Appendix E

COMMENTS ON STATEMENTS ON ENTRAINMENT AS PRESENTED BY THE AEC STAFF IN DRAFT DETAILED STATEMENT ON THE ENVIRONMENTAL CONSIDERATIONS RELATED TO THE PROPOSED ISSUANCE OF AN OPERATING LICENSE TO THE CONSOLIDATED EDISON COMPANY OF NEW YORK FOR THE INDIAN POINT UNIT NO. 2 NUCLEAR GENERATING PLANT

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The AEC Staff, in the Draft Detailed Statement of April 13, 1972, has addressed itself to the question of entrainment of fish eggs and larvae at Indian Point. Detailed analysis of the possible effects of such entrainment have been presented. Conclusions to these analyses appear in a number of locations. Pertinent quotations are as follows:

1. <u>In Summary and Conclusions, page ii</u>

In Unit No. 2, aquatic biota impinged on the intake structure or entrained in the cooling water will be exposed to severe mechanical, chemical (chlorine), and thermal conditions; as a consequence, up to 25% of the average number of eggs and larvae of certain species of fish that annually pass by the Plant may be killed; under the most adverse conditions, up to 100% of some of the entrained planktonic species may be killed; and fish kills of a magnitude two or three times greater than those caused by Unit No. 1 may occur.

2. <u>In the Summary of Conclusions, page iv</u>

From review and evaluation of the applicant's Environmental Report and Supplements thereto, and from independent observations and analyses discussed in this Statement, the regulatory staff has reached the following conclusions concerning the environmental impact of the Plant's operation:

a. The operations of Units Nos. 1 and 2 with the present once-through cooling system has the potential for long-term environmental impact on the aquatic biota inhabiting the Hudson River which could result in permanent damage to the fish population in the Hudson River, Long Island Sound, the adjacent New Jersey coast, and the New York Bight The potential impact is due to possible damage to aquatic biota (including fish eggs, larvae, and plankton) from entrainment in the cooling water system resulting in exposure of the biota to severe mechanical, chemical (chlorine) and thermal conditions and impingement on the intake structure.

b. The estimate of potential environmental impact identified above and discussed in this Statement is based on inconclusive and incomplete data from the applicant. Existing information is insufficient to accurately predict the degree to which the potential damage will eventually take place during operation.

3. In Chapter V, "Environmental Impacts of Indian Point Unit No. 2 with Unit No. 1 Operation", Section D-2-e, "Biological Impact of Station Operation of Unit Nos. 1 and 2, Sources of Potential Biological Damage, - Entrainment." page V-42

Large numbers of planktonic organisms will pass through the condensers during Plant operation, and, more importantly, a considerably large proportion of the biota will be withdrawn with the addition of Unit No. 2 (Fig. V-5). These organisms will include bacteria, planktonic algae, many invertebrate species, fish eggs and larvae. Table V-6 lists the fish species in the area whose eggs and larvae are known to be vulnerable to entrainment. During their passage through the Plant, these organisms will be exposed to mechanical, thermal and chemical damage. High mortality may result, especially for fragile species or during periods of chlorination. The methods used to determine the fraction of organisms entrained are presented in Appendix V-1. The monthly average probability of randomly distributed plankton moving downstream to be withdrawn varies from a low of about 6% in April to a high of 31% in August, although during drought conditions withdrawal may exceed 45%. Plankton that migrate via density flows to maintain their position in the river will be the most susceptible to entrainment, since they may remain in the area for several weeks.

4. In Chapter V, "Environmental Impact of Indian Point Unit No. 2 with Unit No. 1 Operation," Section D-3-a, "Biological Impact of Station Operation of Units No. 1 and 2, - Probable Biological Effects, - Direct Effects of Plant and Station Operation on Biota." page V-52

The striped bass is the best-studied species in the area that appears to be vulnerable to population changes and will be used to illustrate possible Station impact. Adult striped bass migrate upstream in the spring and spawn upstream from Indian Point. The eggs and larvae drift with the currents in a net downstream direction; large numbers pass the Plant. Several studies have indicated that the principal nursery area for the species is below Indian Point in Haverstraw Bay but that there are some less extensive nursery areas upstream. High entrainment mortality of larvae and eggs as they drift past Indian Point Units Nos. 1 and 2 could result in a loss of 25% or more of the larvae and eggs that pass the Plant en route to their nursery area (see Appendix V-II). Based on the sizes and numbers of the young of the year in the estuary in late July and August, it appears that 75% to 90% of the surviving portion of the total yearly reproduction is below Indian Point. If we assume: (1) that all those fish migrated past the Plant during a life stage which was susceptible to entrainment; (2) that density-independent

factors are responsible for mortality in the populations; and (3) that entrainment mortality is 100%, then the operation of Indian Point Units Nos. 1 and 2 will effectively reduce recruitment resulting from reproduction by about 19% to 22%. This is a maximum estimated loss of recruitment which would result from entrainment of 25% of the striped bass eggs and larvae that pass the Plant and would not likely be reached. However, losses of the young of the year and 1-year age classes from impingement on the intake screens will add to the actual entrainment mortality and could offset the increases in survival during entrainment, so that the total yearly recruitment loss for each subsequent year class in the population may be as high as 15% to 20% from direct effects of Plant operation. Sustained reproductive losses of this magnitude over a long period of time would result in substantial reductions of the striped bass populations that spawn in the Hudson, including those of both the Hudson itself and the area from the south New Jersey coast to Long Island Sound.

This statement is followed by a discussion of numerous factors that may partially offset the estimates given above. The section is then concluded:

These same arguments apply to other species that spawn in the area and may cause important losses of recruitment to local populations of the alewife, blueback herring, bay anchovy, tomcod, smelt, and Atlantic silversides, as well as striped bass.

5. <u>Chapter VII, "Adverse Environmental Effects which cannot be Avoided," Section A, "Factors Responsible for Adverse Effects, page VII-1</u>.

Several factors associated with the operation of Indian Point Units Nos. 1 and 2 are capable of producing adverse effects. The more important of these factors in the order of their importance include:

1. *Entrainment of large numbers of planktonic organism in the once-through system.....*

6. Chapter VII, "Adverse Environmental Effects which cannot be Avoided,"Section B-4, "Probable Adverse Effects - Biological Impact," page VII-6.

The entrainment of planktonic organisms appear to be the most serious threat to the aquatic community. Entrained organisms will be exposed to mechanical, thermal, and chemical damage. Most species of the aquatic organisms in the area will be subject to entrainment at some life stage. These include phytoplankton, planktonic crustaceans, and larval stages of benthic invertegrates and of many of the estuarine fishes which use the area for spawning. The species of fish which appear most likely to be affected include the striped bass, alewife, blueback herring, tomcod, smelt and white perch.

7. Chapter VIII, "The Relationship Between Local Short Term Usage on Man's Environment and Maintenance and Enhancement of Long Term Productivity," Section B-2, "Uses of Adverse to Productivity - Water Uses," Page VIII-4.

In consideration of the impacts and alternatives discussed in detail in Chapters IV, V, VI, VII, X and XI, the staff has concluded that the only effect of the operation possibly inimical to the objectives of NEPA with respect to productivity is the potential for further degradation of the Hudson River estuary, which is used as the spawning and nursery area in the life cycle of many marine aquatic organisms that spend much of their adult life in the coastal areas of northern New Jersey, New York and Long Island. Such degradation would, indeed, over the long-term diminish the productivity of the area to an extent that cannot be stated in precise terms at present. Only the yearly cost of replacing the estimated number of fish that might be killed has been calculated (see Chapter XI). The ultimate impact on commercial and sport fishing has not been estimated, since the decline of the Hudson River fishery is problematical at this time.

8. Chapter IX, "Irreversible and Irretrievable Commitments of Resources," Section B, "Water and Air Resources," page IX-4

The proposed action when taken has a potential of affecting the aquatic organisms essential to maintaining a fish population of the Hudson River as well as that along the Long Island Sound,

New Jersey coast and the New York Bight so that the population could deteriorate beyond the point of rehabilitation. In this event, operation of the Plant could entail an irreversible commitment of the river as a resource.

9. Chapter XI, "Alternatives to Proposed Action and Cost Benefit Analysis of Environmental Effects," Section B, "Summary of Alternatives," page XI-12.

The important areas of disagreement between the applicant's analysis and that of the staff are the following:

(2) Environmental effects from operation of the intake-discharge structure have a potential for long-term significant biological damage to aquatic bioto not only in the localized area in the vicinity of Indian Point Unit No. 2, but also in the Hudson River estuary, New Jersey coast and New York Bight. (see Chapter V.D. 3)

There are other areas of difference which are relatively minor. The staff feels that there are insufficient data available to make a reasonably accurate estimate on long-term effects on biota. Of the major differences between the staff and the applicant in the analysis and evaluation of available information, the entrainment of nonscreenable fish eggs, larval, and fingerlings and the impingement of fish on the intake structure appear to be the major impacts on the aquatic ecosystem. Although the staff does not feel that the impacts can be quantified at this time, the staff does not agree with the small impact of about 2-3% damage to eggs larval made by the applicant. Details of the staff's disagreements are given in Chapters V.D., and Appendices II-1, V-2, and XI-1.

