5. AQUATIC EFFECTS

The withdrawal, treatment and discharge of power plant cooling water involves a number of biological stresses. Organisms passing through a cooling system ("entrained") are exposed to abrupt thermal and pressure changes, abrasion, and often, biocidal chemicals. Some larger biota get caught against the mesh screens ("impinged") guarding intakes. Discharges can locally alter a receiving body's ability to support aquatic communities.

Chesapeake Bay and its tidal tributaries are Maryland's primary source of cooling water. Prospects of new and larger power plants have heightened concern over whether power plants will cumulatively reduce the sustained yield of fisheries through a gradual but progressive impact on water quality.

Methods for assessing biological impact are quite new, and data reliability and interpretation is, as often as not, arguable. Quantitative work has been largely site-specific. Theoretical or empirical techniques for extrapolating localized findings to the larger areas appropriate to a cumulative evaluation are still in a trial stage. The aquatic impact of Maryland power plants are discussed against this background.

A. Sources of Aquatic Effects of Power Plants

For brevity, this discussion deals with type of impact deemed to be the most important relative to an evaluation of cumulative impact of Maryland power plants. Characteristics of major sources of aquatic effects are summarized in Table 5.1. More detailed introductions are given elsewhere (1 - 3).

1. Impingement

Cooling water is drawn into the plant past 3/8-in mesh screens which block suspended debris. Organisms too large to pass through the mesh openings may be pinned on the screen by water velocity -- a prospect that is markedly greater when fish are weakened by disease, abnormal seasonal stresses, etc. When the screens are rotated for cleaning, a fraction of the impinged organisms are injured while others will successfully be returned to receiving waters through a bypass conduit.

TABLE 5.1

MAJOR TYPES OF AQUATIC EFFECTS OF POWER PLANT OPERATIONS

Sources of Effects	Primary Susceptable Organisms	Class of Stress Mechanical	Thermal	Chemical
Impingement	Juvenile fish, crabs	x	-	-
Entrainment	Ichthyoplankton[a] Zooplankton[b] Phytoplankton[c]	x	x	x
Discharge Effects	Adult and Juvenile Fish, Benthics[d] Shellfish	-	x	x

[a] Eggs and larvae of fish

[b] Minute animals present in the water column

[c] Minute plants present in the water column

[d] Organisms living in or on the bottom

Blue crabs and juvenile fish are the Bay biota most susceptible to impingement. Impingement mortality of hard-bodied crabs is too slight to significantly affect this ubiquitous population (4). Fish kills due to impingement have occurred in several estuaries on the Atlantic seaboard (2, 3). These often involved juveniles whose swimming ability was impaired by low water temperatures or low dissolved oxygen. Fish have been noted to congregate in the intake embayments of some Maryland (Morgantown and Calvert Cliffs) plants. Maryland has experienced a few such episodes to date: indications are that these were associated with periods of low dissolved oxygen.

Engineering efforts to reduce the likelihood of impingement have led to intake designs intended to be less attractive to schooling fish (5). Trial use of bubble screens and underwater sound generators to repel fish from the intake area have met with mixed success (6).

2. Entrainment

During their passage through a cooling system, entrained organisms are abruptly heated in the condenser tubes (average temperature rise is 12°F). Biological response to this heating is a function of the temperature rise. (ΔT), the ambient temperature itself, and the length of exposure to elevated temperatures. A common way of expressing thermal stress is "dose" -- the product of temperature rise (in °C), and duration of exposure (in seconds). Power plant operations in Maryland encompass a large spread of dose values: from 1,277 degree-seconds at the Gould Street plant to 79,200 degree-seconds at Chalk Point. Plants with long effluent canals, such as Chalk Point, retain the heated water longer, thus increasing dose. High velocity discharges, like the one used at Calvert Cliffs, rapidly dilutes the effluent and thereby reduces dose. Cooling towers (used at Benning Road, for example) recycle cooling water, greatly prolonging the thermal dose: the volume of cooling water used is only a few percent of that withdrawn by a once-through system with the same cooling capacity.

Entrained organisms also experience shear and pressure forces. These mechanical stresses and their consequences have not been well quantified.

In many plants, biocides (primarily chlorine) are added to cooling water to prevent biofouling in the condenser system. The amount of chlorine used depends on many factors, including volume of cooling water, ambient water quality, water temperatures, concentrations of organisms in the cooling water, and levels of amino compounds. In general, plants located in more saline areas use more chlorine than those on freshwater. Amounts of chlorine used by Maryland power plants are shown in Figure 5.1.

Of the three kinds of stress, thermal, mechanical and chemical, thermal appears to be the least ecologically significant for the temperature rises (ΔT's) found at Maryland power plants (7). The results of several recent studies supporting this conclusion are summarized in Table 5.2. Thermally-induced mortalities, if any, occur during the summer when water temperatures are maximal. However, mechanical stress causes significant mortality to entrained fish larvae at all times (7). When chlorine is used, it causes mortalities among several types of plankton (cf. Table 5.3) (7 - 10).

The contribution of each stress mode to impact is a function of the volume of flow of cooling water and the ΔT of the plant. If the flow is decreased, entrained organisms will experience a higher ΔT, but fewer will be exposed to mechanical and chemical stress.

3. Discharge-Related Effects

The dispersion of thermal discharges has been modeled, studied, and debated for many years. Potential environmental effects have been described in great detail (3). The consensus is that benthic communities (bottom dwellers) are the most

FIGURE 5.1

CHLORINATION RATES VERSUS COOLING FLOW RATES FOR ONCE-THROUGH SYSTEMS IN MARYLAND AREA PLANTS FOR 1974

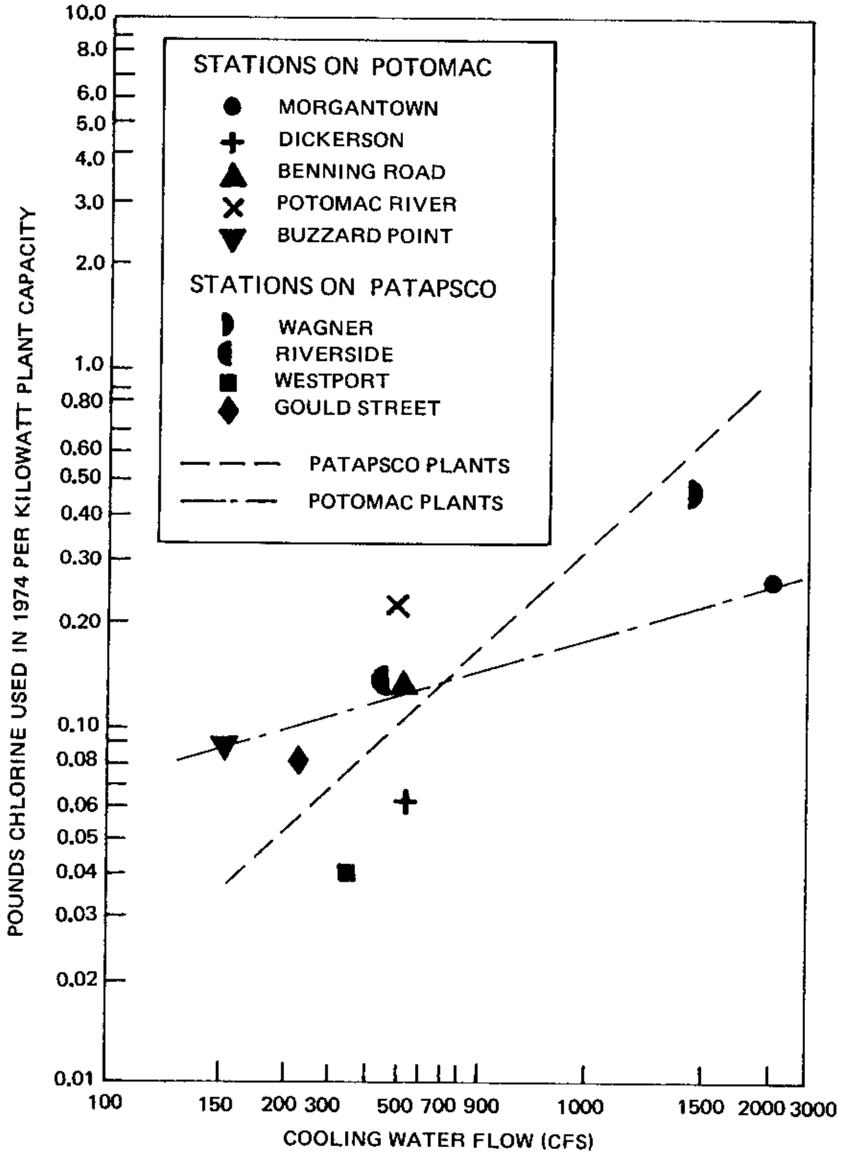


TABLE 5.2

THERMAL TOLERANCE STUDIES

Organism	Reference	Ambient Temperature	ΔT	Exposure Time	Observed Mortality	Thermal Dose Range (degree-seconds)
Amphipod (Gamarus) Mysid Shrimp (Neomysis) Grass Shrimp (Palaemonites) Blue crab (Callinectes) Mud crab (Rhithrapanapeus)	(11)	5°C 15°C 25°C 30°C	5°C	4 min. with 15 min. temperature decay to ambient	None	1,200+
Amphipod (Gamarus)	(9)	25°C 11.7°C	10°C 16.7°C	5-60 min. 180 min.	None None	3,000-36,000 172,800
Mysid shrimp (Neomysis)	(12)	14-22.5°C	less than 30.5°C	2,4,6 min.	Little or none	3,600-10,800
American shad eggs Alewife eggs Blueback herring eggs Striped bass eggs White perch eggs	(13)	12-18°C	6-10°C	2.5-60 min.	Little or none	900-36,000
Menhaden larvae Spot larvae Pinfish larvae Flounder larvae	(14)	5°C 10°C 15°C 20°C	12,15, 18°C	5,10,20, 30,40 min.	Little or none at 12° CΔT, except menhaden (significant mortality when ambient exceeded 10°C) Significant mortality of all species at ΔT >12°C.	3,600-48,000
Striped bass larvae	(15)	?	15, 20°C	2.5-180 min.	Significant mortalities or effects at ΔT >15°C.	2,250-216,000

prone to heat-plume impact because, being immobile, they have constant exposure. To date, no documented deleterious thermal plume effects of a significant nature have been reported in Maryland.

