the quality of available groundwater data would make the dose estimates almost impossible to confirm.

Q11 What, then, is your estimate of the correct doses for liquid pathway contamination resulting from basemat penetration?

A11 I have not performed an independent dose assessment for liquid pathways involving releases to the ground, but expect that there is great uncertainty implicit with the dose calculation. Data used in making the estimates are so limited and of such dubious quality that I seriously doubt that a better analysis could have been performed. I presently estimate, however, that for the same conditions used by the licensees (i.e., no source interdiction or restrictions on usage other than the shellfishing ban), the upper bound of total body individual and population doses could be one to two orders of magnitude greater than the licensees' estimates reported in A.9. I partially base this appraisal on an evaluation of the licensees' analysis in the IPPSS, performed by our consultant, Battelle-Pacific Northwest Laboratories (Ref. 5 and Ref. 5a). I believe, however, that it is not realistic to exclude interdiction or mitigation from the analyses since it is highly likely that a range of measures could and would be brought into play after such a severe accident, involving basemat penetration, to reduce doses to very low levels. Furthermore, to be consistent with the Staff's evaluation of atmospheric releases (Dr. Acharya's Testimony, Section III.C), interdiction should be assumed for dose estimates.

Q12 What measures could be used to reduce doses from ground water liquid pathway releases?

A12 References 1, 3 and 6 identify methods by which the reactor core or the contaminated ground water could be isolated (mitigation). Among the methods discussed which might be applicable at the present site are pressure grouting to seal fractures in bed rock, dewatering of the area and then treating the withdrawn water, and artificial recharge to reverse the water table gradient. The NRC staff is funding additional research to investigate mitigative techniques which can realistically be applied to a variety of nuclear power plant sites following accidents. Initial indications support the feasibility of intercepting the contamination before it reaches water users, providing that there is sufficient time to act.

Additionally, any radionuclides escaping to the river would undoubtedly be closely monitored and protective actions (interdiction) invoked to prevent harmful levels of exposure to the public.

Q13 How would liquid pathway releases behave in the Hudson River?

A13 The contamination of the Hudson River caused by a large scale liquid pathway release would have several forms:

1. Radionuclides which remain largely in the dissolved state (e.g., tritium, iodine, strontium, technecium, ruthenium) would contaminate the water, but would be largely purged from the Hudson River and estuary by fresh water advection and tidal flushing in a period of months following the release. These radionuclides would also contaminate aquatic life residing in the river. This contamination of

aquatic life would be more persistent than the contamination of the water itself.

2. Some radionuclides, for example cesium, cobalt and plutonium, show a great affinity for sediment, and will therefore contaminate the river bottom and shorelines in addition to the water and aquatic life. This type of contamination is not quickly flushed from the river or estuary, and would therefore be much more persistent than the strictly dissolved variety. Contaminated sediments would also serve as a long-term source of radionuclides to aquatic life.

Of particular importance are the isotopes cesium-134 and cesium-137, which would be major contributors to the long term liquid pathway doses in the Hudson River because they would be abundant in sump water, are relatively long lived, and have relatively high sorption, bioaccumluation and dose factors. Cesium isotopes released to the Hudson River as a result of weapons testing fallout and low-level releases from Indian Point, have been extensively studied for over a decade (e.g., Ref. 7, Ref. 8). The behavior of cesium in the Hudson River and estuary has been found to be very complicated, because sorption by sediment and bioaccumulation by aquatic life are both relatively high in fresh water, and relatively low in salt water. The Hudson River experiences wide changes in salinity both along its length and seasonally. During periods of high freshwater flow, the salt wedge is pushed downstream of Indian Point, but is frequently upstream of Indian Point during dry weather. If the radioactive release from the Indian Point plant were to occur when the salinity at Indian Point was low, cesium sorption onto sediments and bioaccumulation in fish would be high. Conversely, if the releases were to occur when the water at Indian Point was brackish, sorption and bioaccumulation would be greatly reduced. Furthermore, a fraction of the cesium sorbed to sediment during fresh water periods would be subsequently released from the sediment when it came in contact with salt water, either because of a seasonal salinity intrusion or because the sediment was physically transported further downstream. Cesium released from contaminated sediment in this manner has been shown to act as a source of contamination to fish, although the direct contamination to fish from ingestion of contaminated sediment appears to be much less important (Ref. 9).

Contaminated sediments would accumulate in harbors and coves between Indian Point and the Atlantic Ocean. Most of the open areas of the river would receive relatively little sediment accumulation. New York Harbor, over 40 miles downstream from Indian Point, would receive a sizable fraction of the contaminated sediment. Approximately 10-30 percent of the low level releases of cesium from Indian Point are estimated to accumulate in the lower Hudson River and New York Harbor (Ref. 10). Under present conditions, most of this cesium is removed with sediment by maintenance dredging and dumped at sea. I would expect that in the case of a large liquid release to the Hudson River, the behavior of sorbed radionuclides such as cesium would be the same as that observed for low-level releases, especially if the release occurred over a period of several months. For a short duration release, the behavior of sorbed radionuclides would be strongly affected by conditions in the river, such as salinity and sediment load, at the time of the release.

Q14 Can you bound the estimate of risk to the general population for the liquid pathway case?

A14 The worst liquid pathway contamination of the Hudson River which could occur would be the case of a large sump water release, coupled with a groundwater travel time at the lower end of the predicted range. For short groundwater travel times, relatively little of the sump water radioactivity would decay, and there might be insufficient time to interdict the groundwater pathway. This accident could therefore release large quantities of hazardous radionuclides to the Hudson River. I do not believe, however, that it is possible with the available data to estimate the probability of a short groundwater travel time, so I cannot express my conclusions in terms of risk.

Q15 What would be the likely response to a large liquid pathway release?

A15 If a large fraction of the contaminated sump water from a core melt accident were to escape through the ground, serious contamination of the Hudson River would result. I would therefore expect that a realistic response to such an accident would be highly precautionary. Monitoring of groundwater and surface water contamination would start almost immediately. Samples of water, fish and sediment would be continually monitored to gage their levels of radiation and danger to the public. The public would be prohibited from coming in contact with dangerous levels of contamination. Recreational uses of the affected water and shoreline would be restricted. Essential uses of the river would also be restricted to the extent possible to protect people from unnecessary radiation exposures.

Q16 Recognizing that you cannot estimate the probability associated with a large liquid release to the Hudson River, what would maximum individual exposure rates be to individuals caused by the deterministic, bounding case liquid pathway release?

A16 There would probably be exposure to people who either ignored the prohibitions, or who necessarily had to come in contact with the contaminated water or sediment. I have therefore calculated the potential exposure rates to these individuals for the worst case liquid release.

I calculated a maximum external exposure of about 40 millirems per hour to an individual immersed in the contaminated water near Indian Point, based on the entire sump water inventory released uniformly to the Hudson River over a period of 30 days, and an average fresh water flowrate of about 19000 cubic feet per second. I assumed complete mixing across the Hudson River and used immersion dose factors from Reference 11. A higher rate of release or lower river flow would lead to a proportionately higher exposure rate. The exposure rate would decrease with distance from Indian Point because of tidal diffusion. Furthermore, once the release ceased, the dissolved radioactivity would be flushed from the estuary in a matter of one to several months. Unless the exposure were prolonged, the dose to the individual would be much lower than what would be considered necessary for early health effects.

Contaminated sediments would probably pose more of a threat than contaminated water because of their much greater persistance and higher radioactivity. People who might come in contact with contaminated sediment include dredge operators and those whose work would bring them close to the shoreline.

Maintenance of New York Harbor involves the dredging of about 2 million metric tons annually (Ref. 10). A stoppage of dredging would lead eventually to shoaling severe enough to interfere with shipping. It is therefore reasonable to assume that dredging of the harbor would have to resume sometime following the accident. I calculated an external whole body dose rate of about 0.6 rem/hr for a person in close contact with dredge spoils from New York Harbor four years after the postulated sump water release. I based my estimate on the measured radiocesium profile caused by low-level Indian Point releases (Ref. 12), scaled up to the accident release, and assumed that a one meter thickness of sediment was removed. I then applied dose rate factors for surface irradiation from Ref. 11 and gamma photon shielding factors from Ref. 13 to calculate the dose one meter above the spoils. While protection of the exposed individuals would be desirable and probable, the calculated dose, even for a hypothetical 8 hour work day, would still be much less than the threshold level for early health effects. Other people coming into contact with contaminated sediments in New York Harbor, such as divers, dock workers and other personnel who must work close to the shoreline, would also be exposed to contaminated sediments, but at lower rates than that calculated above.

I have also calculated the ground exposure at Verplanck Beach, on the Hudson River, about 2 miles downstream of Indian Point, to be about 0.4 rem/hr one year following the postulated release. I estimated this rate of exposure by using water-sediment transfer factors, derived from measured radiocesium levels on Verplanck Beach (Ref. 13) resulting from low-level Indian Point releases, to predict radionuclide surface concentrations for the postulated liquid pathway release. I then applied the factors used in WASH-1400 for dose rate caused by standing on contaminated ground (Ref. 14).

Q17 How would the dredge spoils be disposed?

A17 Dredge spoils from the Hudson River are usually dumped at sea in the New York Bight. Radioactively contaminated sediments, however, could be classified as "low level radioactive waste," and dumping them at sea might violate U.S. or international laws (e.g., Ref. 16, Ref. 17).

Q18 How long would hazardous levels of radioactive contamination persist in the Hudson River?

A18 The definition of "acceptable level of contamination" is highly uncertain, and would depend on the interpretation of various regulatory authorities. I cannot address this aspect of the question. I can, however, describe the natural and man-made factors which would cause the river, estuary and harbor to be purified of contamination.

Dissolved radionuclides and some very fine suspended sediments will be flushed to sea by freshwater advection and tidal diffusion. The time scale for removal of dissolved radionuclides would be on the order of one to several months.

Radioactively contaminated sediments would be more persistent, and would tend to be deposited in particular portions of the river such as harbors and coves. There are several factors in addition to radioactive decay which tend to remove or mitigate sediment contamination:

1. The sediments can be carried downstream by suspension and bedload transport phenomena. These mechanisms merely alleviates the problem in one area by increasing the problem in another area;

2. The radionuclides can be desorbed from the sediment and carried away in the dissolved form. The important radionuclides, cesium and cobalt undergo desorption in the presence of salt water during salinity intrusions into the estuary.