10. Appendix V-2, "Entrainment," page A-69

Thus, the probability that a larval striped bass migrating downstream would be entrained is about 25%. Comparison of the freshwater inflows used in these calculations with inflows during the period from 1944 to 1964 indicates that these values were similar to the median conditions.

A discussion of various offsetting factors then follows: The Staff then concludes:

Consequently, the Staff believes that the total average probability of withdrawal of larval striped bass migration downstream past the Station is approximated by the 25% figure, and that this fraction is the best estimate than can be made using available information.

In conclusion, based on these considerations, about 25% of the larval striped bass may be entrained as they migrate downstream past the Indian Point site.

The Staff supposition of damage to the Hudson River fishery and to the population in the offshore waters thus appears to be primarily based on its calculation that some 25% of the planktonic forms of many of the various fishes using the estuary will be entrained and presumably destroyed.

Our approach in these comments is directed first at a critical evaluation of the procedures employed by the Staff to obtain the 25% factor, and then will address the numerous non-quantitative statements made by the Staff regarding possible offsetting mechanisms.

The critique to follow will include the following items:

1. A demonstration that the Staff calculation of available dilution flow at Indian Point, as given by Equations 1 and 2 and Figure A-II-6, in Appendix II-1, entitled "Characteristics of Hudson River Circulation at Indian Point, in Relation to Dilution," employs an inaccurate and theoretically unsupportable methodology, and in the Hudson seriously underestimates available dilution flow at Indian Point.

2. Modification of the probability model given by Equations 1 through 12, Appendix V-2. This probability model was employed by the Staff to compute entrainment loss. The modification includes the quantification of the influence of vertical diurnal movement and estuary density flow on entrainment.

   The Staff's calculation of a 25% entrainment loss is then revised, employing a theoretically and experimentally supportable means of estimating dilution flow in the Hudson River, and the modifications made on the probability model.

1. Criticism of Staff Calculations of Available Dilution Flow at Indian Point

Pages A-4 through A-7 state clearly the Staff's belief that the flow available for dilution in an estuary is given by:

$$Q_T = \frac{Q_F}{1-S/S_0} \qquad \ldots(1)$$

in which:

Q_T = total dilution flow at point in the estuary

Q_F = net freshwater discharge

S = the section average salt concentration at a given point along the estuary's longitudinal axis

S_0 = the ocean salt concentration

Equation (1) above is identical to Equation (2) (Page A-4), provided that the salinity of the freshwater is zero, and that volume is replaced by volume per unit time, or flow rate (Q). The assumption of zero salinity in the freshwater discharge is quite valid for the Hudson River. The staff replaces volume by flow in constructing Figure A-II-6.

Freshwater flow and salinity data taken from the applicant's Environmental Report Supplement are then reproduced in Figure A-II-5. These data are then employed in conjunction with Staff Equation (2) to obtain the relationship between freshwater flow and dilution flow at Indian Point in Figure A-II-6.

We submit that this procedure is generally invalid in predicting estuary dilution flows. We will show that this method of predicting estuary dilution flow defies analytical development, and has been discounted by most investigators shortly after its appearance in the literature in the early 1950s.

The Staff's reference for their Equations (1) and (2) is a paper by Ketchum, entitled "Eutrophication of Estuaries", which appeared in 1969 in the proceedings of a symposium on eutrophication.[1] Pertinent excerpts from this reference follow:

> *I will mention a few of the essential characteristics of estuarine circulation as they relate to the distribution of pollutants. I will not go into detail because this is covered by Carpenter, Pritchard and Whaley in this volume (page 210). The estuary offers advantages not offered by the river in its ability to dilute and disperse added contaminants.*
>
> *In the river itself, the volume of water available to dilute a pollutant is furnished simply by the river flow, which carries the contaminant downstream at a rate determined solely by the river flow and the geometry of the river bed. In the estuary, the circulation is more complex, although the net seaward flow is also determined by the rate of river flow. If no mixing were involved, this fresh river water would merely flow seaward as a layer on top of undiluted seawater. Mixing is involved, however, and salinity gradually increases down the estuary as river water mixes with more and more seawater. Seawater must flow into the estuary to provide the salt needed to balance the system. In a steady-state condition, the volume of seawater entering the estuary in a given unit of time equals the volume flowing out; there is no augmentation of the net seaward flow. The seawater thus entrained with the freshwater does, however, increase the diluting capacity of the mixed water that is escaping from the estuary. This effect can be evaluated by using the distribution of salt water and freshwater in the estuary.*

[1] Ketchum, B.H. "Eutrophication of Estuaries". Eutrophication: Causes, Consequences, Correctives. National Academy of Sciences, Washington, 1969. p. 197

The amount of freshwater contained in any given sample of brackish water can be calculated from the salinity, since

$$F = 1 - \frac{S}{\sigma}$$

in which F is the fraction of freshwater in the sample, S is the salinity of the sample, and σ is the salinity of the "source" seawater. If the average freshwater content of a complete cross section is known, the volume available for the dilution of the pollutant at that location can be approximated. To obtain the fraction of freshwater in a complete cross section of the estuary, it is necessary to integrate the values from top to bottom and from bank to bank. The volume available for the dilution of the pollutant in a given period is determined approximately by dividing the rate of river flow by the fraction of freshwater in the cross section. If the section is 50 percent freshwater, two volumes must move seaward to move one volume of river water seaward. Closer to the mouth of the estuary, where the amount of freshwater has been reduced to 10 percent, ten volumes must move seaward to remove the river water. A more precise determination of the diluting volume requires detailed knowledge of the circulation. But this simple calculation shows that the total volume available for dilution increases in the seaward direction.*

The underlined statements show clearly that Ketchum's estimate of dilution flow is given by Equation (1) above, or Equation (2) in Appendix A-2 of the AEC Draft Detailed Statement. Note that the last section of the excerpt suggests that Ketchum himself could be viewing this calculation as merely an indication of a trend toward increased dilution as one moves seaward in an estuary, rather than a hard and fast quantitative estimate of dilution flow.

This last statement is made recognizing that Ketchum introduced this method of computation of dilution flow in the early 1950s.[2]

Note: Underlining added for purposes of this reviewer.

*This statement, combined with Ketchum's expression for the fraction of freshwater, is precisely equivalent to Equation (1) above.

[2]Ketchum, B.H. "The Flushing of Tidal Estuaries". Sewage and Industrial Wastes, Vol. 23, No. 2, February 1951. pp. 198-209

Before presenting various comments from the literature on this computation procedure for estimating dilution flow in an estuary, a few statements on the calculation are in order.

The calculation of the fraction of freshwater flow at any point in the estuary, given by Ketchum's definition of "F", above, or by the denominator of Equation (1), above, is generally accepted as correct. This merely states that at any point in the estuary a certain percentage of the water there is of freshwater origin, and the remainder is of ocean origin. This split can be obtained by recognizing that the total volume is the sum of the volume of ocean water origin, containing salt of ocean concentration, and the volume of freshwater origin, containing no salt.

The problem arises when one attempts to show that this percentage split can be employed, along with the freshwater flow, to calculate movement or dilution flow. Ketchum, for example, in the excerpt given above, simply states;

> The volume available for the dilution of the pollutant in a given period is determined approximately be dividing the rate of river flow by the fraction of freshwater in the cross section.

After presentation of the literature comments on Ketchum's work, we shall show the problems which arise when one tries to demonstrate the validity of Ketchum's procedure analytically.

In 1953, Stommel, a coworker of Ketchum's at the Woods Hole Oceanographic Institute, presented a paper[3] in which his intent was to provide a method of estuary pollution analysis that would avoid the difficulties that had been observed in employing Ketchum's methods since its introduction in 1950. It should be noted at this point, that Ketchum's major contribution was not the computational procedure given above, but rather a modification of the "Tidal Prism" concept, a procedure that had been employed to estimate dilution flow, but which was shown by Ketchum to overestimate that flow very grossly. Ketchum merely employed the computational procedure discussed above as a means of verifying his prediction, via the modified tidal prism, of dilution flow. Stommel's introductory remarks are excerpted below:

> *Papers recently published by Ketchum (1) and Arons and Stomel (2) have presumed to give a theoretical account of the distribution of freshwater in an estuary. Pritchard (3), however, justly has pointed out that these treatments are at best applicable only to estuaries so intensely tidally mixed that they exhibit no vertical stratification. In such cases the salt is carried upstream against the main river flow by turbulence. Ketchum proposed a mixing process, which he called "exchange ratio", and was able to compute the salinity distribution in the Raritan. Using the published data (4) on the Severn estuary, the author and Harlow G. Farmer found that the method of the "exchange ratio" gave a grossly incorrect salinity distribution. Inasmuch as the Severn is unstratified, and appear to fit all the requirements of Ketchum's analysis, it is quite clear that the method of the exchange ratio is not nearly so general as was proposed.*

[3] Stommel, Henry. "Computation of Pollution in a Vertically Mixed Estuary". Contribution #640 from the Woods Hole Oceanographic Institution. Sewage and Industrial Wastes, Vol. 25, No. 9, September 1953. pp. 1065-1071.