Aquatic life, from algae to finfish, are sensitive to chlorine and its long-lived residuals (16). Clam larvae may suffer mortality from levels as low as 1 ppb of chlorine residuals; adult spot, a common Bay fish, die at levels of 0.2 ppm (Table 5.3) (10). Calculated chlorine residual concentrations in the discharge canal at Morgantown during normal operations ranged from 0 to 0.5 ppm, overlapping the lethal concentrations for some organisms (Table 5.3) (17). No chlorine-related mortality was found by field examination. The single documented chlorine-related kill in Maryland occurred at PEPCO's Chalk Point plant in the late 1960's (3). Forty thousand crabs in the discharge canal of the plant were killed by what may have been faulty chlorination schedules or release of toxic waters stored during a period of shutdown. The kills were eliminated by more careful scheduling of operations.

TABLE 5.3

TOLERANCE LEVELS (TL_{50}) OF AQUATIC ORGANISMS FOR CHLORINE RESIDUALS

Organism	TL_{50}	Exposure Time
Clam larvae	1 ppb	96 hours
Oyster larvae	5 ppb	" "
Copepod - <u>Acartia tonsa</u>	50 ppb	" "
Spot	0.2 ppm	" "
Grass shrimp	0.3 ppm	" "
Pipefish	0.3 ppm	" "
Algae	0.6 ppm	4 hours
Level at which shell production in adult oysters is reduced 50%	5 ppb	48 hours

Source: Reference 10

Maryland State water quality regulations limit the total discharge of chlorine residuals to 0.5 ppm in tidal waters. Maryland power plants are operating within these limits. Sewage treatment plants in Maryland use about 25 million pounds of chlorine annually compared to approximately 2 million pounds by Maryland power plants. Because of the potential impact of chlorine, alternative biolfouling control techniques (mechanical cleaning -- Amertap system, bromine chloride) are being tested by power companies and in Federal and State laboratories.

Regulations recently promulgated by EPA will limit chlorine discharges to an average concentration of 0.2 ppm after 1 July 1977.

B. Distributions of Aquatic Resources With Respect to Power Plant Sites

Regional power plant impact is a function of individual plant characteristics and the relationship of plant sites to the location and sensitivity of important fisheries.

1. Aquatic Resources

Commercial and recreational fisheries figure prominently among the natural resources of the Bay. Table 5.4 lists the commercial landings for the period 1972-74. This list includes most estuarine species of particular recreational value.

Important shellfish are estuarine or marine (i.e. occur only in saline waters). Finfish can be divided into three separate groups: freshwater (e.g., catfish and bullheads), marine or estuarine (e.g., spot, seatrout, menhaden), and anadromous (e.g., alewives, shad, and striped bass). The latter group consists of fish which migrate into freshwater to spawn but spend most of their lives in estuaries or at sea. As noted in Table 5.4, the dollar value of anadromous fish comprises over 60% of the value of all fish taken.

Freshwater species like sunfishes are omitted from the list because the restricted movement of these species makes it unlikely that cumulative effects can be expected from power plant operations. Locations of existing and proposed Maryland plants overlap only slightly the habitats of the freshwater species.

2. Resource Distribution in Relation to Power Plant Sites

The Chesapeake Bay is a tidal estuary. Nutrient-rich runoff moves down the tributaries to mix with intruding seawater. Maryland's portion of the Bay has salinities ranging

TABLE 5.4

MARYLAND COMMERCIAL LANDINGS(a)

	1972		1973		1974	
	Pounds	Dollars	Pounds	Dollars	Pounds	Dollars
Fish						
Alewives*	1,654,641	$ 33,098	2,331,424	$ 45,254	1,387,676	$ 31,801
Bluefish	59,075	5,802	275,330	23,097	372,738	28,357
Catfish and Bullheads	386,340	39,567	295,083	31,125	302,628	37,908
Eels	229,764	33,164	180,466	44,118	144,527	42,984
Menhaden	6,212,002	124,614	9,686,956	221,059	4,932,962	128,631
Sea trout	313,428	34,125	539,520	74,615	372,832	47,754
Shad*	954,145	117,299	597,914	105,573	221,444	46,000
Spot	68,171	10,974	27,322	5,244	10,018	1,383
Striped bass*	3,185,929	917,548	4,677,617	1,451,800	3,382,852	880,329
White perch*	1,108,033	204,784	762,719	162,697	497,755	93,402
Yellow perch*	101,465	13,549	35,523	7,150	35,409	5,070
Other finfish and Unclassified	897,610	185,717	1,179,483	246,222	1,602,952	277,375
TOTAL FISH	15,170,603	$ 1,720,241	20,589,357	$ 2,417,954	13,263,793	$ 1,620,994
Anadromous fish and % of total		$ 1,286,278 (74%)		$ 1,772,474 (73%)		$ 1,056,602 (65%)
Shellfish						
Blue crabs (hard, soft, peeler)	25,050,531	$ 3,114,209	20,723,286	$ 3,484,057	24,973,677	$ 4,631,815
Soft clams	1,949,520	1,014,782	668,688	557,240	1,766,136	1,501,210
Oysters	19,052,800	11,963,272	19,055,700	12,561,489	17,263,970	11,588,664
Turtles (snapper)	18,023	3,597	24,353	5,189	36,540	10,226
Terrapin (Diamondback)	3,545	1,523	1,458	709	1,733	1,016
TOTAL SHELLFISH(b)	46,074,419	$16,097,383	40,473,485	$16,608,684	44,042,056	$17,732,931
GRAND TOTAL	61,245,022	$17,817,624	61,062,842	$19,026,638	57,058,849	$19,353,925

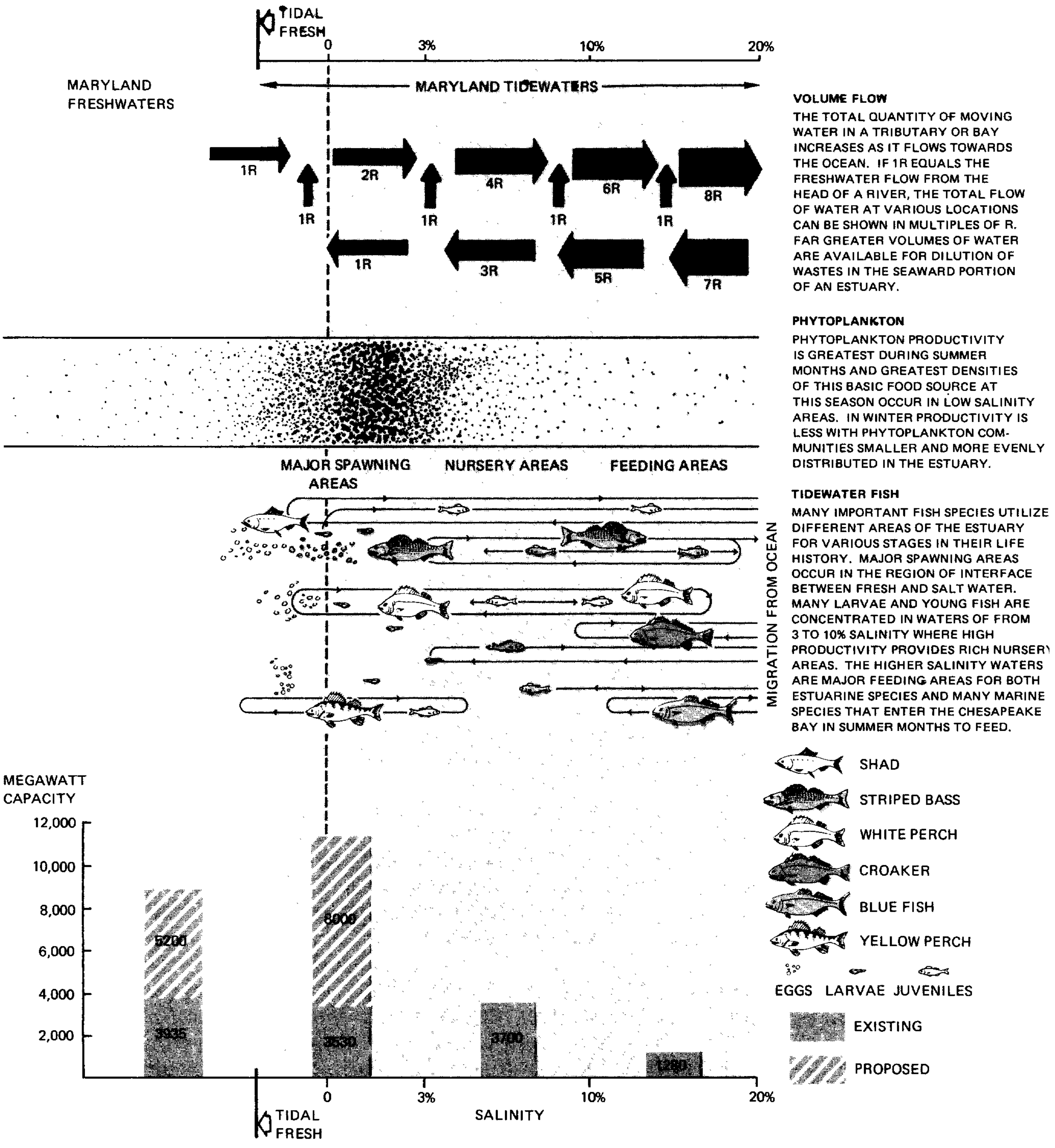
(a) Source: "Maryland Landings," Current Fisheries Statistics Nos. 6385 and 6660 (Preliminary), U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, December 1973 and December 1974.

(b) Exclusive of the following species limited primarily to Atlantic Ocean waters: lobsters, hard and surf clams, conch, and squid.

* Anadromous species

FIGURE 5.2

POWER PLANTS IN RELATION TO THE ECOLOGY OF THE ESTUARY



VOLUME FLOW

THE TOTAL QUANTITY OF MOVING WATER IN A TRIBUTARY OR BAY INCREASES AS IT FLOWS TOWARDS THE OCEAN. IF 1R EQUALS THE FRESHWATER FLOW FROM THE HEAD OF A RIVER, THE TOTAL FLOW OF WATER AT VARIOUS LOCATIONS CAN BE SHOWN IN MULTIPLES OF R. FAR GREATER VOLUMES OF WATER ARE AVAILABLE FOR DILUTION OF WASTES IN THE SEAWARD PORTION OF AN ESTUARY.

PHYTOPLANKTON

PHYTOPLANKTON PRODUCTIVITY IS GREATEST DURING SUMMER MONTHS AND GREATEST DENSITIES OF THIS BASIC FOOD SOURCE AT THIS SEASON OCCUR IN LOW SALINITY AREAS. IN WINTER PRODUCTIVITY IS LESS WITH PHYTOPLANKTON COMMUNITIES SMALLER AND MORE EVENLY DISTRIBUTED IN THE ESTUARY.