3. Contaminated sediments can be buried and diluted by fresh sediments, effectively reducing their concentration but not actually removing them from the estuary.

4. The sediments can be artificially dredged from areas where they collect, and disposed on land or at sea.

All of these mechanisms have been identified in the Hudson River and New York Harbor.

In the vicinity of Indian Point, radiocesium is removed mostly by sediment transport and desorption caused by salinity intrusion. The effective halflife (time for sediment concentration to be halved) of radiocesium in the open river near Indian Point is about 1 year (Ref. 9). River shoreline sediments, although contaminated to a lower degree than bottom sediments, are more persistent. I have not been able to predict the halflife of contamination on river shorelines, but it is greater than one year and is probably several years.

In New York Harbor, and other areas of high sedimentation, burial and dilution by fresh sediments is the most important mechanism for reducing sediment concentration. The effective halflife of all pollutants in areas of moderate to heavy sedimentation is on the order of 2 years (Ref. 13). Substantial quantities of contaminated sediments are also removed from New York Harbor and other shoaling areas by dredging.

Q19 How contaminated would the beaches along the Atlantic Ocean be following the release?

A19 The Atlantic Ocean Beaches such as Coney Island and Rockway are heavily utilized, so any contamination would have relatively large effect on population dose. Fortunately, it appears that these beaches would be very much less affected than the beaches and bottom sediments of the Hudson River and New York Harbor. The Atlantic Ocean beaches are largely quartz sand with a very low fraction of fine material (Ref. 18), while river sediments are mostly very fine silts and clays, very little of which leave New York Harbor except as dredge spoils. In fact, the net direction of natural sediment transport is into the Harbor from the ocean. I know of no direct measurements of Hudson River pollutants on the Atlantic Ocean beaches, but sandy New York Bight and Raratan Bay samples are at least 2 to 3 orders of magnitude lower in concentrations of these contaminants than are New York Harbor sediments (Ref. 8). I therefore estimate that the beaches would be at least 2 to 3 orders of magnitude less contaminated than the harbor or river beach sediments.

Q20 How do the dose rates and risks which you have calculated for the liquid pathway releases to the Hudson River compare to other accident pathways considered for the Indian Point Probabilistic Safety Study?

A20 I conclude that the consequences of a large liquid release to the Hudson River would be relatively small compared to consequences evaluated for the airborne release cases, and that the risk would be much lower. I base my conclusion on the following factors:

1. The probability of a core melt with basemat penetration and sump water release is relatively small compared to the probability of an airborne release. A basemat penetration without sump water release would be more probable than one with sump water release, but would have much lower consequences and greater interdiction potential.

2. It is not possible to demonstrate unequivocally that the travel time and retardation at the site would be great enough to effectively institute ground water interdiction, but long travel times are entirely possible also. If such were the case, it would be highly likely that a large fraction of the contamination would be stopped before reaching the Hudson River.

3. Most of the exposure from the liquid pathway contamination of the Hudson River could be prevented by denial of use of the river; and

4. The dose rates to individuals calculated for exposure to contaminated sediments and beaches would be of the same order of magnitude as

direct land exposure dose rates for much more probable and widespread airborne release cases.

Exhibit 1 shows the ground surface dose exposure rates one meter above an infinite smooth plain, calculated using the CRAC model (Ref. 14) for Release Category C (RC-C) one year following the accident as a function of downwind distance from the site. This case alone is shown because it dominates the overall calculated risk for airborne releases. Two curves are shown. The lower curve is the dose rate from the mean ground deposition of the 91 trials (see Dr. Archarya's testimony Section III.C for a description of the sampling procedure used in the "CRAC" analysis). The higher curve is the dose rate calculated for the highest deposition rates from the 91 CRAC trials. The comparison of the Verplanck Beach and New York Harbor sediment dose rates calculated for the worst case liquid pathway release are seen to be less than or comparable to airborne ground contamination dose rates alone over great distances from the site. The RC-C event also has a higher probability than the groundwater liquid pathway sump water release case (2.96×10^{-4} per year for Unit 2 and 1.52×10^{-4} per year for Unit 3). It should also be recognized that ground exposure was just one of several pathways evaluated for airborne releases. Since the probability of the sump water release coupled with short groundwater travel time would be very small, I conclude that the risks associated with liquid pathway releases would be encompassed by risks already calculated for airborne release scenarios.

Q21 Is the liquid pathway risk resulting from releases to the ground, therefore, unimportant?

A21 If a basement penetration were to occur, the liquid pathway from ground water releases would likely be economically important because of the costs involved with mitigation, monitoring, and the potential denial of uses of the contaminated waters. In addition, the airborne releases associated with basemat penetration scenarios (Release Category H, Dr. Acharya's Testimony Section III-C), would be relatively small compared to airborne releases in other categories, especially for the cases where much of the radioactivity would be tied up in the sump water. Therefore, the liquid pathway could be an important component of the basemat penetration scenario (Release Category H) risk, especially economic. The total basemat penetration risk, however, is very small compared to other airborne release risks, so it is not likely that groundwater liquid pathway risks would significantly contribute to the overall health or economic risk.

Q22 What is the relative importance of airborne contamination of the liquid pathway to that of contamination resulting from release to the ground?

A22 In my judgment, the airborne contamination of the liquid pathway appears to be more important for a number of reasons:

1. As discussed above the probability of a large sump water release to the ground coupled with a groundwater travel time too short to allow interception of the source, would be extremely small.

2. Once airborne radionuclides are released, they cannot be effectively interdicted until they have fallen on land or water.

3. While ground-water releases would affect only the Hudson River, with little chance of contaminating drinking water supplies, airborne releases might affect surface fresh water resources over a wide area, especially drinking water sources for the heavily populated northeastern states including New York City (although the levels of contamination would be low). Airborne releases might also affect ground-water resources, but to much lower levels of contamination than surface water.

Q23 What quantity of radionuclides could be potentially released to the Hudson River as a result atmospheric fallout from Indian Point accidents, and how does it compare to the ground-water release case previously described?

A23 A useful comparison between the ground-water and atmospheric contamination of surface water is to estimate the maximum quantities of radionuclides entering the Hudson River for each case. For the sake of this comparison, I have made the following assumptions:

1. That for the ground-water releases, the magnitude of the radioactive source terms and the physical parameters for transport through the ground are those stated by the licensees in Section 6.7 of the IPPSS. No credit is taken for source mitigation; and

2. That the Release Category C, as defined in the testimony of J. Meyer, Section III.B, airborne release applies and that winds are blowing in the direction that maximizes fallout in the Hudson River basin.

The licensees' analysis of significant* radionuclides entering the river from the sump-water releases, assuming expected conditions of ground-water transport characteristics and no interdiction, was about 2.4 x 10^6 curies of Ru-106, 25,000 curies of Sr-90, and 730 curies of Cs-137. For the more probable basemat penetration without sump-water release, the licensees estimated that only 1250 curies of Ru-106 and 480 curies of Sr-90 would escape to the river. I conclude that there is a high probability that the quantity of radionuclides reaching the Hudson River through ground-water could be greatly reduced or virtually eliminated with mitigative measures applied before the contaminated ground water reached the river, as previously discussed.

Radionuclides in atmospheric releases would be deposited on the land and open water surrounding the plant. Impacts would depend largely on the wind direction, atmospheric stability and precipitation at the time of release and in the following hours and days. Analysis of fallout using the models of the CRAC code indicates that if the winds were blowing in the north or northwest direction, roughly 65% of the non-noble-gas radionuclides released to the environment would be deposited in the Hudson River basin (i.e., all land and water surface area from which the Hudson River derives its fresh water inflow). From data on atmospheric weapons fallout and concentrations in surface waters (Ref. 19, Ref. 20), I have estimated that roughly 14% of the Sr-90, 1.1% of the Cs-137, and 0.072% of

over
what
period?

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*A spectrum of radionuclides was considered but the ones reported here are by far the largest contributors to dose.

23%

the Cs-134 deposited in the drainage basin would eventually enter the waters of the Hudson River from runoff, direct fallout on surface water bodies, and infiltration into ground water. Therefore, for a large atmospheric release sequence (Release Category C), I estimate that 18,000 curies of Sr-90, 1,100 curies of Cs-134, and 10,000 curies of Cs-137 would enter the Hudson River for the up-river wind direction. I have also made an order of magnitude estimate of 10^5 curies of Ru-106 entering the Hudson River by this pathway, although I have no firm data on which to base a transfer coefficient.

For the cases stated, uninterdicted liquid pathway doses to users of the Hudson River from airborne contamination would be potentially greater than those for the ground-water contamination route because of the relatively greater quantities of high dose rate cesium isotopes. In addition, drinking water intakes upstream from the plant on the Hudson River would only be seriously affected by airborne releases, not by the ground-water releases.

Q24 What are the potential effects of airborne releases to bodies of water other than the Hudson River?

A24 Airborne releases could contaminate the reservoirs and their watersheds which service the heavily populated areas of the northeast. Analysis with the CRAC code shows that, following an accidental release and if the wind were blowing in the proper direction, greater than half of the cesium and strontium released could be deposited onto the watershed of the Hudson River and the upper Delaware River, which contain the reservoirs serving the New York City area with drinking water. Radionuclides could accumulate in fresh-water fish of these reservoirs and potentially contribute to individual and population doses.

Q25 What would the potential consequences be if the wind were not blowing in the direction of these reservoirs?

A25 Winds blowing in a more westerly direction would carry the plume toward other major drainages such as the Delaware River and Susquehanna River basins, which service the water supplies for several large cities. A wind blowing to the northeast or east could affect the water supplies of the Housatonic and Connecticut Rivers and other rivers in New England. A wind to the southeast could potentially affect the ground-water resources of Long Island as a result of the infiltration of deposited radionuclides. I expect, however, that groundwater would not be as seriously affected by atmospheric fallout as would surface water, because many of the radionuclides would be effectively trapped by the soil overlying the aquifer. It should be recognized that the wind direction for maximum consequences through the liquid pathway does not necessarily correspond to the direction for maximum consequences for the (traditional) airborne pathway, so it would be incorrect to simply add the risks for both pathways.