Pritchard[4,5,6] has discussed, on a number of occasions, the various procedures employed by Ketchum. Reference 4 is a written discussion of a paper by Todd and Lau, in which Pritchard disagrees strongly with the manner in which these authors' propose that estuarine salinity profiles be employed to estimate freshwater flow. The proposed method employs an approach similar to Ketchum's. Excerpts from this discussion follow:

> *The estuary offers many interesting and important problems to the physical hydrographer, and it is encouraging to find that hydrologists are extending their work into this intermediate zone between the river and the ocean. It is unfortunate, however, that this paper by Todd and Lau exhibits a lack of understanding of the mechanisms of circulation and mixing in a tidal estuary.*
>
> *To a casual reader the concepts presented by these authors are disarmingly clear and simple. Unfortunately, they have not used the basic hydrodynamic concept of continuity in its complete form which has led them to misinterpret the equations they develop, particularly their Equ. (1). The error results from the assumption that sea water on the one hand and freshwater on the other can be considered as the two species involved in the mixing processes in an estuary, when infact, the two separate species which are involved are the salt and the water. The processes of turbulent diffusion, or 'mixing', can lead to a net upstream transport of salt without a net upstream transport of water....*

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4 Pritchard, D.W. "Discussion of 'On Estimating Stream Flow into Tidal Estuaries," by David K. Todd and Leung-Ku Lau." which appears in Transactions, American Geophysical Union, Vol. 37, 1956, pp. 468-473. Pritchard's discussion appeared in Vol. 38, No. 4, August 1957. pp. 581-584.

5 Pritchard, D.W. "The Equation of Mass Continuity and Salt Continuity in Estuaries". Journal of Marine Research, Vol. 17, 1958. pp. 412-423

6 Pritchard, D.W.. "Estuarine Hydrography". Recent Advances in Geophysics, Vol. 1, 1952.

...The error results from an incomplete use of continuity concepts which presents a continuity argument for fresh water only. Actually there are two species to which the continuity concepts apply in the estuary: the water (actually mass) and the salt. Other investigators have made this same error. An apparent reasonable argument is frequently presented along lines something like the following: A certain amount of fresh water flows into the estuary from the river. In order to maintain continuity an equal amount of fresh water must be carried through each section, and since, as one proceeds down the estuary, the salt content increases, it is evident (?) that only a portion of the volume can be fresh water, and so the seaward directed flow must increase in proportion to the decreasing fraction of fresh water. The correct application of continuity concepts recognizes that it is the mass of water on the one hand, and the salt on the other that is conserved over one or more tidal cycles, not the 'fresh water'....

...It might be appropriate to point out that Ketchum (1950) made the same questionable assumption that Todd and Lau did when he defined a non-tidal drift (NTD) as NTD = $R/\bar{F} \times \bar{A}$. Ketchum's arguments parallel the disarmingly simple but erroneous presentation given earlier in this critique.

We interpret the authors (Todd and Lau) closure to Pritchard's discussion, as a circumlocution of Pritchard's arguments, rather than a direct statement of disagreement, suggesting their recognition of the accuracy of Pritchard's analysis.

The following statement appears in a very extensive analysis of the effect of pollution on the Thames Estuary.[7]

[7] "Effects of Polluting Discharges on the Thames Estuary". Department of Scientific and Industrial Research, Water Pollution Research. Technical Paper No. 11, Chapter 14, 'Tidal Mixing', under Section entitled" 'Theories of Estuarine Mixing', 1964. p. 392

KETCHUM'S THEORY

Ketchum[4-6] divides an estuary into segments such that the length of each is equal to the average excursion of a particle of water on the flood tide. The position of the landward boundary of the first segment is determined by the river flow and the cross-sectional areas at high and low water. In one paper[4] he considers the mixing process may be represented by assuming that, during each tidal cycle, the water is completely mixed within each segment at high water, and that there is an exchange of water between adjacent segments during the ebb—the amount of water removed from a segment being given by the ratio of the difference between the volumes of the segment at high and low water to the volume at high water.

The final equations express the proportion of fresh water in each segment solely in terms of the river flow and the volumes of the segments at high and low water. However, these equations do not follow rigidly from the theoretical model and, although the method has the very considerable merit of simplicity, this concept of tidal mixing is undoubtedly over-simplified, and it is evident that the theory is unlikely to be applicable to all estuaries even though it has been used successfully in particular cases. It is sufficient here to indicate that it cannot be used in the case of the Thames Estuary. Ketchum found that his method did not apply to the Delaware Estuary, and he was not surprised to learn that it did not apply to the Thames[7].

In Fig. 220 the continuous curve shows the approximate observed equilibrium distribution of salinity for a flow at Teddington of 1500 m.g.d. (derived from several years' records of the London County Council), and the broken curve is the distribution calculated (for average tidal conditions) by means of Ketchum's theory. There is a similar disparity between the observed and calculated distributions for flows of 500 and 3000 m.g.d.

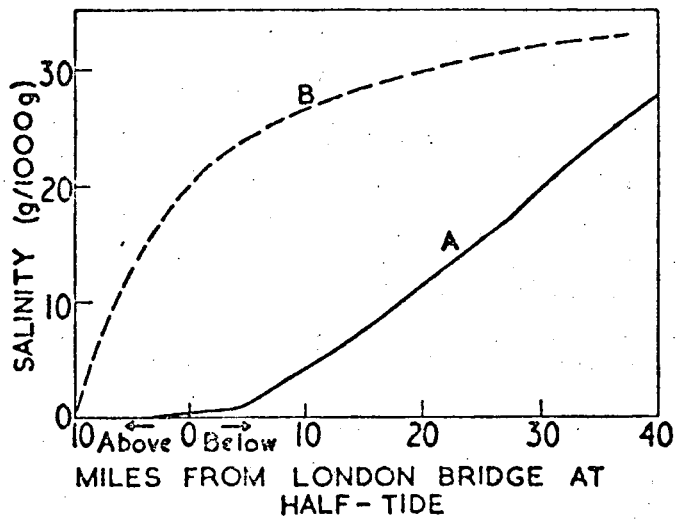

FIG. 220. Equilibrium distribution of salinity in Thames Estuary when flow at Teddington is 1500 m.g.d.
(*A*) *Observed*
(*B*) *Calculated using Ketchum's representation of mixing*

Ketchum references taken from Reference 7

4. KETCHUM, B. H. *J. mar. Res.*, 1951, **10**, 18.
5. KETCHUM, B. H. *The Exchanges of Fresh and Salt Waters in Tidal Estuaries.* Woods Hole Oceanographic Institution, Colloquium on Flushing of Estuaries, 1950, p. 1.
6. KETCHUM, B. H. *Sewage industr. Wastes*, 1951, **23**, 198.
7. KETCHUM, B. H. Personal communication, 1957.

Thus, it is clear that the methodology employed by the Staff to estimate estuary dilution flow has not met with general acceptance by the field, and, in general, has been discarded in favor of models which recognize more details of observed physical behavior in estuaries, particularly that of salinity-induced circulation.

Before going on to a theoretical presentation as to why the Staff method is unacceptable, and while on this topic of behavior in the Thames River, it should be noted that several investigators including Bowden[8], Preddy & Webber[9] and Inglis & Allen[10] have concluded that the Thames River, like the Hudson, falls into the class of partially stratified estuaries. Similarity between the Thames and Hudson River circulation patterns and mixing characteristics is supported by field observations which established existence of density induced circulation in the Thames[10] and the Hudson[11], relatively high dispersion coefficients (33.8×10^5 cm^2/sec or about 10 square miles per day in the salt intruded reaches of both estuaries) and comparable circulation and mixing classification criteria, such as the ratio of tidal amplitude to freshwater used by Bowden[8], the ratio of the flood tide to freshwater volumes used by Pritchard, or the vertical stratification factor (VSF) employed by QL&M[11].

[8] Bowden, K.F. "Circulation and Diffusion." Estuaries, Publication #83, American Assoc. for the Advancement of Science, Wash., D.C. 1967. p. 20

[9] Preddy, W.S. and B. Weber. "The calculation of Pollution of the Thames Estuary by a Theory of Quantized Mixing," International Conference on Water Pollution, Paper No. 42, September 1962.

[10] Inglis, Sir Claude and F.H. Allen. "The Regimen of the Thames Estuary." Porc. Inst. Civil Engineers (London), 7:827-868. 1957

[11] Quirk, Lawler & Matusky Engineers. "Environmental Effects of Bowline Generating Station on the Hudson River". Vol. 1-4, QL&M Project No. 169-1, March 1971.

Rejection of the Staff's methodology via theoretical reasoning follows.

Transport phenomenon such as the volume rate of flow available for dilution in an estuary, should always be derivable by application of one or more of the equations of mass, momentum and energy to the system in question. When the system is viewed macroscopically, a conventional means of applying these basic and quantitative laws of physics is control volume analysis. In this method, a finite and typical volume segment of the system is drawn, and rates at which mass momentum or energy flow through, and are produced and or consumed within the segment, are written down. Each entry is then assigned its proper position in an inventory or "balance" equation and a result obtained.