TIDEWATER FISH

MANY IMPORTANT FISH SPECIES UTILIZE DIFFERENT AREAS OF THE ESTUARY FOR VARIOUS STAGES IN THEIR LIFE HISTORY. MAJOR SPAWNING AREAS OCCUR IN THE REGION OF INTERFACE BETWEEN FRESH AND SALT WATER. MANY LARVAE AND YOUNG FISH ARE CONCENTRATED IN WATERS OF FROM 3 TO 10% SALINITY WHERE HIGH PRODUCTIVITY PROVIDES RICH NURSERY AREAS. THE HIGHER SALINITY WATERS ARE MAJOR FEEDING AREAS FOR BOTH ESTUARINE SPECIES AND MANY MARINE SPECIES THAT ENTER THE CHESAPEAKE BAY IN SUMMER MONTHS TO FEED.

from fresh (0 parts per thousand) to about 20 ppt (2/3 the salinity of undiluted seawater). The salinity gradient from the head of the Bay to its mouth largely controls habitat use. Figure 5.2 encompasses salinity regimes with zones of biological activity of estuaries, and the location of existing and proposed electrical generation.

The strong influence of salinity on the finfish life stages is illustrated in Figure 5.2. Some anadromous fish (e.g., striped bass) spawn in freshwater just above the fresh-saltwater interface: others (e.g., alewives) move up into the headwaters of the tributaries. Striped bass and American shad spawn for relatively short times (usually late spring) and use well-defined areas for this purpose (Figure 5.3). Ocean spawners (e.g., bluefish and croaker) enter the Maryland Bay at the post-larval stage. Juveniles of most important species favor salinities of 0 - 10 ppt -- which encompass approximately one-half the Bay. Adults range over all salinities. The distributions of all life stages change seasonally, as illustrated in Figure 5.3 for the striped bass.

Commercially important shellfish are seldom found in harvestable numbers in waters with salinity less than 5 ppt. The preponderance of proposed and existing generating capacity in the State is situated on waters of less than 5 ppt salinity (Figure 5.2), so that commercial shellfish bars should not come under the influence of power plant operations.

C. Impact of Power Plants on Resources

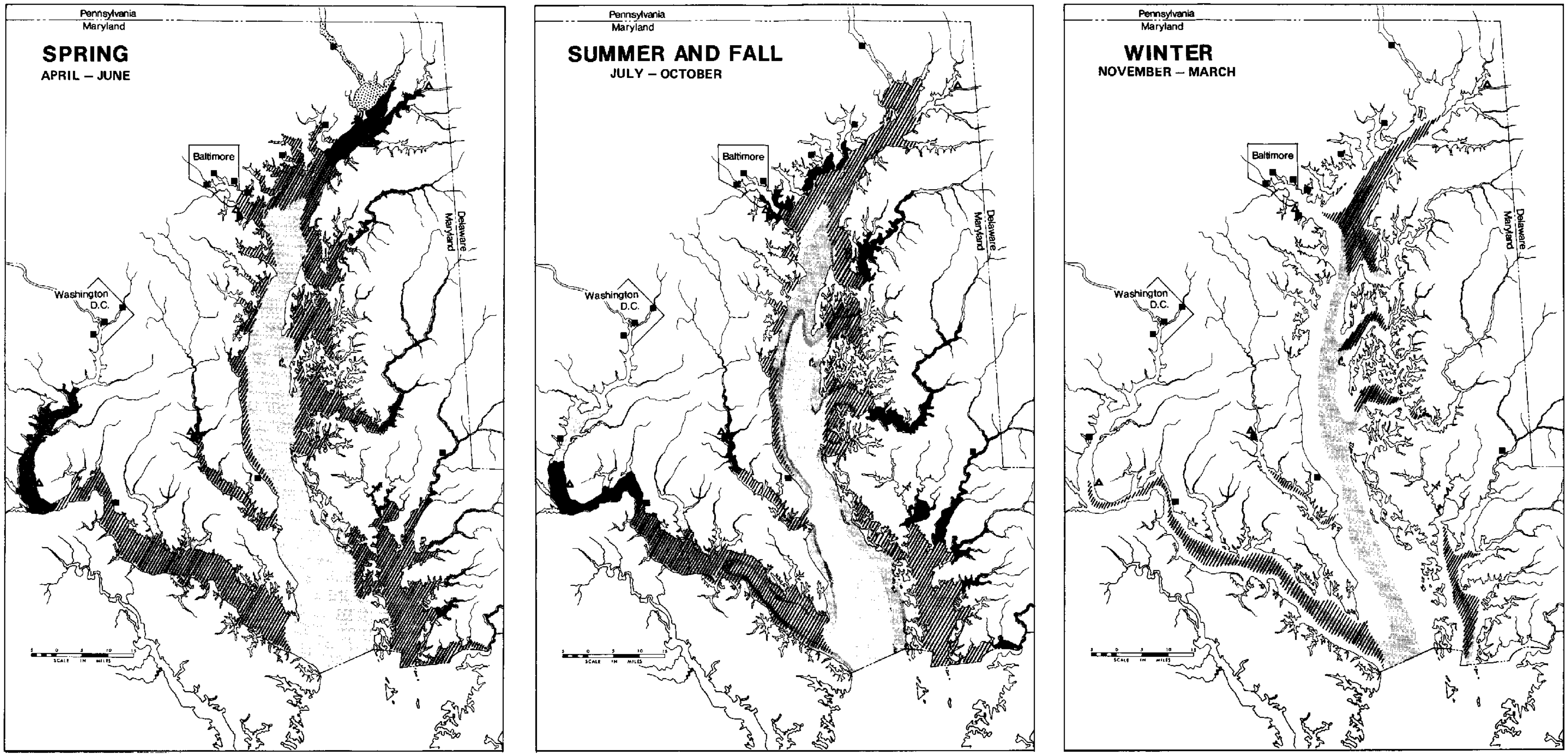
Potential power plant impacts to a living resource include: (1) killing at some life stage; (2) excluding an organism from an essential habitat (e.g., spawning area); and (3) depriving or depleting food organisms.

Of these, the impact most directly evident involves kills of adult and juvenile fish (2, 3). Regional impacts from such kills are negligibly slight unless they occur chronically and in areas where fish concentrate (e.g., spawning grounds). The small number of impingement episodes recorded in Maryland is not of this latter type.

Repeated kills of shad, herring, and alewives occurred during the 1960's at the Conowingo hydroelectric generating station on the Susquehanna. Springtime kills of spawning anadromous fish occurred below the dam when the turbines were shut off at night, and no water passed the dam site. The cause of mortality was traced to a depletion of dissolved oxygen by fish massed at the foot of the dam during spawning runs (18). These kills have not been repeated since an agreement between the utility and the Maryland Department of Natural Resources went into effect, guaranteeing a continuous minimum flow of 5,000 cfs through the dam during the spawning season.

FIGURE 5.3

DISTRIBUTION OF STRIPED BASS IN RELATION TO POWER PLANTS IN MARYLAND



SPRING: Large schools of striped bass migrate to tidal-fresh and slightly brackish waters to spawn. Arriving in April, most of these fish have left by the end of June. Some will be found in the lower reaches of the rivers and in the Chesapeake Bay proper, en route to or from the spawning grounds. Juveniles from the previous year's hatch move from their wintering grounds as warm weather approaches and spread throughout the tributaries.

SUMMER AND FALL: Schools of striped bass have moved down from the spawning areas and spread throughout the Bay system. They feed actively at the surface and are generally more concentrated along shoal areas. Juveniles are found primarily in the tributaries, the smallest remaining mostly in upstream nursery areas.

WINTER: As cold weather approaches, adult striped bass move to deeper channel waters where they overwinter. Juveniles, spawned the previous spring, also move to these deeper waters, but generally they remain within the tributaries rather than the Bay proper.

■ Striped Bass spawning areas

░ Adults—Dark shade indicates areas of greatest concentrations.

▒ Areas of former striped bass spawning no longer suitable.

▨ Juveniles.

■ Nursery areas for young-of-the-year.

■ Existing Power Plants.

△ Proposed Power Plants.

A potential for adverse power plant effects on a regionally significant scale involves loss of fish eggs or larvae. Much of the State's present and proposed generation is located on salinities similar to those used for spawning and nursery grounds (cf. Figure 5.2). Shellfish populations are not prone to depletion by entrainment because their spawning is widespread: oyster spat or clam larvae produced in one region can migrate appreciable distances before settling. These can compensate for local power plant-induced attrition. Finfish stocks supported by ubiquitous spawn, for example, the white perch, are buffered against localized impacts. This is not true of striped bass whose population vulnerability is magnified if their relatively few spawning grounds come under stress. Bass spawn only once in a normal year, and growth to sexual maturity takes 3-5 years, so regeneration cycles are reckoned in half-decades. How loss of some fraction of a year's eggs and larvae translates into a subsequent reduction of the harvestable fishery is the subject of intense study. This information is essential for linking power plant entrainment (which is measureable) to future resource availability. Elaborate mathematical simulations of fishery dynamics do not compare well with field data (19). The tempo of research on this topic has increased substantially in the last two years.

Migration route blockage by heated effluents is mentioned frequently as being one of the more ecologically disruptive side effects of power generation. Extensive monitoring of Pacific salmon and American shad movement past power plants have detected no modification of migration patterns (20, 21). In fact, accumulating evidence from estuaries around the country fails to confirm any cases of this purported mechanism.

Exclusion refers to a discharge's rendering a habitat unsuitable for one or more kinds of indigenous biota. The rate of power plant discharge is a few percent of natural circulation in the usual estuarine situation. Dilution quenches the excess temperature rapidly when discharge structures are designed properly. At Morgantown, the mixing zone between heated discharge and ambient water is estimated to extend 1,500 to 2,000 ft out from the plant (17). The consequences of excluding organisms from an area this small would not be significant.

Zooplankton and phytoplankton, the bases of the food chain of the Bay, comprise most of the organisms suffering entrainment mortality. Any depletions in these food chain organisms are a transient phenomenon (5) because of their very short generation times. Phytoplankton reproduce in 12 hours, and zooplankton reproduce in 2 - 3 days (17).

Forage fish (e.g., menhaden, bay anchovies), occupying the middle of the food chain, are not capable of rapidly recouping population losses from power plant damage like the plankton on which they feed. The resiliency of their populations results from their ubiquitous abundance and non-localized spawning distributions (22, 23).

D. Maryland Power Plant Characteristics

Some characteristics of existing Maryland power plants pertinent to aquatic impact are listed in Table 5.5 and discussed in detail below. Other information relating to these plants and proposed plants is provided in Figure 3.1 of Chapter 3.