Q26 What, therefore, is the liquid pathway risk associated with the airborne releases from the plants?

A26 I have performed calculations to quantify the risk associated with an accidental contamination of the New York City water supply system from an airborne release of radionuclides at Indian Point. I have restricted my detailed analyses to this system primarily because good quality data were available, and the system represents the most heavily used and vulnerable water supply in the region which could be affected by an airborne release at Indian Point. Later, in Q/A39, I extrapolate the New York system consequences to include other supplies as well.

Q27 Can you describe the New York City water supply system in relation to the Indian Point site?

A27 Yes. New York City and several surrounding communities to the north and northwest are supplied with drinking water by a complicated system of reservoirs and aqueducts, as shown in Exhibits 2 and 3, supplemented with minor amounts of ground water (Ref 21). There is also a rarely used intake on the Hudson River at Chelsea, which is about 20 miles upstream of Indian Point. There are three main aqueducts bringing water to New York City from areas over 100 miles from downtown Manhattan. The Croton system consists of coupled reservoirs in the watershed to the east of Indian Point. It supplies an average of 122 million gallons per day to New York City. Although the Croton system is the smallest of the three major aqueduct systems, it is also the closest to the Indian Point plants, and is therefore more vulnerable to atmospheric contamination.

The Catskill system consists of Schoharie and Ashokan reservoirs to the north-northwest of the site. Water from this system is conveyed to New York City via the Catskill aqueduct, which supplies an average of 424 million gallons per day.

The Delaware system consists of Cannonville, Neversink, Pepacton, and Rondout reservoirs, to the northwest of the site. An average of 824 million gallons per day are conveyed to New York City via the Delaware aqueduct. The Delaware system is the largest, but is also the farthest from the site.

Much smaller amounts of water are supplied to public and private systems of the metropolitan area by wells in Richmond, Queens, and Long Island. The Chelsea intake on the Hudson River is capable of supplying 100 million gallons per day to the Delaware aqueduct, but is presently not in use. There is also a minor amount of surface water supplied from the Bronx River watershed.

Q28 What happens to the water once it reaches New York City?

A28 Once the aqueducts reach New York City, water is distributed by means of a complicated, interconnected system of holding reservoirs and underground tunnels, shown in Exhibit 3.

Q29 Describe the methods by which you predicted the level of contamination of the New York City water supply as a result of accidental airborne releases.

A29 I first developed an empirical model relating the concentrations of Sr-90 and Cs-137 in New York City water to the quantity of radionuclides deposited on the land surface. I used published data on radioactive fallout deposition and tap water concentrations in New York City (Ref. 22) to adjust the parameters of this model. Comparison of New York City fallout data with that of other fallout data from stations in the eastern

United States indicates that the New York City station data would be fairly representative of the fallout in the watersheds for the reservoirs in question. The predicted and measured annual average concentrations of Sr-90 in New York City tap water are shown in Exhibit 4. It should be noted that the model implicitly includes any removal of Sr-90 by water treatment or man-made or natural processes between the reservoirs and the users' water taps.

Q30 Why is your analysis restricted to Sr-90?

A30 A screening analysis which considered the potential quantities of each radionuclide released to the atmosphere in large accidents, its halflife, dose factor and the relative ease at which it moved from the land surface to water led me to the conclusion that for drinking water, Sr-90 alone would be responsible for about 80 to 90 percent of the long-term whole body dose. Neglecting all other radionuclides but Sr-90 would lead to only a small error in the drinking water dose estimates. In light of the large uncertainty in other portions of the dose assessment, the assumption that all drinking water dose is caused by Sr-90 alone is justified.

Q31 Please continue with your description of the analytic techniques.

A31 The CRAC code used for the analysis of risk for the traditional airborne pathway, as described in the testimony of Dr. Acharya, Section III.C, was slightly modified to store on magnetic tape intermediate values of ground depositions of Sr-90 versus distance for each of the 91 assumed starting times for the release category C case.

Q32 Why did you consider only Release Category C?

A32 This accident dominated the risk for the airborne pathway analysis, and I suspected that the same would be true for the pathway due to airborne contamination of drinking water. Combining the probabilities of the 9 release events considered by Dr. Acharya in his testimony with the quantities of radionuclides released and their dose factors leads me to the conclusion that the RC-C event alone would account for about 98 percent of the airborne/liquid pathway risk. Therefore, the other cases can be neglected in terms of risk.

Q33 Please continue your discussion.

A33 The intermediate stored data from the RC-C event were then used in a computer program which factored watershed dimensions, distance, and the wind direction probability (wind rose) to predict the cumulative frequency distribution (CDF) of Sr-90 deposition on the watersheds for the Croton, Catskill, and Delaware systems, either separately or combined. The Sr-90 deposition was then used to calculate the cumulative frequency distribution for New York City tap water concentrations using the empirical concentration model, from which dose estimates could be made.

Q34 What were the results of your calculations?

A34 I will first show the predicted tap water concentrations for each of the three systems, Croton, Catskill, and Delaware, since each system can be considered as a separate unit.

Exhibits 5, 6, and 7 show the predicted tap water Sr-90 concentrations for the Croton, Catskill, and Delaware systems respectively. Two curves are plotted on each graph showing the cumulative probability that the concentration would not be exceeded. For each system, the higher curve is the annual average concentration for the first year following the accident. The lower curve is the tap water concentration five years after the accident, which is shown to give perspective to the degree of persistance of the contamination problem. Also shown on the figures is the 300 picocuries per liter Maximum Permissible Concentration (MPC) for Sr-90 (10 CFR 20, Appendix B) for unrestricted areas, which could conceivably be used as a benchmark or standard of acceptability for drinking water (even though MPC pertains to normal rather than accidental releases). Each concentration considers that no steps have been taken to reduce the concentration by such measures as further water treatment or dilution. Using the Croton system for an example, Exhibit 5 shows that following the RC-C accidental release, there will be about an 11 percent probability that MPC would be exceeded for the first year average concentration, and a 5 percent chance that the concentration would still exceed MPC after 5 years. The probabilities of exceeding MPC for the Catskill and Delaware systems are less because of their greater distances from the reactors.

Q35 What would concentrations be for periods less than a year following the accident? Why is only the annual average concentration shown for the first year?

A35 The empirical tapwater concentration model was derived from slowly varying data taken over long periods of time, and cannot be used to reliably calculate concentrations for times shorter than one year following the accident. For the case of an instantaneous deposition, the model would predict an infinite concentration. This, of course, would not really be the case because of long holdups of at least several months on the land, in the reservoirs, and in the distribution system. Furthermore, since the doses from ingestion of radionuclides in tapwater would be well below threshold at which acute health effects or fatalities might be observed, (as defined in the testimony of Dr. Acharya, Sect. III C) concentrations can be used on an annual average basis for the purposes of calculating chronic dose commitments to individuals and populations.

Q36 Have you restricted your analysis only to drinking water?

A36 I have concluded on the basis of an approximate analysis that drinking water contamination would give an overwhelmingly larger population dose than other liquid pathways which could be contaminated by airborne releases from Indian Point. My analysis was based on recreational fish catch statistics for most of eastern New York State (Ref 23), and assumed that these fish would be exposed to Sr-90 and Cs-137 concentrations which I have calculated for the New York City water system. Only freshwater fish were considered, because bioaccumulation for freshwater fish is markedly higher than for saltwater fish, and the highest water concentrations would be expected in inland fresh waters. Neglecting saltwater fish and shellfish is not expected to alter my conclusion. I further conclude that the fisheries estimate is conservative for a least one reason: our experience with the TMI accident shows that recreational fishing diminishes dramatically for the period of concern (Ref 24). Even if we have substantially overestimated the fish catch, the population dose attributable to fish ingestion would be relatively small, probably less than one percent of that from drinking water.

Q37 Please continue with your presentation.

A37 Since the water supply for New York City is derived from all three watersheds, considering combinations of the systems is also important. The contamination probabilities of the three systems is highly correlated because an event affecting one watershed is likely to affect another also. It would be incorrect to simply add the probabilities for each watershed. Therefore, two more runs were performed. The first considered the Catskill and Delaware systems as one watershed, weighted by their relative contribution to the New York City supply. The second run considered the Delaware, Catskill, and Croton systems as one watershed, each weighted by its relative contribution.

The significance of the combined Delaware-Catskill run is twofold. First, the outflows of both the Delaware and Catskill aqueducts physically mix in Kensico Reservoir near White Plains NY, and it is unlikely that either of the aqueducts could be isolated without serious difficulties in supplying New York City. Secondly, the combined flow from the system accounts for about 91 percent of the total New York City use. Exhibit 8 shows that there is about a 1.1 percent chance of exceeding MPC for the first year for Sr-90 in the combined Catskill-Delaware system.

The combined Delaware, Catskill, Croton run shown in Exhibit 9 gives the weighted average tap water concentration for the entire system. Since the Croton aqueduct water is not physically mixed with water from the other two aqueducts before being distributed, concentrations in the parts of the city served by different aqueducts would not necessarily be the same. The average concentrations calculated from this run, however, can be used to calculate population doses, but not necessarily individual doses or the probabilities of exceeding MPC.

Q38 What are the predicted consequences of the calculated concentrations in the New York City Water Supply?

A38 Concentrations of Sr-90 in drinking water would be well below the levels necessary to cause prompt health effects or fatalities. For example, if no restrictions on drinking water were put into effect, and water with the highest calculated concentration for the Croton system were ingested for one year, the maximum individual dose commitment to an adult would be roughly 20 rems for bone and 5 rems for total body, using the ingestion dose factors of Regulatory Guide 1.109 (Ref. 25). The very large population served, however, would allow the accumulation of a large population dose, even at relatively low concentration levels.

Doses were calculated for an assumed population of 11 million people in New York City and other users served, ingesting water for the first year following the accident, and also for ingesting water for an infinite period following the accident. Population breakdowns, dose factors and ingestion rates are those suggested in USNRC Regulatory Guide 1.109 (Ref. 25). Exhibits 10 and 11 show the population doses (bone and whole body) versus cumulative probability following the RC-C accident scenario, which would be accumulated for a one year ingestion period following the accident. These doses use the concentrations calculated for the combined Delaware-Catskill-Croton system. The probability-weighted doses for this case, given the RC-C release occurs, can be calculated by integrating under the curves of exhibits 10 and 11. The first year doses are 2.5×10^6 person-rems for bone and 6.3×10^5 person-rems whole body.