This procedure is applied below to illustrate the development of the two layer estuary model, and then employed to demonstrate the difficulty in deriving the intuitive formulation of estuary dilution flow employed by the Staff.

Consider the typical estuary segment shown below. Freshwater flows into the segment at a rate Q_F. In an attempt to recognize its dilution by salt water, as evidenced by a continually increasing salinity concentration as one moves seaward in the estuary, ocean water is assumed to flow into the estuary, predominantly along the bottom half of the estuary, due to its greater density.

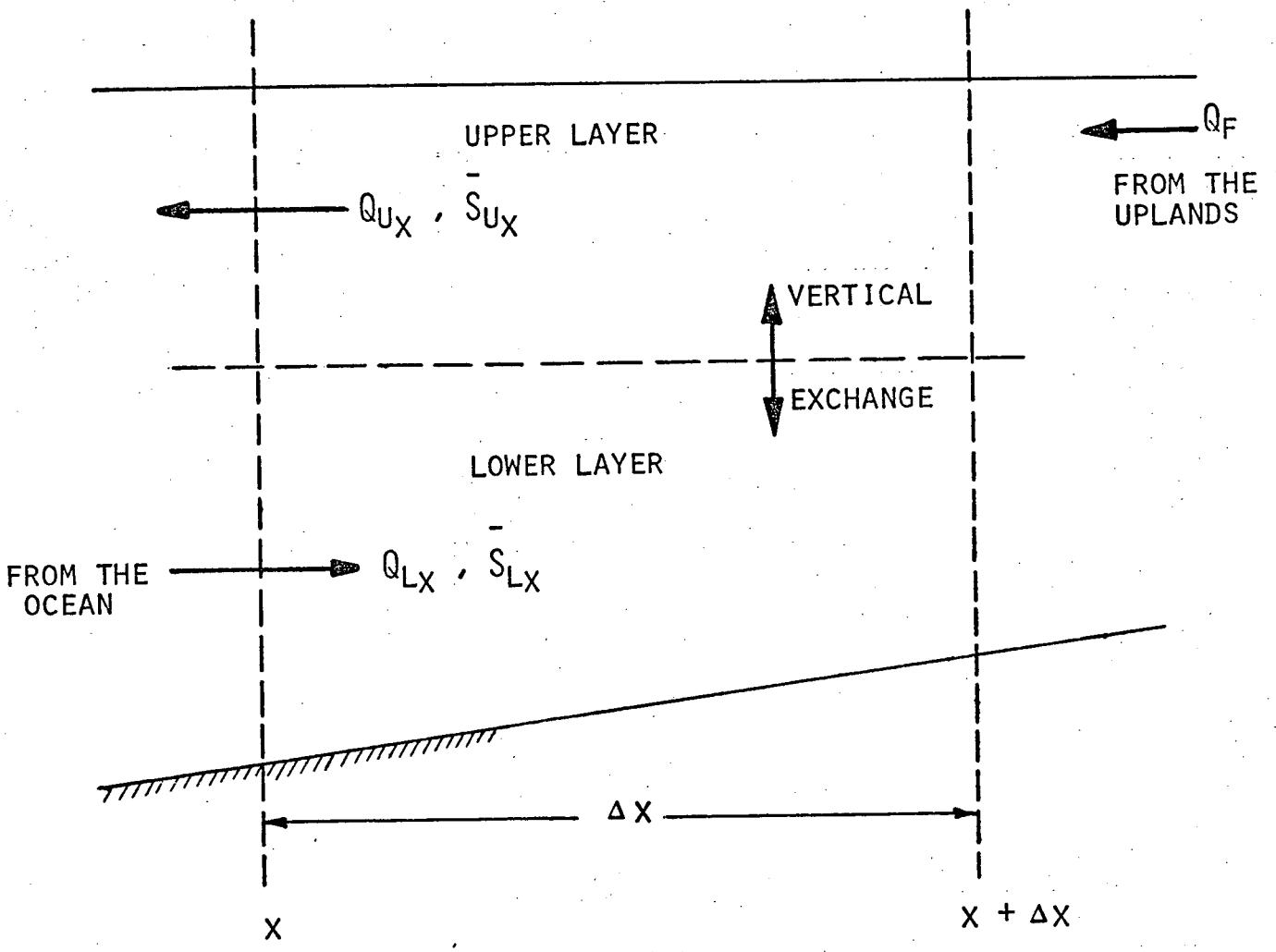

FIGURE 1 - Two Layer Exchange of Water in an Estuary

A steady-state condition is assigned, so that there can be no net transport of salt either into or out of the estuary. In the real world, tidal average behavior approaches this steady condition when external factors controlling movement in the estuary, such as ocean tide, winds, etc., and in particular, river freshwater discharge, remain constant, or nearly so, for extended periods.

Note that the long term condition is a quasi-steady condition. Freshwater discharge undergoes a yearly cycle of high and low water flows, preventing any long term net landward flux of salt. The estuaries salt profile oscillates about some mean position, just as a freshwater discharge oscillates throughout the year about a yearly average runoff value. Since there is no net flux of salt, a mechanism must be provided for returning the salt introduced to the estuary in the landward directed underflow, shown by Q_L in Figure 1. To provide such a return mechanism, water is assumed to be mixed vertically by some means and then returned to the ocean by a seaward movement which takes place predominantly in the upper layer.

Note that a physical rationale is available to explain the postulated movement. This rationale includes the notion of density current development occuring in a system in which waters of different density are brought in contact with each other, and the notion of vertical mixing via tide-induced turbulence.

The notion of vertical mixing is necessary to permit continuous transfer of the heavier seawater up into the layer in which the lighter freshwater is presumed to be moving. Without this, only shear at the salt water-freshwater interface would be available to affect the transfer. This would result in only a fraction of the transfer which can be expected in the presence of tidal turbulence, and in fact describes the stratified, or "salt wedge" type of estuary.

At this point, we have succeeded in developing a conceptual model of estuary water movement. Note that since a macroscopic view is the objective, details of the mixing and transfer process are not required at this point. We are simply attempting to structure an overall view of the estuary, with the objective of writing a statement to describe in a quantitative fashion, the observation that freshwater discharge is diluted by ocean water as it moves down the estuary.

The Law of Conservation of Mass is applied to both the water and the salt in the estuary. This is done by writing a material balance over the volume segments shown in Figure 1.

Since there is no loss or gain of either salt or water within the segment, due to generation or decay processes, and since we are dealing with a steady condition, so that no accumulation of either material can occur over time within the segment, the required balance can be struck across any cross-section of the segment to describe the behavior at that section. This is done first, before striking a balance over the whole volume segment.

Consider Section X in Figure 1. Since there is no net flux of salt, the salt moving into the estuary across the lower portion of the section must balance that moving out of the estuary across the upper half. This is written:

$$Q_U \cdot \overline{S}_U\}_X = Q_L \cdot \overline{S}_L\}_X \qquad \ldots(2)$$

in which:

Q_U, Q_L = the total upper and lower layer flows, respectively

$\overline{S}_U$, $\overline{S}_L$ = the average upper and lower layer salt concentrations, respectively

Since the net overall movement is out of the estuary (seaward), and is given simply by Q_F, the freshwater flow, the upper layer flow, Q_U, must exceed the lower layer flow, Q_L, by this amount. This is written:

$$Q_U - Q_L = Q_F \qquad \ldots(3)$$

Substitution of Equation (3) into Equation (2) yields:

$$Q_U = \frac{Q_F \overline{S}_L}{\overline{S}_L - \overline{S}_U} \qquad \ldots(4)$$

Subscript "X" has been dropped since the section location was arbitrary and Equation(4) is the so-called "salt budget" equation and is described by a number of authors. (see, for example,Reference 8.)

A material balance may now be struck over the whole volume segment. Upper and lower layer flows are entering and leaving the segment at sections X and X + ΔX. The general inventory equation for mass is written:

$$\text{Rate of Mass Input} - \text{Rate of Mass Output} + \text{Rate of Production of Mass} - \text{Rate of Loss of Mass} = \text{Rate of Accumulation of Mass} \quad \ldots (5)$$

In applying Equation (5) to the system in Figure 1, the last three terms are all zero, for both water and salt. There is no production or loss of either water or salt within the segment, and, since the system is at steady-state, no accumulation of either material occurs.

Application of Equation (5) to salt movement through the segment ΔX yields:

$$\text{Input} - \text{Output} = 0$$

$$Q_U \cdot \bar{S}_U\}_{X+\Delta X} + Q_L \cdot \bar{S}_L\}_X - Q_U \cdot \bar{S}_U\}_X - Q_L \cdot \bar{S}_L\}_{X+\Delta X} = 0 \quad \ldots (6)$$

Rearrangement and division by ΔX yields:

$$\left[\frac{Q_U \cdot \bar{S}_U\}_{X+\Delta X} - Q_U \bar{S}_U\}_X}{\Delta X}\right] - \left[\frac{Q_L \cdot \bar{S}_L\}_{X+\Delta X} - Q_L \bar{S}_L\}_X}{\Delta X}\right] = 0$$

The limit of this Equation as $\Delta X \to 0$ yields:

$$\frac{d(Q_u \cdot \bar{S}_u - Q_L \cdot \bar{S}_L)}{dX} = 0 \qquad \ldots(7)$$

Integration yields:

$$Q_u \cdot \bar{S}_u - Q_L \cdot \bar{S}_L = \text{Constant}$$

Consideration of the no net salt flux condition requires that the integration constant be zero. The result is identical to Equation (2).