The ratio of cooling water flow to receiving body flow determines entrainment probability and dilution of discharge pollutants. The potential for dilution in an estuary is greater in its lower reaches where circulation is more vigorous. Most existing plants are located in the middle reaches of their estuaries (see Figure 5.2) where flows are many times greater than cooling water flows.

Several newer plants have incorporated into their design ecologically motivated engineering features, including curtain walls, mechanical cleaning, and augmentation pumping. The two newest Maryland plants (Morgantown and Calvert Cliffs) have curtain walls. These structures extend down into the water column from the surface at the entrance to the intake embayment. Their function is to insure that cooling water is withdrawn from the bottom of the water column, where water temperatures and densities of organisms tend to be lower than at the surface.

These two plants also use mechanical scrubbing sponges (Amertap system) for cleaning condenser tubes. This allows minimal use or elimination of chlorine for biofouling prevention.

Chalk Point and Morgantown use augmentation pumping, mixing water from condensers with additional cooling water prior to discharge. The intent of this blending was to meet a 90°F maximum discharge requirement. This practice has been found to be ecologically counterproductive because larger numbers of organisms are exposed to plant stress (17).

E. Resource Characterization of Plant Sites

The juxtaposition of power plant sites and resource habitats vital to valuable aquatic species determines the degree of risk to important fisheries. As mentioned earlier, the fish most imperiled are those whose major spawning or nursery grounds are subject to power plant-induced perturbations.

1. Hydroelectric Plants

Conowingo Hydroelectric Station has been implicated

TABLE 5.5

SOME PARAMETERS FOR OPERATING MARYLAND POWER PLANTS RELATING TO AQUATIC STRESS

Utility[b]	Station	Unit Completion Dates	Average Annual Chlorine Use (lb/kw)		Typical Summer Thermal Dose: D = ΔT (°F) x t (sec)[a]			Average Water Flow[c] (cfs)		Average Flow of Receiving Water[d] (cfs)	Receiving Water Body	Profile of Receiving Body (ft)		Discharge Canal	Curtain Wall	Mechanical Cleaning
			1972	1974				With-drawn	Through Condenser			Width	Outfall Depth			
APSCO	R. P. Smith	1923–58	0	0	2,520	8.4	300	125.1	121.1	3141[e]	Potomac	700	0	X		
BG+E	C. P. Crane	1961–63	0	0	16,422	11	1,428	636	636	Tidal	Seneca Cr. (Patapsco)	1,320	1	X		
BG+E	Gould St.	1926–52	0.92	0.08	1,277	13.3	96	237	237	Tidal	Patapsco	5,300	4	X		
BG+E	Riverside	1942–53	0.45	0.16	2,970	15	198	486	486	Tidal	Patapsco	8,000	8	X		
BG+E	H.A. Wagner	1956–72	0.42	0.43	2,496	13	192 (max)	1,471	1,471	Tidal	Patapsco	10,600	#1-6:6 #4:1.5	X		
BG+E	Westport	1905–50	0.78	0.04	2,554	13.3	192	353	353	Tidal	Patapsco	2,200	4.5	X		
BG+E	Calvert Cliffs	1974–	--	0	2,400	10	240	2,754 (one unit)	2,754	Tidal	Ches. Bay	26,400	20	(g)	X	X
Dlmrva	Vienna	1928–71	0	0.08	NA	12	NA	130	124	Tidal	Nanticoke	1,000	15	X		
PEPCO	Benning Rd.	1906–72	0.1	0.14	NA	#10-12: 10 #13:17 #15-16: 24[c]	NA	266	520.1	Tidal	Anacostia	NA	2			
PEPCO	Buzzard Point	1933–45	0.004	0.09	NA	10	NA	155	155	Tidal	Anacostia	NA	NA			
PEPCO	Chalk Point	1964–65	1.02	1.20	79,200	11	7,200	871	696	Tidal	Patuxent	6,200	NA	X		
PEPCO	Dickerson	1959–62	0.13	0.06	4,800	16	300	584	553	9810[e]	Potomac	600	8	X		(f)
PEPCO	Morgantown	1970–71	0.44	0.26	24,000	10	2,400	2,229	2,222	Tidal	Potomac	10,000	20	X	X	X
PEPCO	Potomac River	1949–57	0.29	0.23	NA	14	NA	520	518	Tidal	Potomac	NA	NA			
VEPCO	Possum Point	1948–62	0	0	6,278	14.6	430	522	522	Tidal	Potomac	NA	2			

Source of data (except for columns labeled "Typical Summer Dose," " Curtain Wall," and "Mech. Cleaning") = "Steam-Electric Plant Air and Water Quality Control Data for the Year Ended December 31, 1974 for each Utility, as reported to the Federal Power Commission, and the 1972 chlorination data, which was obtained from Reference 47. ΔT(°F) = average temperature rise over condenser for 1974 as reported for each plant to the FPC except for Chalk Point, Dickerson, Morgantown and Calvert Cliffs where design temperature rises are used. ΔT's for Benning Rd., Buzzard Pt. and Potomac River from PEPCO. Calvert Cliffs data from BG+E.

[a] Includes retention time in effluent canals.

[b] APSCO = Allegheny Power Service Corporation; BG+E = Baltimore Gas and Electric Company; Delmarva = Delmarva Power and Light Company; PEPCO = Potomac Electric Power Company; VEPCO = Virginia Electric and Power Company.

[c] Once-through cooling systems, with the exceptions of Vienna and Benning Road, which utilize mechanical draft cooling towers for 61% and 72%. respectively, of their generation.

[d] The flushing rates (and biological regeneration times) of tidal, stratified systems are currently being investigated: this is important to know because the relative impact to an ecosystem depends upon the percentage of natural flow taken into the power plant.

[e] Source of data: Patrick N. Walker, "Flow Characteristics of Maryland Streams," Maryland Geological Survey, Report of Investigations, No. 16, (1971).

[f] Dickerson has ability to back-flush on-line.

[g] Discharge tunnel

as a source of impact to major resource species. Fish kills at Conowingo have been accompanied over the years by declines in runs of shad and alewives (18). Declines have also occurred in other rivers along the Atlantic Coast (24). Thus, the plant may not be the responsible factor in the Susquehanna. No kills have occurred there since new operational procedures were implemented in 1971, and no additional cumulative impact would be expected in the future.

2. Non-Tidal Freshwater Power Plants

R. P. Smith and Dickerson, both on the Potomac, are relatively old plants of low- to medium-generating capacity (Table 5.5). Fish around these plants are typical warm-water varieties (e.g., sunfish, catfish) common to local rivers (25). Planktonic organisms occur in normally low densities, and common freshwater benthic organisms are present (25-27). Periodic flooding is the determining factor limiting productivity in this area (27).

3. Baltimore Plants

These plants are situated on the Patapsco River and its tributaries and Seneca Creek (see Figure 3.1). This part of the Bay is not a spawning ground of consequence (28). White perch, the most common fish (28), are found virtually throughout the Bay and spawn in nearly all tributaries (22). The entire region is closed to shellfishing (30). With the exception of Wagner and Crane, these plants are all older than 20 years, are used for peaking service, and are likely to see less service as Calvert Cliffs increases generation.

4. Washington Plants

Urban runoff, farm runoff, and sewage discharges have created chronic oxygen deficiencies in these waters (31).* This decline in water quality has been reflected in a reduction in diversity and abundance of fish (32 - 34) to the extent that no viable fisheries remain.

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*The depletion of DO in Maryland waters due to urban runoff and oxygen demand of sewage is demonstrated by EPA studies of water quality in the Potomac River around Washington, D. C. (48 - 52). Data for 1971, the most recent available, show an average summer DO concentration of 7.7 ppm in the upper Potomac (i.e., from Chain Bridge to Indian Head), and 8.1 ppm riverwide (52). At one location in the upper Potomac, however, measured DO levels in the summer were below 1.0 ppm. In comparision, DO levels in the Potomac estuary at Maryland Point, site of the proposed Douglas Point nuclear power plant, have never fallen below 5 ppm, and averaged 7.0 ppm for the period 1962-1971. The EPA Water Criterion for the Protection of Aquatic Life is 4.0 ppm DO at all times to protect most species (48).

5. Estuarine Plants

Morgantown and Possum Point are both located near regions of the Potomac River used by striped bass for spawning. Salinities at Morgantown are too low for important shellfish and too high for the spawning of important finfish (36). Few striped bass eggs and larvae were taken at the plant intake during repeated studies of entrainment (35). Too few larvae are entrained to constitute a threat to the population (39).

Recent work (39) indicates that Possum Point entrains a maximum of approximately 2% of striped bass larvae produced annually. Possum Point is situated above major shellfish beds.

The Nanticoke River, location of the Vienna plant, is a striped bass spawning ground. Recent expansion of the generating capacity of that site was accompanied by construction of cooling towers to minimize withdrawals. Striped bass eggs and larvae are entrained at this plant (40). Consequences of this entrainment are presently unknown.

Calvert Cliffs is the State's only nuclear power plant. Extensive preoperational studies have documented the absence of spawning or concentrations of important species at this site (4, 41). This plant is being closely monitored by State, Federal, and utility investigators (37).

Sporadic kills of fish and crabs have occurred at Chalk Point (in the late 1960's), possibly related to discharged chlorine (3). The greening of oysters as a result of heavy metal discharge was associated with start-up operations (38). These episodes have not recurred. Only goby and anchovy larvae were found among entrained species at Chalk Point in recent studies (43). Thus, this plant is likely to be exerting minimum impact on important species.

F. Proposed New Generating Facilities

Of proposed new generating capacity, only one completely new facility and expansions of four existing facilities are expected to be completed in the next ten years.

Brandon Shores, the new facility, will be located on a tributary of the Patapsco River in tidal, low salinity waters. As such it can be considered a member of the Baltimore metropolitan area group of plants. The expansion of the Riverside and Perryman plants falls into the same category. Extensive studies of the aquatic biota of these areas have been made (28, 29, 44 - 46). Following the arguments presented earlier, these new plants can be expected to contribute minimally to impact on Bay resources.

The additional expansions will be constructed at

Dickerson (Potomac River) and Chalk Point (Patuxent River). New units at both these facilities will have closed circulating systems utilizing cooling towers, as will the plants discussed above. As a result, additional cooling water withdrawals will be minimal, and they are not expected to contribute to increased aquatic impact.

G. REFERENCES

Chapter 5

1. Jensen, L. D., "The Effects of Thermal Discharges into Surface Waters," in Human and Ecologic Effects of Nuclear Power Plants, Leonard A. Sagan, M. D. (ed.) Charles C. Thomas, Publishers, Springfield, Ill., 1974.