For the infinite ingestion period, the doses are 9.0×10^6 person-rems for bone and 2.2×10^6 person-rems whole body.

It is worth noting that about 53 percent of the dose is contributed by the Croton system, although this supply accounts for only about 9 percent of the water used in the total system.

Q39 What is your estimate of the total risk to all public water users outside of those serviced by the New York City supply?

A39 I have not explored in any detail the public water supplies other than New York City, but I have estimated the total risk in person-rems per reactor year to all drinking water users following the RC-C airborne release. I based my estimate on the following factors and assumptions:

1. Because of the proximity of the New York City reservoirs to the Indian Point site, there is not likely to be any surface water supply which could be more highly contaminated from an accident at Indian Point. Including all other surface supplies would, however, raise the probability of water contamination.

2. Population and average radionuclide deposition rates were available to a 500-mile radius from the site. It was assumed that the deposition rate onto land applied to the sources of drinking water of the population at the same radius, and that transfer factors used in

calculating the New York City tap water concentrations would be the same. This assumption neglects the fact that a significant portion of water is supplied from underground sources that would be less affected by an airborne release from the plant.

I estimated that the total risk within a radius of 500 miles of the facility, in terms of uninterdicted population dose from all affected public drinking water would be a factor of 2 to 3 higher than that of New York City alone.

The probabilities of Release Category C without engineering fixes have been defined in the Testimony of J. Meyer, Section III.B to be 2.96 x 10^{-4}/year for Unit 2 and 1.52 x 10^{-4}/year for Unit 3. Using the average population doses for an infinite ingestion period presented above, I calculate that the risks to the total affected population would be about 1630 person-rems/reactor year whole body uninterdicted dose for Unit 2. The total whole body population dose risk for Unit 3 would be about 836 person-rems/reactor year.

Q40 What options are available to alleviate contamination of the public water supplies?

A40 Some actions to lower radionuclide concentrations would be possible. According to the New York City Department of Environmental Protection (DEP, Ref. 21), the Catskill and Delaware watersheds each have a central reservoir (Catskill system - Ashokan Reservoir and Delaware system - Rondout Reservoir). There are no provisions to bypass these central reservoirs, but the feeding reservoirs could be individually isolated.

The Croton system has several routing options for the individual reservoirs. The Croton aqueduct can also be bypassed and water conveyed to New York City via the Delaware Aqueduct.

In the event of contamination of one of the holding reservoirs in New York City, there are bypasses which enable water to be routed around the reservoir.

There is a limited amount of water treatment which could remove radionuclides from the water. Coagulation mixing chambers exist on the Catskill and Delaware Aqueducts prior to entering Kensico Reservoir. Of course, radionuclides removed by coagulation might present a hazard in the form of contaminated chemicals. These chemicals could serve as a long-term chronic source of radioactivity which might slowly be released back to the water if they were not removed from the system.

Construction of treatment facilities for a water system as large as that for New York City (1.4 billion gallons per day) would be a huge undertaking. There is a study underway for a filtration plant for water coming from the Croton System. (Ref.21) The plant would use a diatomaceous earth medium which would have the capability of removing a portion of the radionuclides from the water. The plant would be designed to recycle the diatomaceous earth, however, which might make the process prohibitively expensive for removal of radionuclides, since the medium would have to be discarded once radioactively contaminated.

Q41 Could water from one aqueduct be substituted for water from a contaminated system?

A41 ccording to the DEP, the Catskill and Delaware Aqueducts convey water to Kensico Reservoir where they would normally mix. It is possible that one of the aqueducts could be removed from service, but not without severely restricting water use in the city. Water from the Croton system can be diverted to the Delaware aqueduct, but could supply only a small fraction of normal demand in the absence of the Delaware and Catskill systems. A single accident could contaminate both the Catskill and Delaware systems, but it is less likely that a single accident would contaminate both the Croton system and the combined Catskill-Delaware systems. The Croton and Delaware-Catskill systems are in virtually opposite directions from the Indian Point site, and contamination would most likely be carried by the wind in only one direction following an accident.

Q42 How much uncertainty is there in your analyses of water contamination via the airborne/liquid pathway?

A42 Most of the uncertainty in the CRAC analysis, discussed by Dr. Acharya in his testimony, Section III.C, also applies to the airborne/liquid pathway analyses. Aside from the uncertainties expressed by Dr. Acharya, the following aspects of the CRAC code would be especially important in the airborne/liquid pathway risk analyses:

1. The deposition rate model in CRAC is very crude since it accounts for only two rates, wet and dry deposition, and has no dependence on the rate of rainfall.

2. Wind direction is considered to be independent of other atmospheric phenomena such as stability and rainfall, when actually these variables are likely to be correlated. This might lead to a preferred direction for wet deposition fallout which would not be correctly predicted by CRAC.

3. CRAC uses only the meteorology at the Indian Point site, and at only one elevation, even for transport calculations at great distances from the site. The 10-meter wind direction data used in the staff's atmospheric dispersion analyses clearly show the effects of the steep Hudson River valley, with the highest probability for winds upstream and downstream along the Hudson River. These wind directions "steer" the atmospheric plumes away from watersheds of the New York City water system. If wind direction data from the 122-meter level were used, the liquid/airborne pathway risk would increase by about 20 percent. Winds at that altitude are less influenced by the Hudson River valley than the low altitude winds, and therefore, might be more representative of the dispersion direction for large distances.

Q43 What do you conclude about the risk associated with the liquid pathway?

A43 On the basis of my review and calculations, I am able to draw some tentative conclusions:

1. In the unlikely event of a large accidental release of radioactivity, liquid pathway doses would almost certainly be accumulated by individuals and populations at levels well below the threshold necessary for early fatalities or radiation illness. Population doses would probably be accumulated at very low levels, below protective action

guidelines, but because of the large populations involved, could be on the order of millions of person-rems.

2. Unlike the direct exposure to the atmospheric plume (e.g., inhalation dose), contaminated water or seafood can be interdicted at any level necessary to limit dose. Normal water supplies could be impacted. However, in view of the history in New York City and elsewhere associated with emergency water management and conservative practices, there is little doubt that sufficient quantities of potable water could be supplied at safe concentrations. Some of the water supply options available might include alternative sources (e.g., tank trucks), conservation of uncontaminated supplies, and additional treatment of contaminated water.

3. Liquid pathway contamination caused by the atmospheric release of radionuclides is potentially more serious than liquid pathway contamination from radionuclides released to the ground in a basemat melt-through accident. There is a high probability that contaminated ground water from basemat penetration could be isolated before reaching the Hudson River, but atmospheric release to the environment probably could not. Furthermore, even for potentially large groundwater pathway releases from the site, interdiction to prevent exposure to the public would be confined to the Hudson River. Low-level contamination of water supplies by an atmospheric release, however, would be more widespread and difficult to interdict.

4. Population doses and risks associated with the contamination of the liquid pathway by the groundwater or airborne route would be a small fraction of the population doses and risks which would be accumulated from the traditional airborne pathways considered in Dr. Acharya's testimony, Section III.C. Futhermore, wind directions tending to maximize airborne/liquid pathway doses would not correspond to the directions maximizing the other airborne doses.

Q44 How would your conclusions be changed if the probabilities or the magnitudes of the ground water or atmospheric releases were increased?

A44 Since liquid pathway dose rates are well below the threshold for early health effects, I would expect that the consequences in terms of population dose would increase proportionally to the increase in the quantity of radionuclides released. An increase in the probability of a ground water release would not be expected to affect the probability that the source would be interdicted.

An increase in the quantity or probability of an airborne release would increase the risk from the (traditional) airborne pathway as well as the airborne liquid pathway risk. Therefore, the relative risk of the airborne liquid pathway to the traditional airborne pathway would remain about the same.

Q45 Does this conclude your testimony?

A45 Yes.

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25. U.S. Nuclear Regulatory Commission, "Regulatory Guide 1.109 - Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," Revision 1, Oct. 1977.