Application of Equation (5) to water movement through the segment ΔX yields:

$$\text{Input} - \text{Output} = 0$$

$$Q_u\}_{X+\Delta X} + Q_L\}_X - Q_U\}_X - Q_L\}_{X+\Delta X} = 0$$

Rearrangement, division by ΔX and taking the limit as $\Delta X \to 0$ yields:

$$\frac{d[Q_U - Q_L]}{dX} = 0 \qquad \ldots(8)$$

Integration yields:

$$Q_U - Q_L = \text{Constant}$$

Consideration of the fact that the net overall movement across any section in the segment is given by Q_F, the freshwater flow requires that this integration constant be given by Q_F. The result is identical to Equation 3.

Thus, by use of material balances with salt and water across either an arbitrary cross-section or volume segment of the estuary, we have succeeded in establishing an overall quantitative relation between freshwater flow, estuary dilution flow and observed salt concentration. This relationship is given by Equation (4), in which Q_U, the upper layer flow, is the estuary dilution flow.

Equation (4) suggests that the estuary dilution flow can be calculated, provided one knows the location of the interface between the upper and lower layer and has accurate vertical salt profiles. QL&M has shown that, for for the Hudson, vertical salt profiles tend to follow an "S" shaped distribution with the inflection point near the half depth.[11]

This inflection point can be used to estimate the location of the upper-layer - lower layer interface as follows. The equation of continuity in two dimensions is written:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \qquad \ldots(9)$$

in which:

U = horizontal water velocity at the point X,Y

V = vertical water velocity at the point X,Y

In the two layer system, the vertical distribution of horizontal velocity moves through zero at the upper layer-lower layer interface. Thus, since the interface is roughly horizontal, at the interface , $\partial U/\partial X = 0$. From Equation 9 the vertical velocity is seen to be a maximum at the interface.

The rate of vertical salt transport by vertical turbulence is proportional to the vertical velocity, and should be a maximum at the interface. This vertical salt flux can also be shown to be essentially proportional to the vertical salinity gradient, so that the point at which this gradient is a maximum can be used to estimate the location in the interface. In an "S"-shaped vertical salt profile, such as those observed on the Hudson, the vertical salinity gradient is a maximum at the inflection point.

This is just one means of estimating the location of the interface in using Equation (4) to estimate estuary dilution flow. Knowledge of the velocity distribution is another. In any event, the whole thrust of the work referred to in Reference 11, is directed at a valid estimate of the dilution flow, in which the role vertical salinity gradients play in this estimating process is discussed in detail. It should

be noted that this reference is Reference 4, page III-61, to Chapter III in the AEC Draft Detailed Statement.

The use of Equation 4 and vertical salinity profiles to estimat density flow is recognized by the Staff in Chapter III, pages III-22 to III-27. In this regard, the Staff concludes on III-27:

> *The presence of a net nontidal seaward flow in the salt-intrusion zone of the Hudson is clearly established by means of (1) observed vertical salinity gradients, (2) direct velocity measurements, (3) high computed values for the longitudinal dispersion coefficient. Of these three means of detection, it is thought that only method 1 may be reliably used to obtain a reasonably accurate direct determination.*

The foregoing shows clearly that a model of estuary dilution flow can be developed by application of the Equation of Continuity (Law of Conservation of Mass) to the estuary. To do this, recognition is given to the fact that a vertical density difference exists in any section in the estuary.

No such similar analysis appears to exist which will generate the formulation used by the Staff to estimate estuary dilution flow (Equation (1) above, or Equation (2), page A-4 in the Draft Detailed Statement).

To show this, refer to Figure 1. Since the ultimate formulation (Equation (1)) contains only $\overline{S}$, the area-averaged salt concentration and S_0, the ocean salt concentration, we presume that mixing across the section is assumed

for whatever derivation technique one can conceive of. Actually, no such assumption has to be made; the major point is that since the final expression contains only $\overline{S}$ to represent section salinity behavior, the deriver must use this, and only this value in developing his model.

Due to the observed dilution of Q_F, a seaward flow is assumed to exist and to be larger than Q_F. Use the notation Q_u to define the total seaward flow. Define a landward flow Q_L. Q_L is the makeup flow necessary to permit the existence of Q_u and still maintain a net water flux of Q_F.

Application of a material balance on water across the section X shows that Equation (3) still holds; i.e., that:

$$Q_U = Q_L + Q_F$$

Write a salt balance across section X. Since no attempt is made to define vertical variation of salinity and the investigator is apparently working only with $\overline{S}$, the area-averaged salt concentration, this balance yields:

$$Q_U\overline{S} - Q_L\overline{S} = \text{net section salt flux}$$

The net section salt flux must be zero at steady-state. However, substitution of the preceeding equation for Q_U yields:

$$Q_F\overline{S} = \text{net section salt flux}$$

This is clearly a contradiction and arises because the investigator has not distinguished between the concentrations of salt being carried landward by Q_L and seaward by Q_u. The presumption of landward and seaward flows is clearly necessary if one is to explain dilution of Q_L. This fact is acknowledged by many investigators. Care must be taken, however, to recognize that the actual points within the estuary section at which such flows are crossing, must see flow going in one direction or the other. No one point can see two way flow at the same time. Since this must be the case, one must also realize that the concentrations of salt seen by each flow may (and in fact, must) be different. Therefore, application of $\bar{S}$ to all flows is incorrect.

Proliferation of this error over the years seems to be associated with the assumption of the sectionally homogemeous estuary. Ketchum, for example, ignored vertical variation, assuming complete and immediate mixing with each of his segments. In using salinity, therefore, to "verify" his model, only section average salinities were used.

In discussing Todd and Lau's paper, Pritchard[4] states:

> *The authors have stated certain limitations on their development. A fundemental requirement is that the estuary be sectionally homogeneous, that is, it shall have no vertical or lateral salinity gradients. This is an unfortunate restriction to place on estuarine studies, since the majority of estuaries do exhibit some degree of vertical or lateral stratification, with accompanying circulation patterns related to the mass distribution.*

> *The characteristic circulation patterns in the various types of coastal plain estuaries have been discussed by Stommel (1953) and by Pritchard (1952, 1955). However, an adequate study of even this most simple of estuarine types would be welcome so that one should not be unduly critical of this aspect.*

Pritchard's point in the discussion, as described previously, is that if the assumption of vertical homogeneity is going to be made, presumably for the purposes of simplifying a complex system, then it should be done with great care, recognizing that the existence of vertical salinity variation is part and parcel of what makes the estuary "go".

Witness, for example, his comment in Reference 5, as he introduces the one-dimensional analysis of an estuary:

> *The Case of One Spatial Dimension. Because of the complexity of the general three-dimensional equations, and even of the more restricted two-dimensional equations given above, many investigators have attempted to reduce kinematic and dynamic problems in estuaries to a single spatial dimension. It is in these treatments that the most frequent misuse of continuity concepts has occurred.*

That the assumption of vertical homogeneity is an idealization is again suggested by Pritchard[12] in a discussion of estuary classification:

> *It is, in fact, quite possible that the vertically homogeneous estuary does not exist. Our observational methods may not be sufficiently sophisticated to show the slight degree of vertical stratification which might, on the average, exist in such systems. Only a small vertical stratification would be required to remove some of the anomalous factors mentioned above which are associated with this class of estuary.*

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12. Contribution No. 64 of Chesapeake Bay Institute and the Department of Oceanography, The John Hopkins University, Reproduced by permission from The Sea, vol. 2, Interscience Publishers, 1963.

Bowden suggests that density-induced circulation must exist, even in cases where vertical mixing is intense and the tendency would be simply to assume vertical homogeneity.[13] A pertinent except from this reference follows:

> *Where the tidal currents are most effective, there is an increase in the intensity of vertical turbulent mixing, which is an exchange process, mixing the fresher water downwards as well as the salter water upwards. In this type of estuary, with moderate mixing, a state of dynamic equilibrium is set up, with a two-layer flow and the salinity along a given vertical increasing with depth. The volume of water involved in the density current flow may be many times the river discharge, e.g., the seaward flow in the upper layer may be 40 times the river flow while the upstream flow below it is 39 times the river flow. With very strong tidal currents, the vertical mixing predominates and a third type of estuary has been described, which is so intensely mixed that there is no vertical variation in salinity and the density current flow is no longer present. It would seem, however, that a tendency to differential flow must persist, even under these extreme conditions, since the primary driving force, the longitudinal density gradient, is still present.*

Comparison of Equations (1) and (4) show that estuary dilution flow calculated by each, will be the same when:

$$\frac{\bar{S}}{S_0} = \frac{\bar{S}_U}{\bar{S}_L}$$

These ratios will approach each other close to the true mouth of the estuary, as all values approach the ocean salt concentration. However, the validity of either equation is questionable at this point. Ketchum recognizes this in

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13 Bowden, K.F. "The Mixing Process in a Tidal Estuary," presented at the International Conference on Water Pollution Research, Paper No. 33, of Section 3. September 3-7, 1962. Pergamon Press.