2. Edsal, T. A. and Yocom, T. G., report prepared for U. S. Fish and Wildlife Service, Great Lakes Fishery Laboratory, Ann Arbor, Michigan, 1972.

3. Clark, J. C. and Brownwell, W., "Electric Power Plants in the Coastal Zone -- Environmental Issues," American Littoral Society Special Pub. 7, Highland, New Jersey, October 1973.

4. Semi-annual Environmental Monitoring Report: Calvert Cliffs Nuclear Power Plant, Baltimore Gas and Electric Company, September 1975.

5. Entrainment and Intake Screening Workshop, JHY Homewood Campus, February 5-8, 1973: Agenda and reprints, as available, from Dr. L. Jensen, Department Geography and Environ. Eng., JHU, Baltimore, Maryland.

6. Alevras, R. A., "Status of Air Bubble Fish Protection System at Indian Point Station on the Hudson River," in Second Workshop on Entrainment and Intake Screening, Rept. #15, Johns Hopkins University, Baltimore, Maryland, 1974.

7. Marcy, B. C., Jr., "Entrainment of Organisms at Power Plants, with Emphasis on Fishes -- An Overview," in Fisheries and Energy Production: A Symposium, S. Saila (ed.), D. C. Heath and Company, Lexington, Mass., 1975.

8. Heinle, D. R., et al., "Zooplankton Studies at Morgantown," in Proceedings of the Second Workshop on Entrainment and Intake Screening, Report #15, Johns Hopkins University, Baltimore, Maryland, 1974.

9. Ginn, T. C., et al., "The Effects of Power Plant Condenser Cooling Water Entrainment on the Amphipod, *Gamarus*," Water Res. Vol. 8, p. 937, 1974.

10. Hugget, R., Virginia Institute of Marine Sciences, Gloucester Point, Virginia, Personal Communication, July 1975.

11. Burton, D. T., et al., "Effects of Low ΔT Power Plant Temperatures on Estuarine Invertebrates," in manuscript, 1975.

12. Hair, J. R., "Upper Lethal Temperature and Thermal Shock Tolerance of the Oppossum Shrimp, *Neomysis awatschensis*, from the Sacramento-San Joaquin Estuary, California," *Calif. Fish and Game*, Vol. 57, No. 1, p. 17-27,1971.

13. Schubel, J. R., "Effects of Exposure to Time-Excess Temperature Histories Typically Experienced at Power Plants on the Hatching Success of Fish Eggs," PPRP-4, Power Plant Siting Program, 1974.

14. Hoss, D. E., W. F. Hettler, Jr., and L. C. Coston, "Effects of Thermal Shock on Larval Estuarine Fish -- Ecological Implications With Respect to Entrainment in Power Plant Cooling Systems," in *Proceedings of the Symposium on the Early Life History of Fish*, Oban, Scotland, 1973.

15. Schubel, J. R., "Some Comments on the Thermal Effects of Power Plants on Fish Eggs and Larvae," in *Fisheries and Energy Production: A Symposium*, S. Saila (ed.), D. C. Heath and Company, Lexington, Mass., 1975.

16. "Toxicity of Power Plant Chemicals to Aquatic Life," WASH 1249 (compiled by C. D. Becker and T. O. Thatcher for U. S. Atomic Energy Commission), Pacific Northwest Laboratories, June 1973.

17. Polgar, T. T., L. H. Bongers, G. M. Krainak, "Assessment of Nearfield Manifestations of Power Plant Induced Effects on Zooplankton," MT-75-5, April 1975.

18. "Assessment of the Effects of Hydroelectric Water Discharged from The Conowingo Dam on Spawning Fish in the Lower Susquehanna River," Maryland PPSP, January 1974.

19. Polgar, T. T., R. E. Ulanowicz, D. A. Pyne, and G. M. Krainak, "Investigations of the Rate of Physical Transport Processes in Determining Ichthyoplankton Distributions in the Potomac River," PPRP-11, PPMP-14, Maryland Power Plant Siting Program, Department of Natural Resources, 1975.

20. Templeton, W. L. and C. C. Coutant, "Studies on the Biological Effects of Thermal Discharges from Nuclear Reactors to the Columbia River at Harford," in *Environmental Aspects of Nuclear Power Stations*, International Atomic Energy Agency, Vienna, Austria, 1971.

21. Leggett, W. C. and R. A. Jones, "Annual Progress Report, A Study of the Rate and Pattern of Shad Migration in the Connecticut River Utilizing Sonic Tracking Apparatus," Project No. Connecticut AFC-1-3, 1970.

22. Lippson, A. J., (ed.), The Chesapeake Bay in Maryland -- An Atlas of Natural Resources, The Johns Hopkins University Press, Baltimore, Maryland, 1973.

23. Lippson, A. J. and R. L. Moran, Identification of Early Developmental Stages of Fishes of the Potomac River Estuary, PPSP-MP-13, Martin Marietta Laboratories, 1974.

24. Reagen, S. P. and J. W. Foerster, "Historical Analyses of the Commercial Shad Fisheries," Goucher College Pub. 12, Environmental Studies Program, 1975.

25. "Addendum to the Power Plant Site Evaluation Report: Dickerson Site," by Applied Physics Laboratory, Johns Hopkins University, January 1974.

26. "Power Plant Site Evaluation Interim Report -- Dickerson Site," PPSE-3-1, by Applied Physics Laboratory, Johns Hopkins University, April 1973.

27. "Power Plant Site Evaluation -- Aquatic Biology -- Final Report, Dickerson Site," PPSE-3-2, by Ecological Analysts, Inc., Johns Hopkins University, December 1974.

28. "Addendum to the Brandon Shores Site Evaluation," by Applied Physics Laboratory, Johns Hopkins University, January 1973.

29. "Power Plant Site Evaluation -- Brandon Shores Site," PPSE-1-2, by Applied Physics Laboratory, Johns Hopkins University, November 1972.

30. "Location of Restricted Shellfish Areas," Map, Maryland State Department of Health, January 1975.

31. Pheiffer, T. H., D. R. Donnely, and D. A. Possehl, "Water Quality Conditions in the Chesapeake Bay System," Technical Report 55, EPA, August 1972.

32. Giraldi, A. and A. Dietemann, "Fishes of the Upper Anacostia River System of Maryland," Atlantic Naturalist, Vol. 29, No. 2, p. 61, 1974.

33. O'Dell, C. J., H. J. King, III, and J. P. Gabor, "Survey of Anadromous Fish Spawning Areas," Federal Air Report, U. S. Department Commission, NOAA, Fisheries Administration, Maryland Department of National Resources, Annapolis, Maryland, 1973.

34. Loos, J., "Shore and Tributary Ichthyoplankton and Juvenile Fish Survey," Potomac River Fisheries Program, for the Martin Marietta Corporation, Academy of Natural Sciences of Philadelphia, Philadelphia, Pennsylvania, 1975.

35. Mihursky, J. A., et al., "The Effects of Steam Electric Station Operations on Organisms Pumped Through the Cooling Water System: Macroplankton Studies, Morgantown SES Site," University of Maryland, N. R. I. Ref. No. 74-47, CEES, 1974.

36. Bongers, L. H., et al., "Impact of the Morgantown Steam Electric Station on the Potomac River Estuary: An Interpretive Summary of 1972-1974 Investigations," MT-75-6, Martin Marietta Laboratories, June 1975.

37. "Description of Aquatic Monitoring Programs at the Calvert Cliffs Nuclear Power Plant," Martin Marietta Corporation, March 1975.

38. Roosenburg, W. H., "Greening and Copper Accumulation in the American Oyster, _Crassostrea virginica_, in the Vicinity of a Steam Electric Generating Station," _Ches. Sci._, Vol. 10, p. 241, 1969.

39. "Hydrological-Biological Models of the Impact of Entrainment of Spawn of the Striped Bass (_Marone Saxatilis_) in Proposed Power Plants at Two Areas in the Upper Chesapeake Bay," Preliminary Draft, by Johns Hopkins University, Applied Physics Laboratory, Maryland PPSP, June 1975.

40. Mihursky, J. H., et al., "Final Report on the Effects of Steam Electric Station Operations on Organisms Pumped Through the Cooling Water System, I. Macroplankton Studies, Vienna SES - 1973,"University of Maryland, N. R. I. Ref. No. 74-75, CEES, March 1974.

41. "Ecological Effects of Nuclear Steam Electric Station Operations on Estuarine Systems," Third Progress Report to: U. S. Atomic Energy Commission, N. R. I. Ref. No. 74-100, University of Maryland, Center for Environmental and Estuarine Studies, 1974.

42. McErlean, A. J., et al., "Abundance, Diversity and Seasonal Patterns of Estuarine Fish Populations," _Estuarine and Coastal Marine Science_, Vol. 1, p. 19, 1973.

43. Mihursky, J. A., B. W. Gordon, and J. B. Cooper, "Progress Report on the Effects of Steam Electric Generating Station Operations on Organisms Passed Through the Cooling Water System - Macroplankton Studies, Chalk Point SES Site," University of Maryland, N. R. I. Ref. No. 73-76e, CEES, 1973.

44. "Power Plant Site Evaluation -- Aquatic Biology -- Final Report, Perryman Site," PPSE-2-2, Ecological Analysts, Inc., Johns Hopkins University, December 1974.

45. "Power Plant Site Evaluation Interim Report -- Perryman Site -- Biota of the Bush River," PPSE-2-M-1, Applied Physics Laboratory, Johns Hopkins University, June 1973.

46. "Power Plant Site Evaluation -- Brandon Shores Site," PPSE-1-1, Applied Physics Laboratory, Johns Hopkins University, November 15, 1972.

47. "A Critical State-of-the Art Review of Engineering Aspects of Power Plant Thermal Discharges," report prepared by Hydronautics, Inc. for EPA and Md. PPSP (draft), December 1973.

48. Mason, W. T., Jr., et al., Potomac River Basin Water Quality Status and Trend Assessment, 1962-1973, Interstate Commission on the Potomac River Basin, March 1975.

49. Jaworski, N. A., et al., "A Technical Assessment of Current Water Quality Conditions and Factors Affecting Water Quality in the Upper Potomac Estuary," CTSL, FWPCA, U. S. Department of the Interior, March 1969.

50. Jaworski, N. A., et al., "Nutrient Management of the Potomac Estuary," Technical Report 45, EPA, January 1971.

51. Jaworski, N. A., et al., "A Water Resource-Water Supply Study of the Potomac Estuary," Technical Report 35, EPA, April 1971.