List of Exhibits

10. Population Bone Dose to Users of New York City Supply

11. Population Whole Body Dose to Users of New York City Supply

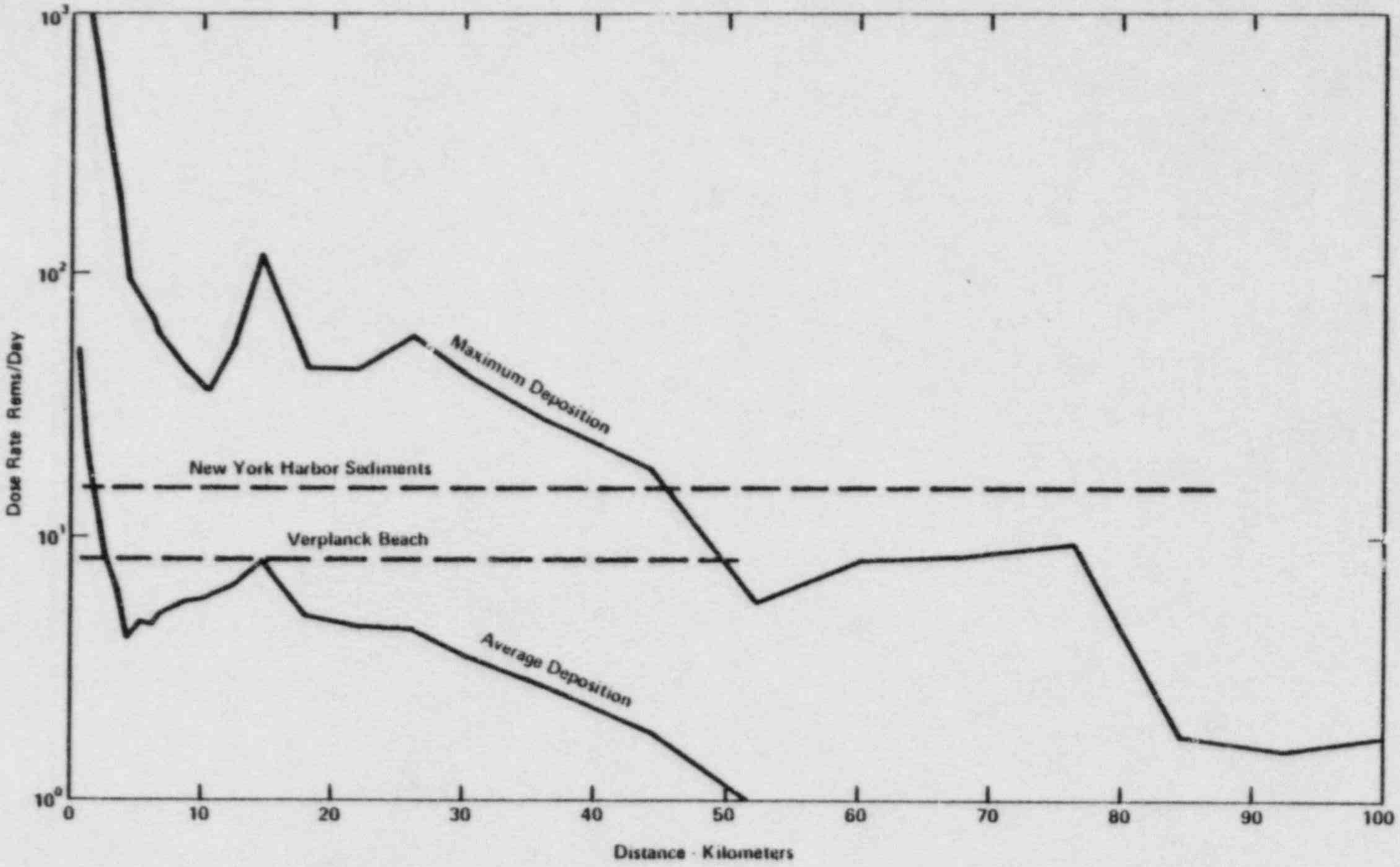

Exhibit 1 · Ground radiation dose rate downwind from Indian Point Site one year following RC-C event

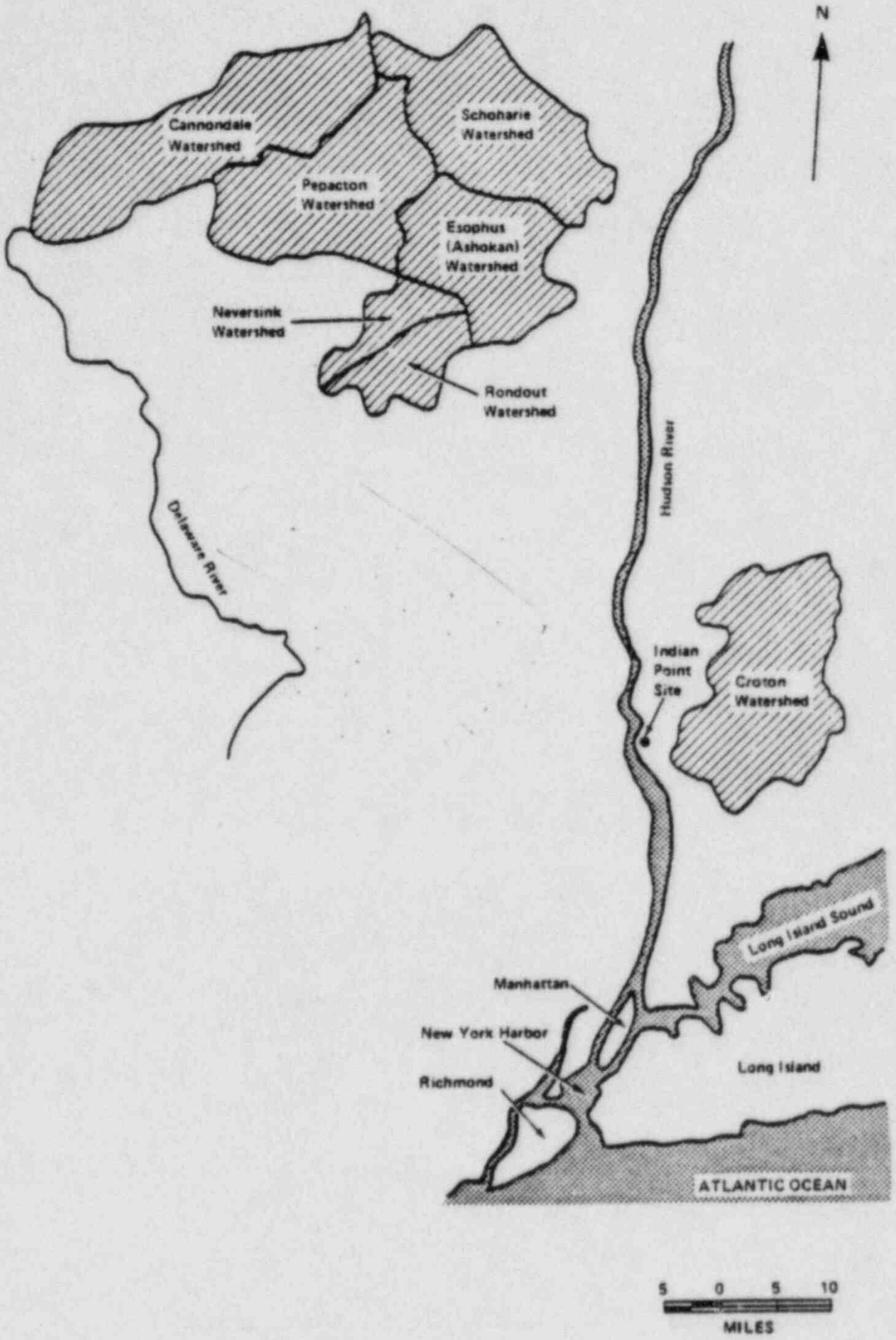

Exhibit 2 - Watersheds in New York City Municipal Supply System
(From Ref. 21)

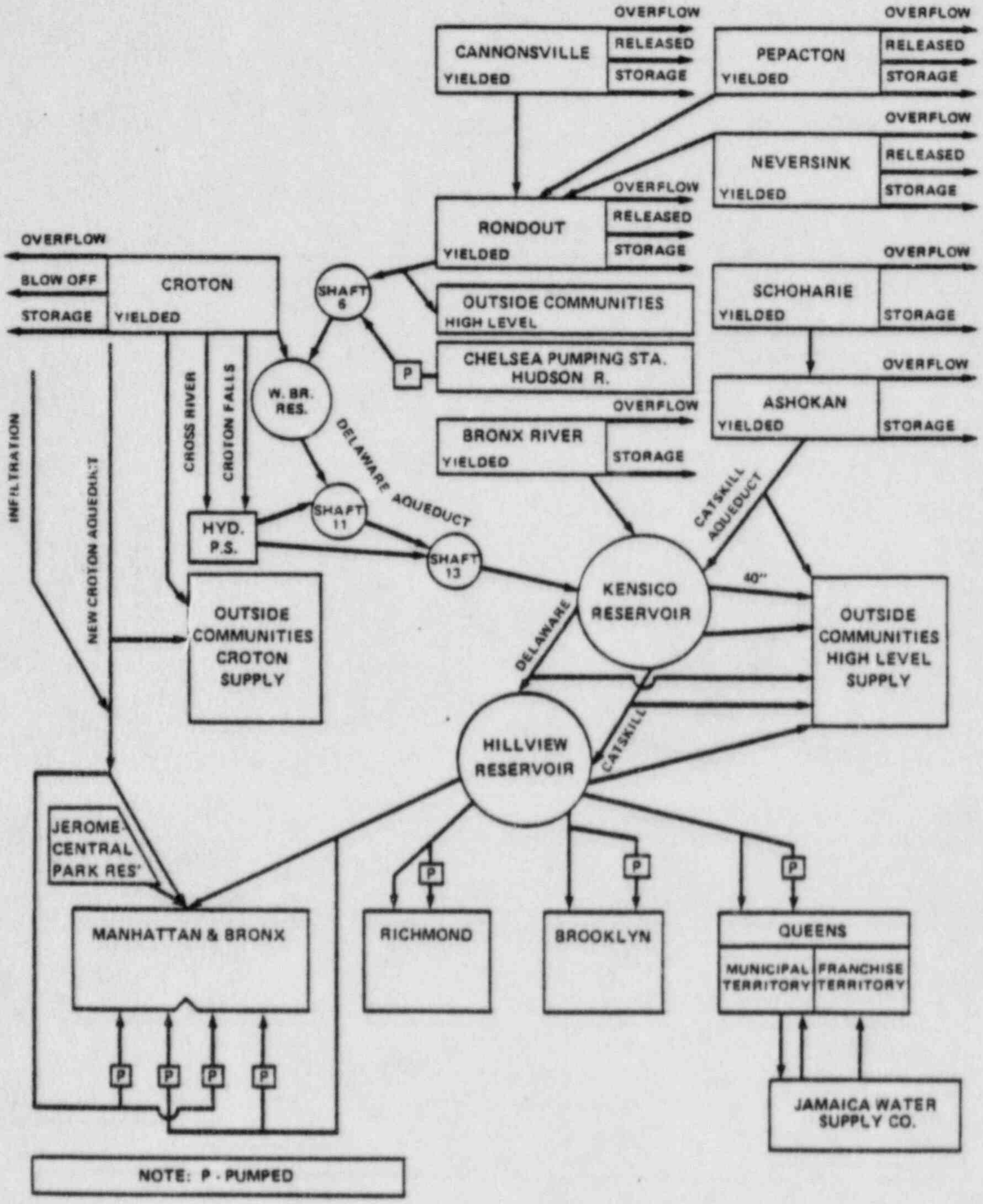

Exhibit 3 - Sources of Supply & Consumtion for New York City System
(From Ref. 21)