Reference 2 above, and the two-layer model presented previously is an idealization of actual estuary circulation. The simple idealization given tends to be inaccurate as one approaches the estuary mouth.

The foregoing literature review and analysis demonstrate clearly that the staff method of estimating estuary dilution flow, for use in its evaluation of entrainment, is highly questionable, if not categorically in error. We submit that a far more accurate estimate of estuary dilution flow in the Hudson River is that given in Reference 11 (Reference 4, Chapter III, draft detailed Statement.

As noted previously, the staff does recognize the existence of density flow in the Hudson in its Chapter III, Section E-1d entitled "The Hudson River Estuary and its Cooling Capacity." The salt budget equation, identical to Equation 4 above, is presented (Equation 1, page III-22) and the Staff goes on to state:

> *The mixing flow calculated in Equation (1) is the upper layer flow in the downstream direction. This should not be confused with what is called dilution flow in Appendix II-1 and Appendix V-2. (This dilution flow is defined by Equation (1) in Appendix II-1). These two appendices deal with the ecological effects of the Hudson River which are better described by the dilution flow concept mentioned above.*

However, no indication is given at this point or in either Appendix as to why "ecological effects.....are better described" by the Staff concept of dilution flow, as given by Equation 1, page 8 of these comments.

2. COMMENTS ON THE STAFF'S CALCULATION OF ENTRAINMENT LOSS

On pages A-62 through A-64, the Staff presents a model of entrainment loss. On pages A-68 and A-69, this model is used to calculate the percentage of larval striped bass entrained by Units 1 and 2 at Indian Point.

This model presents a very conservative view of entrainment in the river. A number of factors are ignored, the consideration of each one of which will result in reduced estimate of the percentage entrained. These considerations include:

1. The role of density induced circulation.
2. The role of vertical diurnal movement of the organisms.
3. Susceptibility to entrainment

These comments are directed toward showing how the factors of density flow and vertical diurnal movement can be introduced to the Staff's model, and how the notions of planktonic movement and uniform distribution make the entrainment models employed by the staff quite conservative.

The Staff's model is based on the concept of the probability of capture of an organism as it passes Indian Point in the flow. The probability of capture per pass is given as Q_C/Q_T, the ratio of the station cooling water flow to the average tidal flow. The oscillating motion of the tide is recognized so the number of passes, or possible times capture can occur, is

greater than once. The number of passes is shown to be given by Q_T/Q_D, the ratio of the average tidal flow to the estuary dilution flow.

Very simply, but approximately stated, the total probability of capture is given by the product of the probability of capture on a single pass times the total number of passes, or

$$P_T = \frac{Q_C}{Q_T} \times \frac{Q_T}{Q_D} = \frac{Q_C}{Q_D} \qquad \ldots\ldots(10)$$

Equation 10 is only close to being accurate when the probability of capture on a single pass is low. Otherwise, recognition must be given to the fact that after each pass, a certain number of organisms has been removed from the system, reducing the number of the original batch, and therefore the number available for capture on the next pass.

The Staff model recognizes this and presents a careful treatment of the probability notion. The probability of withdrawal per pass is shown to be very small and the Staff concludes that an appropriate expression, given by their Equation 12, is:

$$P_T \simeq \frac{Q_C}{Q_D} \left(1-\nu\right)\left[1-1/2\ (1-\nu)\ \frac{Q_C}{Q_D}\right] \qquad \ldots(11)$$

in which: ν = the fraction of particles which have passed the condenser and are re-exposed due to recirculation.

The cooling water recirculation ratio, ν, is obtained using model and prototype data as a tracer and is estimated to be on the order of 14%. Q_C/Q_D is also relatively small, and for ease of explanation in this section, we will use the simple Q_C/Q_D as the staff's estimator of entrainment, recognizing that in the actual case, their actual model will give somewhat lower value since the recirculation and higher order probability terms are not dropped.

Note the Staff's statement after presentation of Equation 12.

> *Equation 12 shows that the total probability of being withdrawn is proportional mainly to the ratio of cooling water flow to the river freshwater flow. It is almost independent of the tidal characteristics, although these characteristics are important in that they provide the mixing and dilution which must be met in order for this model to be accurate.*

We disagree with the last sentence of this statement. When higher order terms are neglected, the model the Staff presents can be obtained just as readily by assuming a plug flow non-tidal river moving at the rate Q_E. From this standpoint is virtually "independent of the tidal characteristics." It is true that the tidal characteristics are important and important from the viewpoint of mixing and dilution, but this mixing and dilution is not recognized by the Staff. No attempt has been made to include estuary flushing or exchange characteristics, the real means by which an estuary mixes and dilutes, other than the previously demonstrated erroneous estimate of estuary dilution flow.

Consider first the role of diurnal migration of the organisms. The Staff addresses itself to this on page A-69, saying:

> *These values are based on area-average susceptibility. However, it is known that the larval striped bass make vertical diurnal migrations in the water column and are most concentrated from mid-depth to the surface at night but from mid-depth to the bottom during the day. These distributional patterns are important since the cooling water is taken from mid-depth to the surface. Thus, there would a significant difference in the day vs. nighttime susceptibility of the larvae, i.e., lower during the day and higher at night. Since the length of day and night are not equal at this time of year, these organisms may be slightly less susceptible to entrainment than predicted using this technique, provided that the deeper water is moving seaward.*

We object to the use of the word "slightly" in the last sentence of the above statement, as well as to the statement that the organisms "are most concentrated from mid-depth to the surface at night."

A more accurate description would be to say that the organisms are known to move up from the bottom during the night, and tend to spread out into a relatively uniform distribution throughout the water column during the night, as opposed to being concentrated in the bottom during the day.

An estimate of the reduced impact of entrainment, due to recognizition of this diurnal movement, can be obtained by computing the average probability of capture throughout the day. During the period of the year when this activity occurs, (± 3 weeks about June 21), daylight hours represent roughly two-thirds of the day and darkness roughly one-third of the day.

Assume that the upper layer larval concentration is zero during the daylight hours, and at night that the concentration of larval organisms is uniform throughout the water column. Actually, there will probably be some organisms in the upper layer during the day but this should be offset by only a tendency to approach uniformity from the bottom up. The longer daylight period will allow a greater period of time over which the organisms are "programmed" to seek the deeper layers. This suggests that the description of concentration below mid-depth during daylight hours is the more stable condition, and that the diurnal upward movement, since it has less time in which to equilibrate, is stable for a shorter percentage of its total period.

Since the cooling water "is taken from mid-depth to the surface," the probability of withdrawal of organisms during the day is zero, and at night is Q_C/Q_T, as before. Thus, the average probability of capture per pass is 1/3 (Q_C/Q_T).

The total number of passes is still given approximately by Q_T/Q_D, so that the fraction entrained is now given by $1/3(Q_C/Q_D)$, or one-third the original estimate, hardly worthy of the statement "slightly less susceptible to entrainment."

The Staff suggests, however, that this technique is only valid "provided that the deeper water is moving seaward."

In the next paragraph on page A-69, the Staff goes on to say:

However, if the density flow is well developed, then these diurnal migrations will cause them to occupy an inland-moving zone during the day and a seaward moving zone at night. Since their occupancy within the water mass moving inland would be of longer duration than within the water mass moving seaward on the surface, the length of time which they are susceptible to entrainment may be much longer than predicted in the above calculations. This is an important consideration in that the probability that they will be withdrawn is related to the number of exposures. A single week of exposure would increase the likelihood of withdrawal to about 34% and 10 days would result in about 45% of the larvae being entrained (assuming random distribution in the water column). These time periods do not seem unrealistic based on the behavior of larval striped bass and the high probability for the occurrence of density flows at Indian Point. As a consequence, the staff believes that the 25% estimate derived by the above calculations is probably somewhat low. However, the increased residence time within the volume of water which passes back and forth in front of Indian Point may be partly offset by a reduction in the average probability of withdrawal per pass, which results from the non-random distribution within the water column. Consequently, the staff believes that the total average probability of withdrawal of larval striped bass migrating downstream past the Station is approximated by the 25% figure, and that this fraction is the best estimate that can be made using avaialble information.

We disagree with the Staff's analysis of the influence of the density flow on entrainment. As presented previously in the two layer flow model, the upper layer flow, Q_U, exceeds the lower layer flow, Q_L, by an amount equal to the freshwater runoff. In Reference (11), QL&M shows that the upper layer flow corresponding to freshwater runoff of 7500 cfs (used by the Staff in their analysis on page A-68) is 35,000 cfs. The corresponding lower layer flow is 28,000 cfs.

More careful analysis of this shows that if the daylight-darkness factor is taken into account, there will be a substantial net transfer in the landward direction rather than seaward. This suggests that if the organisms were subject to the density flows in the manner in which the Staff suggests they are, then the net

movement of all organisms will be upstream, and for some (that portion which remains in the lower layer during the night-time hours) this will be the only movement.