52. Pheiffer, T. H., et al., "Water Quality Conditions in the Chesapeake Bay System," Technical Report 55, EPA, August 1972.

6. RADIOLOGICAL EFFECTS

The paramount concern in siting nuclear power plants is the potential for radiological hazard to surrounding populations. Risk to the public is minimized by rigorous control in siting, design, construction, and operation of reactors (1). Susceptibility to natural and man-made disasters is considered in siting and design so as to minimize chances for accidental releases. Local meteorological parameters, population densities, and evacuation mobilities are taken into account. Normal operations are governed by detailed technical specifications which limit the public radiation dose from normal releases to the lowest practicable levels (2).

A. Status of Nuclear Power in Maryland

The era of nuclear power in Maryland began with the recent start-up of Unit 1 (845 Mw) at Calvert Cliffs. A second unit is scheduled for completion in 1977. Several nuclear sites are mentioned in the current Ten-Year Plan of the Public Service Commission (Exhibit B). Firm construction schedules have been projected for only one of these (Douglas Point). The potential sites are: Douglas Point on the Potomac River (two boiling water reactors totaling 2,200 Mw); the Chesapeake City site on the C & D Canal (high-temperature gas-cooled reactors rated at 2,620 Mw); and a station to be located at either Black Oak or Point of Rocks on the upper Potomac River. All of the above are located in Figure 3.1.

Detailed site investigations at Douglas Point were initiated in the spring of 1973 by PPSP, utility, and AEC teams. Ecological, meteorological, and geological data have been collected for more than a year in preparation for PSC and AEC (now NRC*) hearings. Current estimates are that the earliest Douglas Point Unit I could begin commercial operations would be 1985. Tight money and slackening demand growth prompted cuts by BG&E and PEPCO (5), casting uncertainty on target dates for completion of Calvert Cliffs Unit 2 and possible construction of Douglas Point.

B. Siting and Operating Standards

An abbreviated outline of AEC criteria for siting and operating nuclear power plants appears in Table 6.1. In addition to these requirements, there are guidelines regarding allowable

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*The regulatory functions of the Atomic Energy Commission were formally assumed by the new Nuclear Regulatory Commission in early 1975. Hereafter, the acronyms NRC and AEC will be used according to the dates of the activities considered.

demography at nuclear sites. A total population of 8,000 within the low population zone has been considered a maximum (6). More recently, the AEC* has spoken of requiring special justification for low population zones less than two miles in radius and exclusion zones less than 0.4 miles in radius (7). The AEC is also developing a technique for comparing population distributions out to distances of 30 miles or more. This technique involves computing a "site population factor" (SPF) which sums the populations at various distances from the plant, weighted according to an approximation of meteorological dispersions at each distance, and then compares the sum to that which would be computed for a uniform population density of 1,000 persons/square mile (8). The AEC has identified a SPF of 0.500 (equivalent to a uniform population density of 500 persons/square mile) as the limit for a site. Beyond this limit, the site would require additional justification. (A SPF of 0.500 at two miles is consistent with 8,000 people within two miles.) Figure 6.1 shows the SPF values (for the 30-mile distance) as functions of location in the State.

In addition to population density, the suitability of any given site for a nuclear plant may be influenced by its proximity to hazardous human activities such as operations at airports, military reservations and heavy chemical industry. Natural features such as geologic faults may also affect site suitability. Major geologic features which may constitute potential site safety concerns within the State are identified in Figure 6.2. The acceptable distance from such features to a site can be determined only after detailed analysis.

By combining the information in Figures 6.1 and 6.2 with the dedicated lands depicted in Figure 7.3 and the requirements for adequate cooling water supply, it can be seen that relatively small portions of the State appear favorable for siting nuclear plants. Individual sites within the remaining areas may still be disqualified on the basis of site-specific features such as flood plains, ground water transport, unique wildlife habitats, and potential for subsidence, to name only a few concerns. Those sites which are suitable must be assessed for technological, ecological and sociological costs and benefits on a site-specific basis before those best suited for supplying new power to a projected load center can be identified.

It should be noted that Table 6.1 is an abbreviated version of NRC criteria. Environmental and engineering data satisfactory for NRC documentation typically fill 10-12 volumes. Predictions of population dose, for example, involve estimating deliberate and anticipated accidental releases of specific nuclides, dispersion and decay in water and in the atmosphere, possible biocentration, and human uptake and rejection rates. Figure 6.3 shows schematically the competing processes influencing aquatic vectoring of nuclides. Relative importance of the branching pathways in the Figure depends upon, among other

TABLE 6.1.

ABBREVIATED AEC CRITERIA FOR SITING AND OPERATING NUCLEAR POWER PLANTS[a]

Definitions

Microcurie (μCi) = 37,000 disintegrations per second.
Curie = 37 billion disintegrations per second.
rad = 100 ergs per gram of absorbing material.
rem = (rad)(rbe).
rbe = relative biological effectiveness of the radiation. For most gamma and X-radiation, rbe = 1.

Standards for Release of Radioactive Wastes

The basic standard is a limiting dose to any individual of 0.5 rem whole body/yr and 0.17 rem/yr to a segment of the general population. These limits are related to permitted concentrations of 250 radionuclides in the air and water near a nuclear reactor. An applicant for a reactor license must either assess the individual nuclides present in an effluent and see that their collective concentrations satisfy this relationship or hold the entire activity level below 1×10^{-7} μCi/ml.

Acceptable concentrations for air emissions for some radionuclides, notably those of iodine and strontium, are especially low to compensate for concentrating mechanisms in terrestrial food chains. Aquatic food chain concentrating mechanisms are not reflected in the water standards. Permitted concentrations in seafood are the same as for drinking water. At present, there are no firm recommendations on how to relate permitted seafood concentrations to acceptable concentrations in sea water.

AEC practice has been to require utilities to meet certain well-defined standards, and beyond this, to limit the plant's effluent to the "lowest practicable level." Recently, it has been proposed to make this "lowest practicable" operating principle quantitative by insuring that the dose received by an individual is less than 5% of the natural background dose (or specifically less than 5 mrem/yr). Plant designs will probably be considered acceptable if the dose to individuals from air emissions is less than 5 mrem per year and from water emissions is less than 5 mrem/yr.[b]

Factors to be Considered When Evaluating Sites

Factors considered in the evaluation of sites include those relating both to the proposed reactor design and the characteristics peculiar to the site. It is expected that reactors will reflect through their design, construction, and operation an extremely low probability for accidents that could result in release of significant quantities of radioactive fission products. In addition, the site location and the engineered features included as safeguards against the hazardous consequences of an accident, should one occur, should insure a low risk of public exposure. In particular, the Commission will take the following factors into consideration in determining the acceptability of a site for a power or testing reactor:

(a) **Characteristics** of reactor design and proposed operation including:

(1) Intended use of the reactor including the proposed maximum power level and the nature and inventory of contained radioactive materials;

(2) The extent to which generally accepted engineering standards are applied to the design of the reactor;

(3) The extent to which the reactor incorporates unique or unusual features having a significant bearing on the probability or consequences of accidental release of radioactive materials;

(4) The safety features that are to be engineered into the facility and those barriers that must be breached as a result of an accident before a release of radioactive material to the environment can occur.

(b) **Population density** and use characteristics of the site environs, including the exclusion area, low population zone, and population center distance. The applicant is required to identify for this purpose:

(1) An exclusion area within which the "licensee must have the authority to determine all activities including exclusion or removal of personnel and property from the area." Activities unrelated to operation of the reactor may be permitted to an exclusion area under appropriate limitations, but the licensee must be in a position to clear the area promptly in the event of an emergency. For example, the area may be traversed by a highway, railroad, or waterway, provided these are not so close to the facility as to interfere with normal operations of the facility and provided appropriate and effective arrangements are made to control traffic on the highway, railroad, or waterway in case of emergency.

(2) A low-population zone in which the "total number of residents and the population density are small enough (so that) measures could be taken in their behalf in the event of a serious accident."

AEC regulations do not specify a permissible population density or total population within this zone because the situation varies from case to case. Whether a specific number of people can, for example, be evacuated from a specific area or instructed to take shelter on a timely basis will depend on many factors such as location, number and size of highways, scope and extent of advance planning, and distribution of residents within the area.

(3) A population center distance which is the "distance from the reactor to the nearest boundary of a densely populated center containing more than about 25,000 residents."

(c) **Physical characteristics** of the site, including seismology, meteorology, geology and hydrology.

(1) The design for the facility should conform to accepted building codes or standards for areas having equivalent earthquake histories. No facility should be located closer than one-fourth mile from the surface location of a known active earthquake fault.

(2) Meteorological conditions at the site and in the surrounding area should be considered.

(3) Geological and hydrological characteristics of the proposed site may have a bearing on the consequences of an escape of radioactive material from the facility. Special precautions should be planned if a reactor is to be located at a site where a significant quantity of radioactive effluent might accidentally flow into nearby streams or rivers or might find ready access to underground water tables.

(d) **Where unfavorable physical characteristics** of the site exist, the proposed site may nevertheless be found to be acceptable if the design of the facility includes appropriate and adequate compensating engineering safeguards.

(e) **As an aid in evaluating** a proposed site, an applicant should assume a fission product release from the core, the expected demonstrable leak rate from the containment, and the meteorological conditions pertinent to his site to derive an exclusion area, a low-population zone and population center distance. For the purpose of this analysis, which shall set forth the basis for the numerical values used, the applicant should determine the size of an exclusion area such that an individual located at any point on the boundary for two hours immediately following onset of the postulated fission product release would not receive a total radiation dose to the whole body in excess of 25 rem or a total radiation dose in excess of 300 rem to the thyroid from iodine exposure. Similarly, the size of the low population zone is determined such that an individual located on the boundary for 30 days immediately following the postulated release would not receive a radiation dose in excess of these values. The minimum allowable population center distance is taken as 1-1/3 times the distance to the boundary of the low population zone.