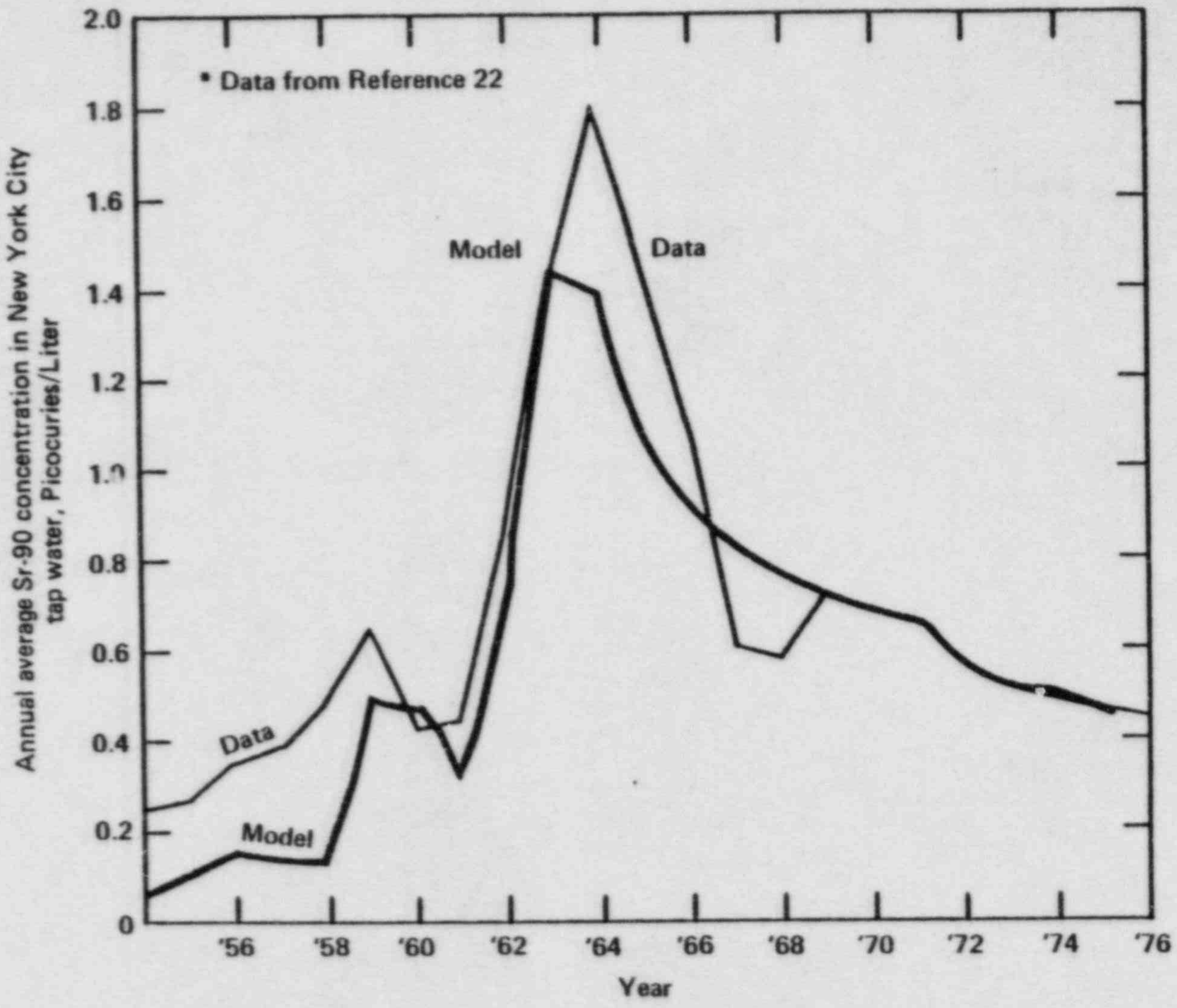

Exhibit 4 - Phenomenological model predictions of New York City tap water Sr-90 concentrations

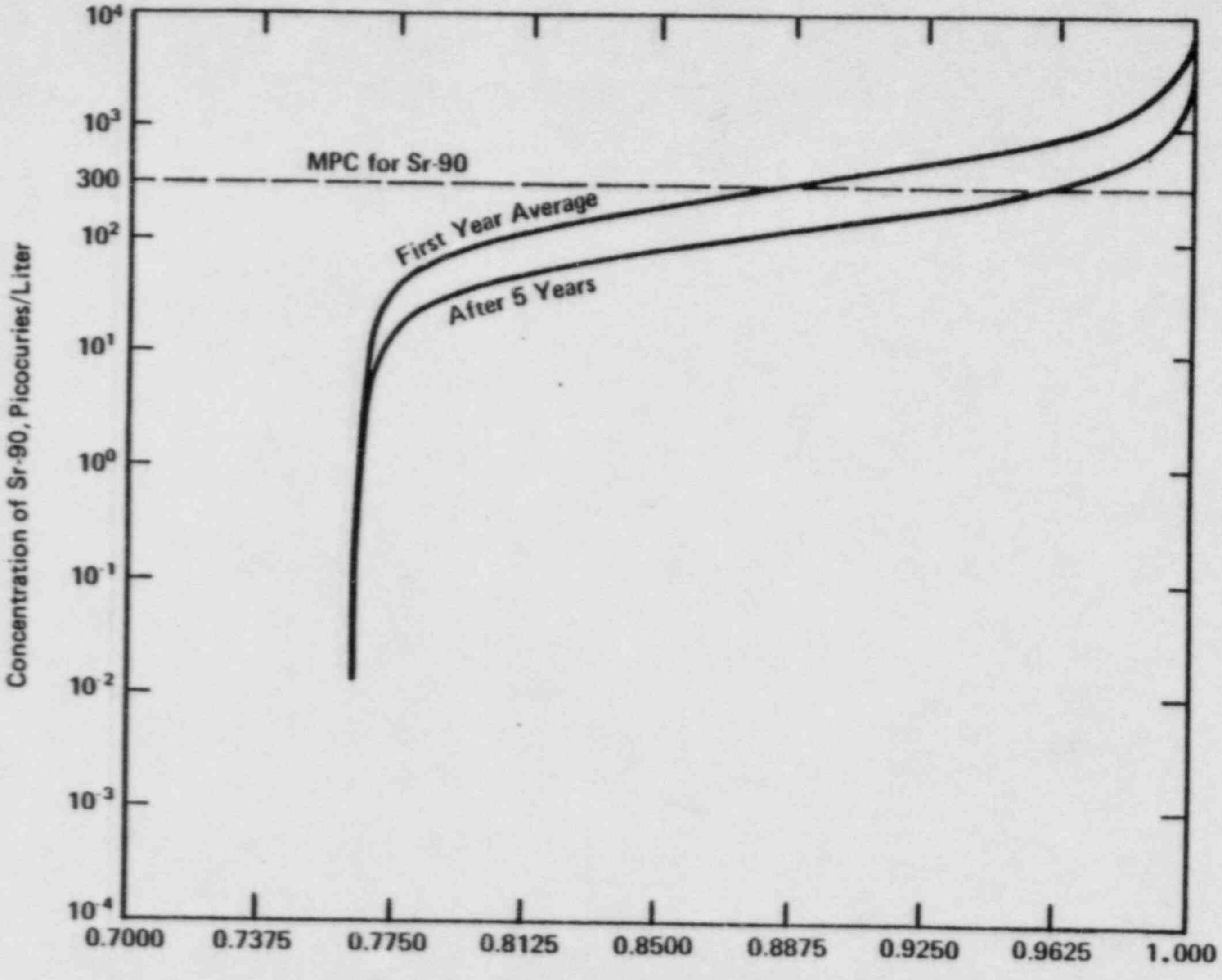

Exhibit 5 - Predicted New York City tap water concentration following the RC-C event (Croton System)

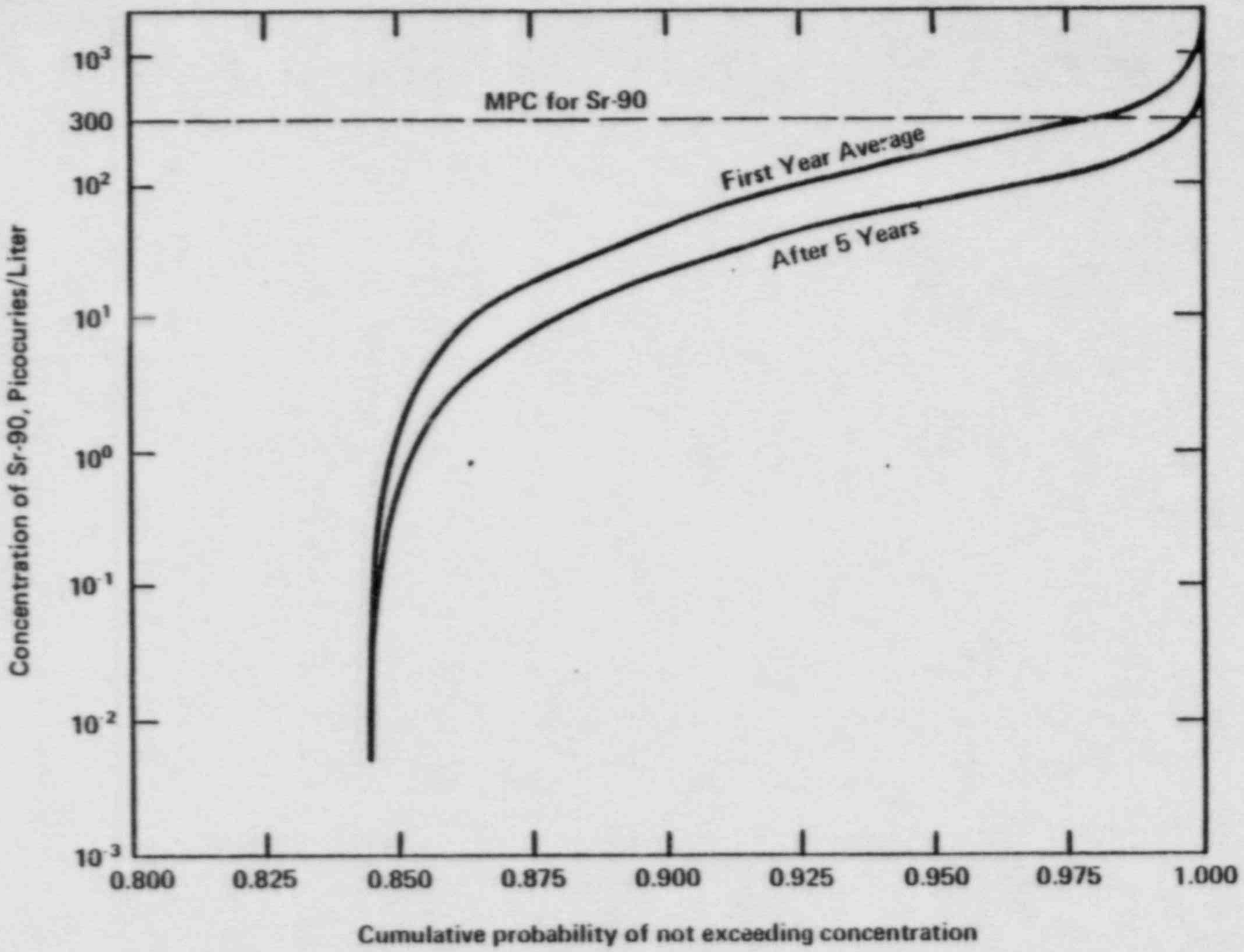

Exhibit 6 - Predicted New York City tap water concentration following the RC-C event
(Catskill System)