Note that, in the model used by the Staff, entrainment only occurs during actual passage past the plant. The influence of density flows as suggested by the Staff would therefore expose only organisms whose origin is below the plant to potential capture by the plant. What we are saying here is that the staff is using a Lagrangian form of reference; i.e., is following the motion of a typical sample of organisms as they move back and forth in the general vicinity of the plant. Simultaneous superposition of the density flow and organism diurnal movement on the Staff's probability model results in a net upstream motion of the organism. Therefore, only those whose origin is below the plant will have an opportunity for capture.*

Simplify the analysis by recognizing that the net effect of the tide is to yield a total probability of capture equal to approximately Q_C/Q_D, when density flow and diurnal movements are not present. By analogy, for a two layer density flow tidal system, in which, for the moment, vertical diurnal movement is neglected, the fraction of entrained organisms is given by Q_C/Q_U, the ratio of the plant flow to the upper layer flow. Recognize also that in this case this capture applies only to those organisms appearing in the upper layer.

* When tidal motion is included, this statement should be modified to include those organisms whose origin is with a tidal excursion above the plant.

Now introduce diurnal movement and recognize that, just as in the tidal analysis, the alternating seaward-landward movement will expose some of the organisms to more than one pass by the plant. Those that will be exposed will be those whose origin is below the plant, and which move up into the upper layer after they have moved landward in the lower layer, past the plant, and then prior to the end of darkness, will move back in the seaward direction past the plant.

The probability of capture per pass, recognizing that roughly half of the organisms reach the upper layer during the darkness hours, will be given by $Q_p/2Q_U$. The number of passes is equal to the number of times the organisms introduced into the seaward directed upper layer pass the plant between the time the particle of water in the lower landward directed layer first reaches the plant from below to the time it finally reaches a point above the plant, at which point the seaward return remains above the plant. This is given as follows:

$$\text{Number of passes past the plant in the upper layer} = \frac{Q_u \cdot T}{Q_L \cdot 2T - Q_u \cdot T}$$

$$= \frac{Q_u}{2Q_L - Q_u}$$

T is the period of darkness and 2T the daylight period. The denominator $[Q_L \cdot 2T - Q_u \cdot T]$ is simply the net upstream movement that takes place each 24 hour day.

To derive the numerator, consider a particle in the lower layer, just $Q_L \cdot 2T$ distance seaward of the plant, at the onset of daylight. On a net, or daily cyclic basis, it must move upstream this distance, less one net translation $(Q_L \cdot 2T - Q_u \cdot T)$ before it can be said to have reached a point such that its organisms, during their sojourn in the return flow, will still be above the plant, and therefore no longer susceptible to entrainment. This net distance is equal to $\{[Q_L \cdot 2T] - [Q_L \cdot 2T - Q_u \cdot T]\}$ or $Q_u \cdot T$, the numerator of the above expression. The ratio of this net upstream movement required to push the particle out of the entrainment zone to the net translation each day, yields the number of passes to which the organisms in the particle are subject.

Following the Staff's probability notation, the formula for entrainment for this case is given:

$$P_T = 1 - (1 - P_e)^n$$

in which: P_T = total fraction entrained

P_e = entrainment per pass, $= \frac{Q_c}{2Q_u}(1 - \nu)$

n = number of passes, $= \frac{Q_u}{2Q_L - Q_u}$

For the case of density flow corresponding to a runoff of 7500 cfs, we have:

Q_c = 2,500 cfs

Q_u = 35,500 cfs

Q_L = 28,000 cfs

ν = 0.14 (page A-64)

P_e = 0.03

P_T = 0.05 or 5% entrainment loss

Summarizing, we believe that three cases may be viewed as possible:

Condition	Percentage Loss by Entrainment
1. Density flow only	3%
2. Diurnal movement only	8%
3. Density flow with diurnal movement	5%

These estimates have been computed employing the Staff model for entrainment loss, modified for either density flow, diurnal movement or both. They show clearly that the Staff opinion that these two mechanisms offset each other is in error, and that the Staff estimate of 25% entrainment loss is not "the best estimate that can be made using available information."

Actually, we believe that all of these models yield conservative estimates of the actual effect. As shown above, the model in which diurnal movement and density flow is introduced, applies essentially to larval organisms originating seaward of the plant. Using the Staff's notion of the interaction between these two mechanisms, it is seen that all organisms originating above

a point between $Q_u \cdot T$ and a tidal excursion above the plant, will not be exposed to entrainment during the planktonic stage.

The foregoing has been presented primarily to indicate that relatively simple models, of the type presented by the Staff in the draft detailed statement, must be interpreted extremely carefully. These models are clearly very conservative and note of this fact should be made. Statements such as:

> *"In conclusion, based on these considerations, about 25% of the larval striped bass may be entrained as they migrate downstream past the Indian Point site". (Reference A-69, Draft Detailed Statement)*

are misleading, when care is not taken to demonstrate, in a similar quantitative fashion, how known river and biological behavior can alter these conclusions.

In its discussion of probable biological effects in Chapter V, "Environmental Impact of Indian Point Unit #2 Operation with Unit #1 Operation", the Staff, on pages V-52 through V-55, discusses the probable impact of its conclusion that 25% of the larval striped bass may be entrained by the plant.

The statement is made that:

> *"The eggs and larvae drift with the currents in a net downstream direction; large numbers pass the plant."*

The Staff then states that data show that 75 to 90% of the young juveniles are below Indian Point by late July and August and

then go on to state:

> *"If we assume: (1) that all these fish migrated past the plant during the life stage which is susceptible to to entrainment; (2) that density independent factors are responsible for mortality in the population; and (3) that entrainment mortality is 100%, then the operation of Indian Point Units #1 & will effectively reduce recruitment resulting from reproduction by about 19% to 22%,"*

We take strong exception to the thrust of these statements. First of all, it is not at all clear just how the eggs and larvae drift with the currents and for how long. The analysis above shows that if purely planktonic behavior, other than diurnal vertical movement is assumed, then only a small portion of the estuaries larval population is even susceptibel to entrainment (those below or just above the plant).

None of the immature stages are purely planktonic. Even the eggs have a density different than water and tend to settle in the absence of any current. Furthermore, the eggs only exist on the order of two days, before hatching; only those eggs spawned in close proximity to the plant could be susceptible to entrainment by the plant as eggs.

The larvae are sometimes described as planktonic, but by as early as the sixth or seventh day of their existence, are reported to absorb the yolk sac and begin diurnal movement. From this time forward their swimming ability increases, suggesting that the description of drifting with the current is not accurate. Furthermore, the presumption that susceptibility to entrainment is controlled by flow ratio is also highly questionable, since

the swimmers may very well avoid the intake.

Studies do show that by September, most of the young striped bass have reached Haverstraw Bay. To assume that this means they are susceptible to entrainment as they pass Indian Point in the manner assumed in the draft detailed statement is misleading. It is true that their passage through the river section bordered on the east by Indian Point probably occurs when they are less than 3 inches long, and in many cases less than 2 inches long, and that fish of 2 inch size or less may be entrained. This does not mean, however, that the entire population passing is planktonic, is subject to tidal and other current drift, is distributed uniformly across the cross-section and, therefore, is subject to 25% entrainment.

These young striped bass are known to seek the bottom as well as shallows and shoal areas, none of which describes the source of the major volume of water passing the Indian Point intake.

In conclusion, we state that the assumptions of uniform distribution across the section, and of downstream drift and planktonic behavior of all entrainable forms are not supportable by the known behavior of the immature fish at many stages of their development. Therefore, the percentage entrainment should be substantially less than the values given above in the modified entrainment model (3 to 8%) and in no way even close to the 25% estimate given by the AEC.

Appendix F

RADIOLOGICAL DISCHARGES

Although Con Edsion concurs with the general conclusions with respect to the radiological discharges and the resulting anticipated doses to man and to biota, there is, however, disagreement with several of the assumptions utilized in arriving at these conclusions. Those areas where major differences exist are discussed below:

I. No credit was given for the blowdown intertie system and the filtration systems which Con Edison has committed to installing prior to the completion of the first refueling outage. Since the release estimates stated should reflect equilibrium operation averaged over the life of the plant, credit should be given for these systems in estimating releases because they will be in-service over the remaining years of the plant life and because the releases prior to their installation should be less than the average because of the time required for (crud) activity to build up and for performance degradation and leakage to occur.

A brief functional description of these new systems follows:

(1) Blowdown Intertie System

The intertie between the Indian Point Unit No. 2 steam generator blowdown lines and the new Indian Point Unit No. 1 secondary purification system is shown in Figure 2.3-14 of the Indian Point Unit No. 2 Environmental Report.

In the event that the leakage from the primary to secondary side of the Indian Point Unit No. 2 steam generators is radioactive, the secondary blowdown which normally would have gone to the steam generator blwodown tank is diverted to the Indian Point Unit No. 1 blowdown flash tank to be treated prior to being discharged to the river. Only 1/3 of the liquid in the flash tank would flash to

steam in the absence of any cooling. From the blowdown flash tank, the flashed steam is sent to the Indian Point Unit No. 1 main condenser flash tank and becomes Indian Point Unit No. 1 feedwater. The reduction in the amount of steam vented plus the very high partition factor for iodine in the condenser would essentially eliminate this source of activity whenever the Unit No. 1 condenser is in operation. Any releases would be through the Indian Point Unit No. 1 condenser air ejector which exhausts to the Indian Point Unit No. 1 stack. When the Unit No. 1 condenser is not operating, gases from the flash tank divert to an already-existing vent and go directly to atmosphere via a vent on the roof.