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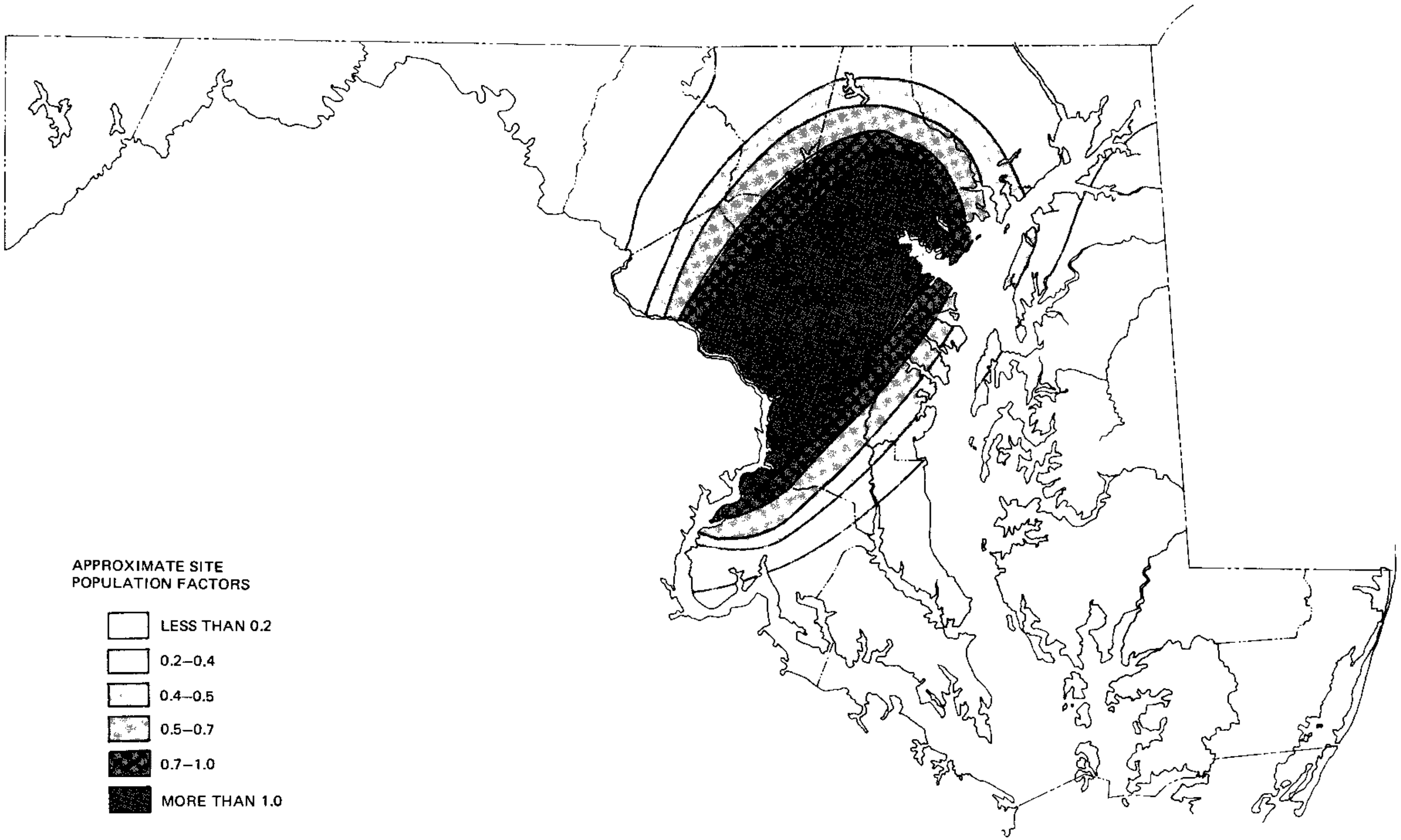
[a] No state may impose regulations more stringent than those set by the AEC.

[b] The specified dose is a whole body dose. The limit for skin is 15 mrem/yr/person, and for the thyroid, 15 mrem/yr/person.

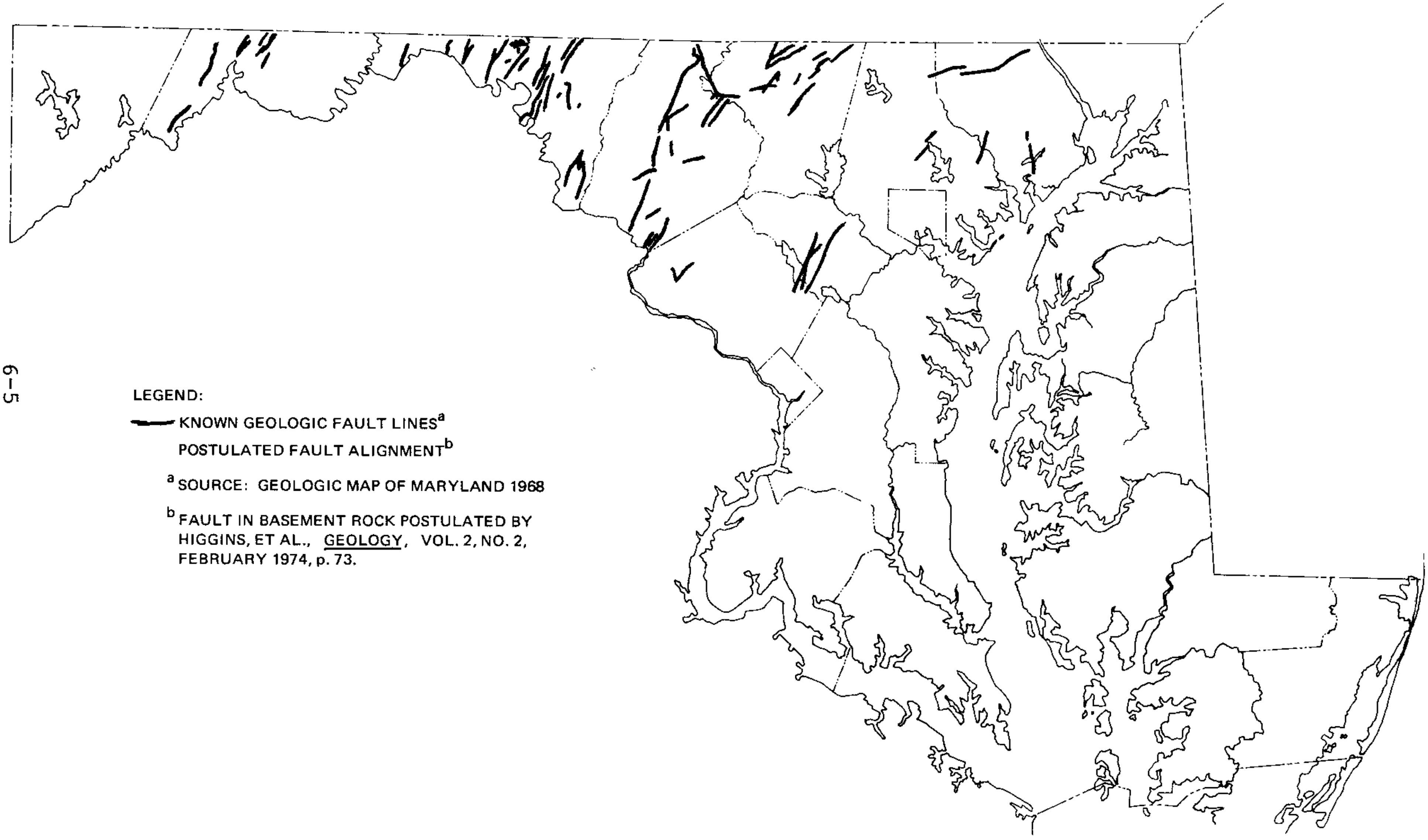
FIGURE 6.1. DISTRIBUTION OF SITE POPULATION FACTOR IN MARYLAND (30-MILE DISTANCE)



SOURCE: REF. 8

FIGURE 6.2

GEOLOGICAL FEATURES WHICH MAY AFFECT POWER PLANT SITING



LEGEND:

━ KNOWN GEOLOGIC FAULT LINES[a]

POSTULATED FAULT ALIGNMENT[b]

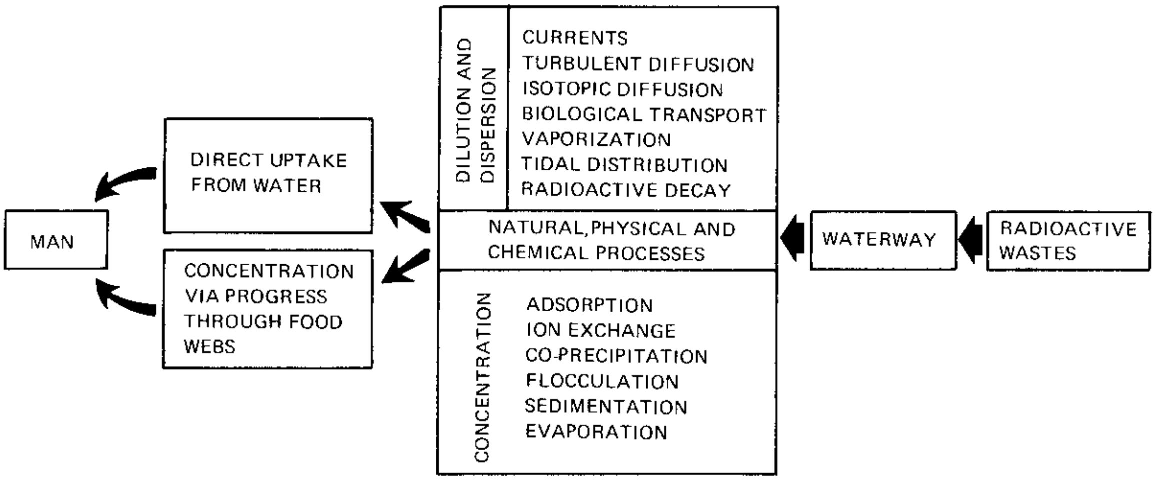
[a] SOURCE: GEOLOGIC MAP OF MARYLAND 1968

[b] FAULT IN BASEMENT ROCK POSTULATED BY HIGGINS, ET AL., <u>GEOLOGY</u>, VOL. 2, NO. 2, FEBRUARY 1974, p. 73.

things, chemical and physical properties of the radionuclide in question.

FIGURE 6.3

VECTORING OF RADIOACTIVE WASTES THROUGH AN AQUATIC ENVIRONMENT



C. Dose Estimates

Radioactive effluents from power reactors in the State will be monitored by the utilities and consulting laboratories (under NRC supervision) and by teams from the Department of Health and Mental Hygiene and the Power Plant Siting Program. Design production and release levels of radwaste are covered by NRC licensing provisions; actual operating levels will be measured in the plant prior to release. Related preoperation phases of monitoring include computation of the dilution and reconcentration factors used to predict dose commitments from emission levels, and measurements of ambient radioactivity, e.g., tritium levels in water and radioiodine in local milk. Preoperation measurements are necessary to establish a base-line upon which to compare environmental concentrations during operation. Because fluctuations in natural radioactivity and fallout tend to be larger than increments due to nuclear power generation, extensive sampling programs must be carried out to ensure statistical validity and to separate plant effects from regional trends. Preoperational monitoring was carried out at Calvert Cliffs for more than three years (9).