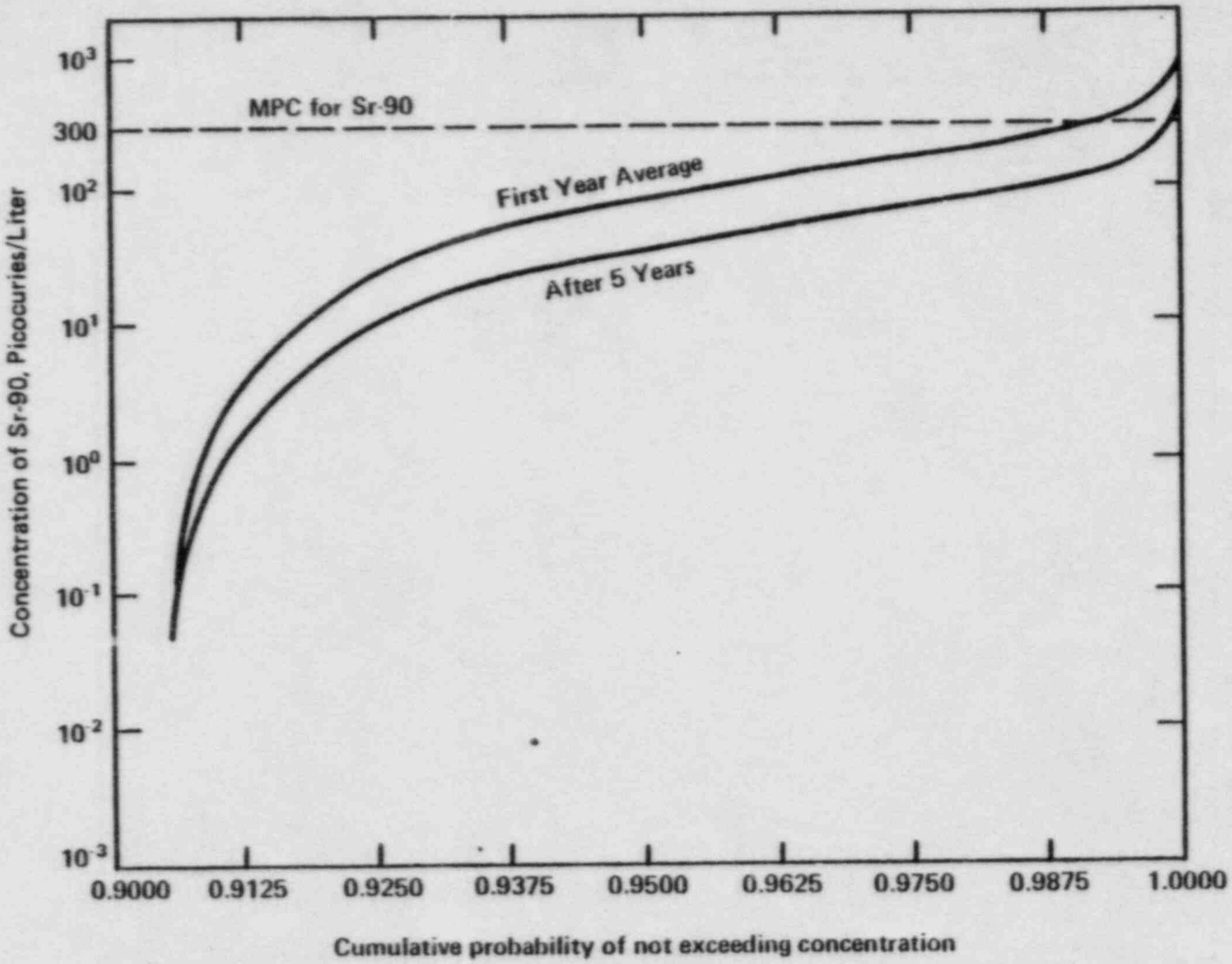

Exhibit 7 - Predicted New York City tap water concentration following the RC-C event
(Delaware System)

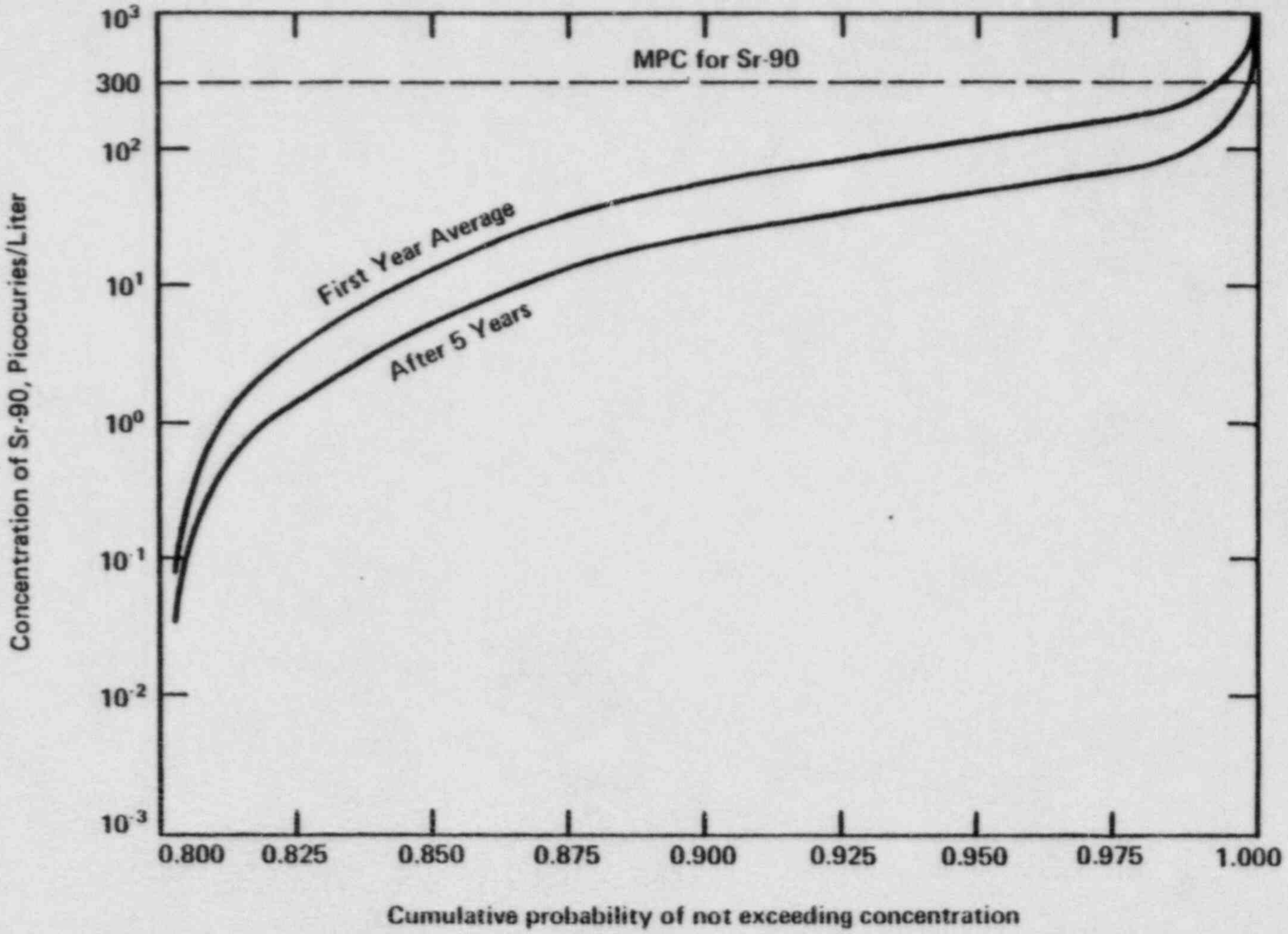

Exhibit 8 - Predicted New York City tap water concentration following the RC-C event (Combined Delaware-Catskill System)