The blowdown flash tank condensate is cooled by river water in a heat exchanger, processed through a filter and demineralizer, and then discharged to the river. In addition, in the event of high activity in the demineralizer effluent, this effluent can be rerouted to the waste collection tanks for recirculation through the filter and demineralizer or for processing through the existing liquid waste disposal system. There are two 66,000 lb/hr in-line booster pumps to overcome the head required to complete the flow path through the filters, demineralizers and overboard piping; two identical 132,000 lb/hr CUNO cartridge-type CG-S filters with pressure differential gauges which will be read periodically to assure changing of cartridges when required and two identical 66,000 lb/hr Illinois Water Treatment 36" x 60" 150 psig ASME code demineralizers, each with 21 cubic feet of IWT NR-6 non-regenerable nuclear grade mixed-bed resin.

Available operating experience to date indicates a minimum decontamination factor of 10 for the demineralizers. (Page III-4, Top).

(2) Filtration System

A simplified diagram of Indian Point Unit No. 2 Air Exhaust Filtration Systems is shown in Figure 1. There are five filtration systems, each of which consists of three filters - roughing, HEPA and charcoal.

The roughing filters remove the large particles from the air stream to preserve the operating life of the HEPA filters. Their construction is fire resistant with the mdeia composed of a glass fiber mat reinforced with stainless steel wire cloth.

The high efficiency particulate air (HEPA) filters are designed and tested for greater than 99% removal efficiency for 0.3 microns or larger particles. The filter media is made of glass fiber with asbestos. Filter frames are made of stainless steel, and asbestos separators resistant to mositure and high temperature are used. The charcoal filters are fabricated with stainless steel frames filled with activated charcoal.

Experiments have demonstrated that the iodine removal efficiencies of at least 99% can be expected. Each charcoal filter plenum is provided with a water dousing system which is designed to drench the absorbers in the extremely unlikely event of a charcoal filter fire.

The HEPA and charcoal filters will be tested in place after installations to insure overall filter design capability is achieved.

There are two Containment Building (CB) purge and/or Primary Auxiliary Building (PAB) exhaust fans in the fan room. Each fan can provide a flow rate of 55,000 cfm. During normal operation (i.e., no CB purging), one fan is operating for PAB exhaust and the other is on standby.

The air streams from the CB purge and the CB pressure relief each pass through their own set of roughing, HEPA and charcoal filters. The other three streams, the PAB exhaust, the Boric Acid Evaporator Building exhaust and the vents from the waste holdup tank pit and the blowdown tank area also each have their own set of roughing, HEPA and charcoal filters. In the case of these three streams, there is a bypass line around the charcoal filter. For these three streams, the roughing and HEPA filter will always be used, but the charcoal may be bypassed if there is no significant iodine in those streams. (Page III-40; Top).

II. Credit should have been given for the Indian Point Unit No. 1 evaporator in estimating the releases from that unit. The evaporator has been operating since March 1, 1972 at about half of its rated 12 gpm capacity with an overall decontamination factor of approximately 100 and an operating factor of about 40 to 50 percent. The capacity of this system is more than sufficient to process all liquids currently going to the liquid waste system at Indian Point Unit No. 1. (Page III-45)

III. Based upon the modifications being made to the Indian Point Unit No. 2 liquid waste disposal system including the addition of a polishing demineralizer, the applicant believes that 10^4 is a conservative estimate of the overall inlet to outlet decontamination factor for all isotipes including radioactivity but excluding tritium.

A brief description of the modifications presently being made to the liquid waste disposal system is presented below:

The main modification to the Indian Point Unit No. 2 liquid waste disposal system is the addition of a distillate cooler, a demineralizer and a filter. The addition of these items will result in a reduction in the activity released from the plant.

The distillate is pumped from the waste evaporator distillate tank, cooled by component cooling water in the heat exchanger (distillate cooler)

before being processed through the demineralizer and the filter, and then collected in the waste condensate tanks.

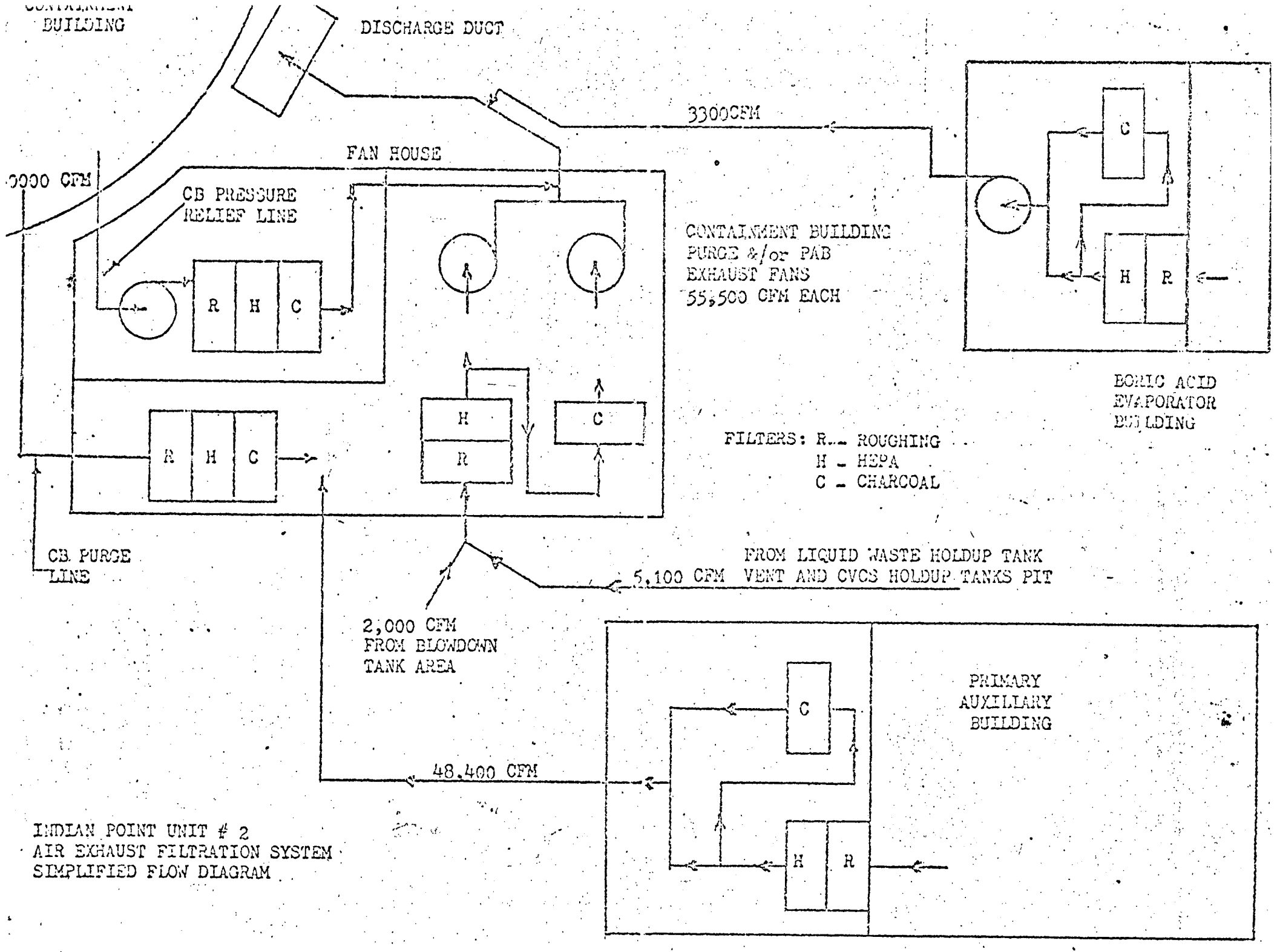
The demineralizer contains 2.5 cubic feet of IRN 150 ROHM-HAAS non-regenerable mixed bed resin.

The filter is CUNO Model No. 51044, and is expected to remove particulate and demineralizer carry-over down to approximately 5.0 micron particles. A pressure gauge at the inlet of the filter will indicate plugging of the filter.

In addition, Ginna-type modifications have been made to the evaporator internals.

Available operating experience demonstrates that a decontamination factor (ratio of inlet to outlet concentration) of ten is the lowest limit to be expected (due solely to the demineralizer) in this kind of a system.

Both the modification of the waste evaporator and the addition of the demineralizer and the filter to the liquid waste disposal system have been completed except for some testing, and both are scheduled for availability by initial criticality. (Page III-42, Bottom; Page III-42, Top; Page A-45, b).



INDIAN POINT UNIT # 2
AIR EXHAUST FILTRATION SYSTEM
SIMPLIFIED FLOW DIAGRAM

FIGURE 1

17-3 H