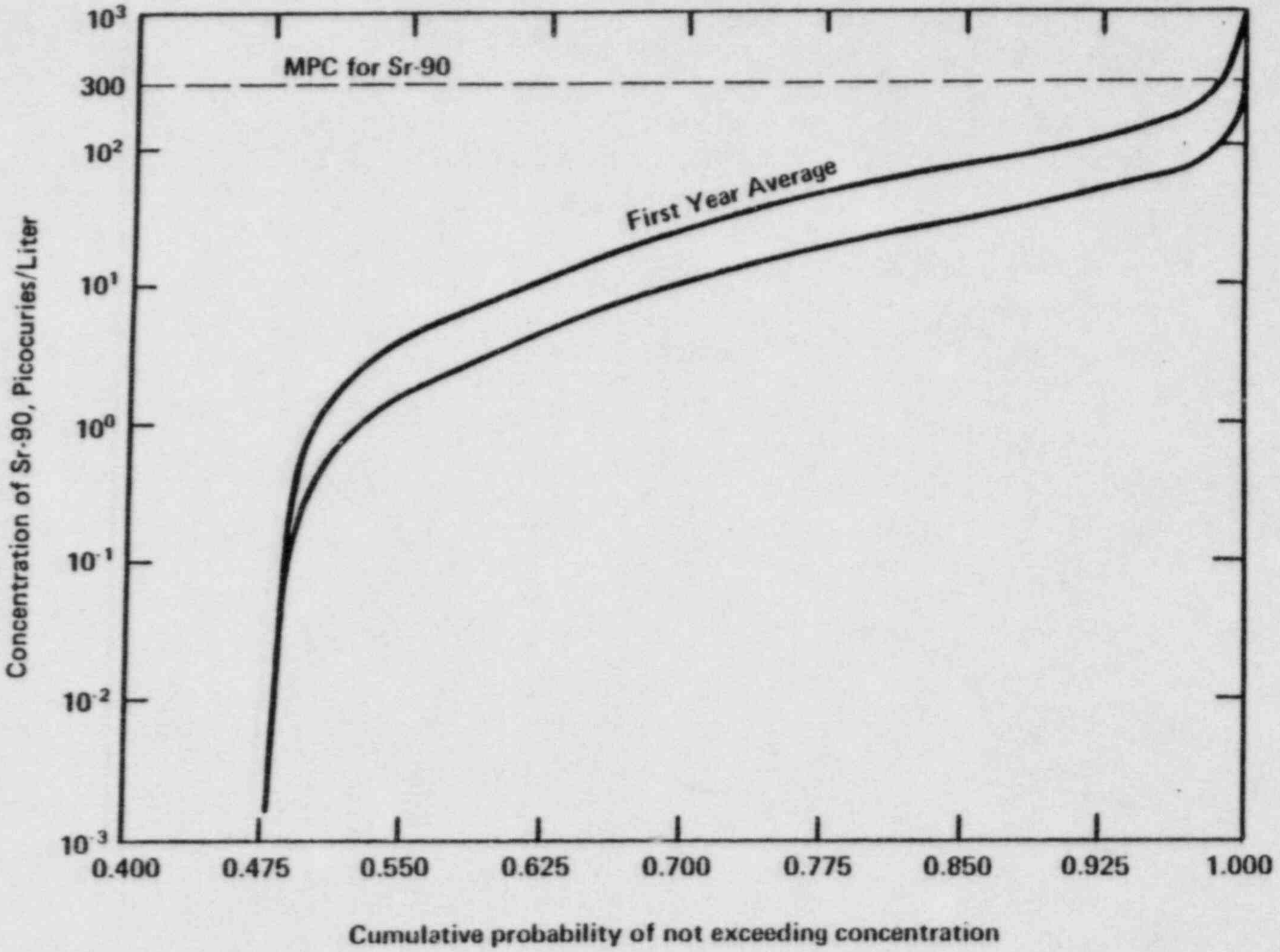

Exhibit 9 - Predicted New York City tap water concentration following the RC-C event
(Combined Delaware-Catskill-Croton System)

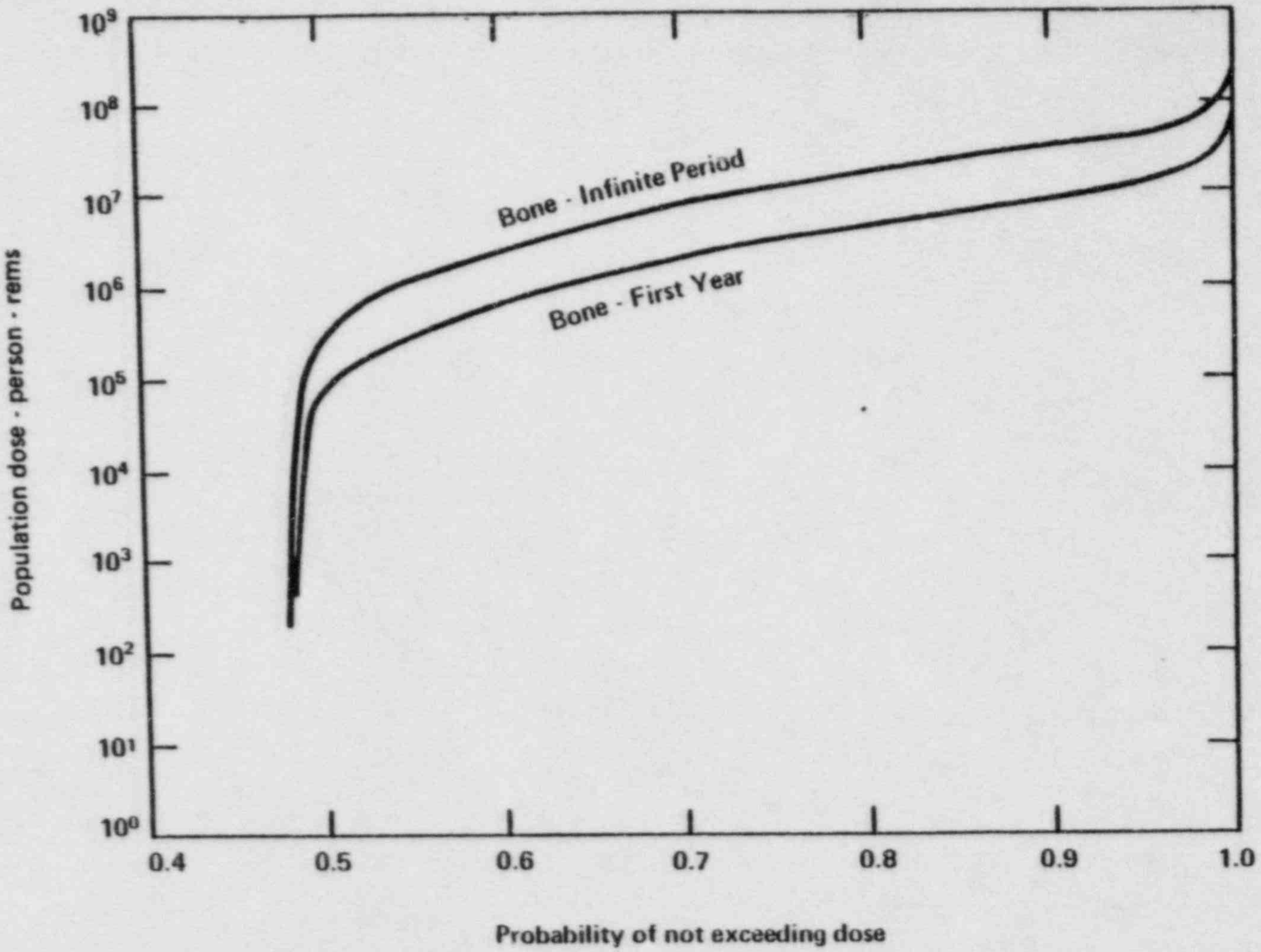

Exhibit 10 - Population bone dose to users of New York City supply

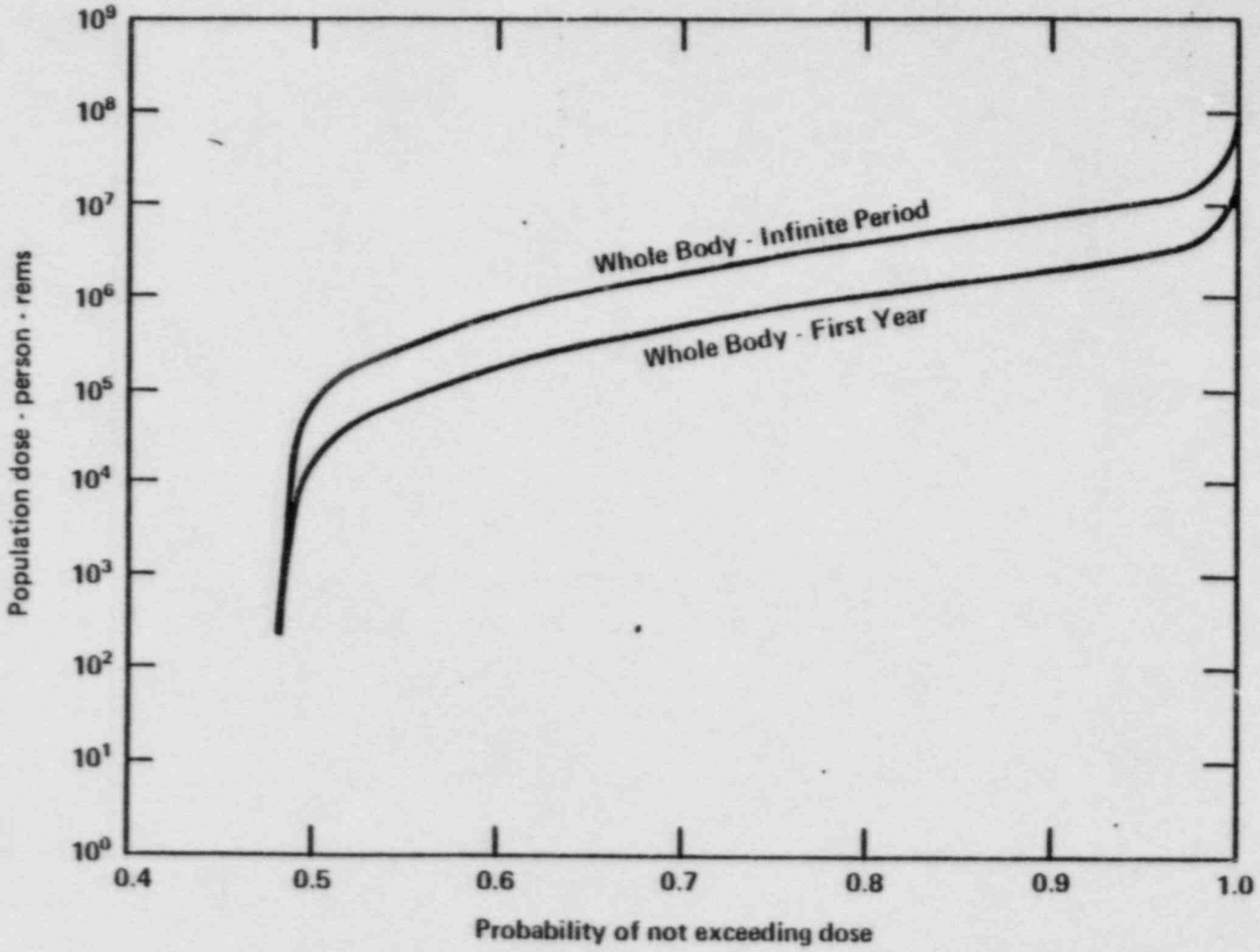

Exhibit 11 - Population whole body dose to users of New York City supply