Since 1969, when the Governor's Task Force Report first issued estimates of radioactive emissions from the Calvert Cliffs plant (10), data gathered from operating reactors has allowed the AEC to refine its predictive models and update emissions estimates. The last predictions, published in April 1973, are presented in Table 6.2 (11), and are about one-third of the 1969 estimates for aqueous releases of tritium, fission

TABLE 6.2

CALCULATED ANNUAL RELEASE OF RADIOACTIVE MATERIAL IN LIQUID EFFLUENTS FROM CALVERT CLIFFS NUCLEAR POWER PLANT

Radionuclide	Ci/yr/unit
Rb-86	0.0013
Sr-89	0.0012
Sr-90	0.00004
Y-90	0.000054
Y-91	0.25
Zr-95	0.0002
Nb-95	0.0002
Mo-99	0.1
Ru-103	0.00014
Rh-103m	0.00014
Rh-105	0.000023
Ru-106	0.000039
Sn-125	0.0000013
Te-125m	0.00012
Sb-127	0.0000075
Te-127m	0.00095
Te-127	0.00095
Te-129m	0.1
Te-129	0.1
Te-131m	0.0014
Te-131	0.00026
I-131	0.27
Te-132	0.047
Cs-134	1.1
Cs-136	0.37
Cs-137	0.06
Ba-137m	0.07
Ba-140	0.0013
La-140	0.0011
Ce-141	0.00021
Ce-143	0.000031
Pr-143	0.00017
Ce-144	0.00012
Nd-147	0.000068
Pm-147	0.000013
Pm-149	0.00005
Cr-51	0.04
Mn-54	0.06
Fe-55	0.23
Fe-59	0.05
Co-58	2.1
Co-60	0.06
Total	~5.0 Ci/yr/unit
H-3	1,000 Ci/yr/unit

CALCULATED ANNUAL RELEASE OF RADIOACTIVE NUCLIDES IN GASEOUS EFFLUENT FROM CALVERT CLIFFS NUCLEAR POWER PLANT

	Discharge Rate (Ci/year/unit)				
Isotope	Containment Purge	Gas Process System	Air Ejector System	Auxiliary Bldg	Total
Kr-85	22	720	4	4	750
Kr-87	0.05	0	3	3	6
Kr-88	0.3	0	10	10	20
Xe-131m	12	10	5	5	32
Xe-133	1,160	17	790	790	2,760
Xe-135	2	0	17	17	36
Xe-138	0.008	0	3	3	6
I-131	0.02	0	0.22	0.01	0.25

products and activation products. Attempts have been made to estimate Calvert Cliffs discharges by "scaling" data on individual pressurized water reactors now in operation, but the results of such attempts vary widely, depending upon the plants and the year(s) of operation chosen. These differences are due to the wide variations in plant cleanup system designs, and prior operating histories of both the reactors and their cleanup systems. The AEC estimates given in Table 6.2 are based on data from a multitude of plants, and are intended to represent the average discharges over a 30-year plant lifetime. From the data now available on operating plants, these estimates appear reasonable (12).

The estimates of radiation exposure to the public have changed as the estimates of radioactive discharges have changed. Table 6.3 presents the AEC's latest predictions for maximum dose to any individual by various exposure pathways (11). The figures for the seafood consumption pathway are based on the conservative assumption that the aquatic species lived in undiluted plant discharge water. Table 6.4 presents the sum of all (total body) radiation exposures predicted to be received annually by persons living within 50 miles of Calvert Cliffs.

TABLE 6.4

TOTAL POPULATION DOSES ESTIMATED FOR
THE CALVERT CLIFFS NUCLEAR POWER PLANT

Pathway	Dose (man-rem/yr)
Air Submersion[a]	0.6
Water	
Seafood Consumption	9.4
Recreation Activities	1.0
Transportation	
of Radioactive Materials[b]	10.
TOTAL	21

[a] Assuming no shielding by buildings.

[b] The major portion of the population dose (~9.4 man-rem) is estimated to be received by the transportation workers.

TABLE 6.3

ESTIMATED RADIATION DOSES FROM THE EFFLUENTS RELEASED FROM THE CALVERT CLIFFS NUCLEAR POWER STATION, UNITS 1 AND 2 [a]

(mrem/yr)

Pathway	Annual Exposure	Skin	Total Body	GI Tract	Thyroid	Bone
Air Submersion [b]	8,766 hr	0.81	0.24	(0.24)	(0.24)	(0.24)
Inhalation [b]	8,766 hr	--	--	--	0.48	--
Inhalation (child)	8,766 hr	--	--	--	0.54	--
Milk Consumption [d]	274 liters	--	--	--	0.37	--
Milk Consumption (child)	274 liters	--	--	--	3.0	--
Swimming	100 hr	2.6×10^{-4}	2.0×10^{-4}	(2.0×10^{-4})	(2.0×10^{-4})	(2.0×10^{-4})
Boating	100 hr	1.3×10^{-4}	1.0×10^{-4}	(1.0×10^{-4})	(1.0×10^{-4})	(1.0×10^{-4})
Shoreline Silt	500 hr	0.24	0.20	(0.20)	(0.20)	(0.20)
Consumption of						
Fish	18 kg	--	0.037	0.078	0.087	0.021
Crustacea	9 kg	--	0.20	1.62	0.22	0.022
Molluscs	9 kg	--	0.043	0.42	0.22	0.037

[a] Assuming release rates in Table 6.2.

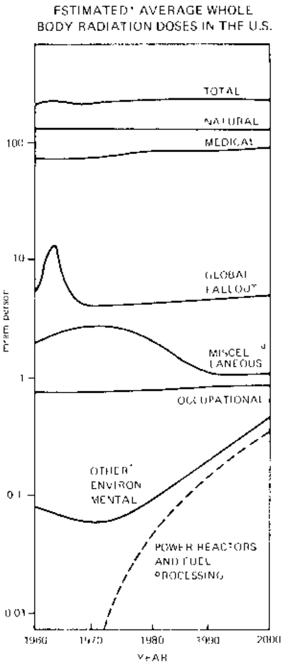
[b] At the site boundary 0.75 mile SE of the Plant.

[c] ( ) indicates internal dose from external source.

[d] Milk from nearest cow, 4.5 miles SW of Plant.

Nuclear power plants are being built in adjoining states, and additional nuclear plants have been proposed for Maryland. Therefore, the question of cumulative radiological impact must be addressed on both a State and regional level. Figure 6.4 shows the radiation dose contributed by nuclear power plants and fuel processing to the estimated per capita whole-body dose received in the United States. The natural radiation component indicated in the Figure is composed of (1) primary cosmic rays from deep space and the energetic products of their collisions in the earth's atmosphere or crust, and (2) decay fragments of terrestrial radioisotopes. Cosmic ray bombardment varies with altitude and latitude: annual whole-body dose in Maryland due to cosmic rays averages about 40 mrem/yr/person -- 60% less than in some Mountain States and slightly less than the 45 mrem/yr/person U. S. average (13).

FIGURE 6.4


ESTIMATED* AVERAGE WHOLE BODY RADIATION DOSES IN THE U.S.

*Source: Reference (13).

[a] Televisions, consumer goods, [illegible], and transport [illegible].

[b] Tests of peaceful nuclear devices.

Dose from terrestrial radioactivity depends on the distribution of natural deposits, weather conditions affecting radon dispersion, and other factors. For instance, the estimated average whole-body terrestrial gamma ray dose for Maryland is 55 mrem/yr/person, while the dose for South Dakota is 115 mrem/yr/person. National average dose is 60 mrem/yr/person (13).

The largest component of man-made dose in the U. S. is due to medical uses of radiation, e.g., medical and dental fluoroscopy, radiography, and use of radiopharmaceuticals.

The estimated population dose received from these sources in 1970 was 15.2 million man-rem (exclusive of occupational exposures and radiation therapy), or 72 mrem/person (13). The "genetically significant dose" (the dose delivered directly to the gonads multiplied by the individual's chances of becoming a parent) from diagnostic radiation in 1970 averaged 20 mrem/person (14).

The next largest source of man-made radioactivity is fallout from weapons tests, which amounts to about 5 mrem/yr/person. Radiation from these tests persists due to the long-lived isotopes Cs-137 and Sr-90.

"Miscellaneous" in Figure 6.4 refers to the dose from color televisions, luminous watches, gauges, and high-altitude air transport (which increases exposure to cosmic ray fluxes). "Occupational" dose is due to the handling and processing of radioactive materials or medical/dental equipment. "Other environmental" refers to doses to the general population due to nuclear power plants, fuel processing and fabricating mills, uranium mines and peaceful uses of nuclear explosives.

Summing the doses from all these sources gives a figure of about 170 mrem/yr/person as the average whole-body dose received by Maryland residents, far more than would be received annually from a nuclear plant such as Calvert Cliffs (cf. Table 6.3). Industrial use of ionizing radiation, particularly the projected increase in nuclear power production, will increase the national per capita dose by approximately 0.1 mrem/yr by 1990 (13), or about 0.05% of the annual per capita dose now being received. The NRC-recommended limit for dose to individuals near power plants (cf. Table 6.1) corresponds to about 5% of the dose received from natural background radiation (~100 mrem/yr/person in Maryland). The average annual dose delivered by the Calvert Cliffs plant to the population within a 50-mile radius of the site is estimated to be only 1/11,500,000 of natural background (11). The dose increment to the population within 50 miles of the proposed Douglas Point plant is estimated at 1/400,000 of the natural background (15). The variation is due to the difference in the type of reactor used at each plant.

D. Radiation Risk from Normal Operations

Ionizing radiation can cause immediate and latent damage to germ and somatic tissues. Genetic risks are cumulative. Irradiation can trigger malignancy in the body, with blood-forming tissues, bone marrow, thyroid, breast, lung, and reproductive organs being the most susceptible (16). For purposes of estimating risk, it is assumed that the frequency of occurrence of cancer and genetic damage is directly proportional to the irradiation dose (16, 17). However, it should be noted that these effects have not actually been observed at low radiation exposures, but only at levels a thousand or more times higher than doses received by members of the public in the vicinity of nuclear power plants (18). The relationship between incremental dose and expected increase in neoplasms is generally expressed as number of excess cases versus irradiation dose in man-rem. The rates derived from long-term observation of Japanese bomb victims are 50-165 cancers per one million man-rem. The current range of estimates based on this and other data is 60 to 480 fatal cases per one million man-rem, with a mean value of 180 deaths per million man-rem being the value most commonly used for impact estimates.

Genetic effects must be treated somewhat differently. The effects of genetic damage are felt by the descendants of the irradiated population. The relationship between incremental radiation dose and expected increase in genetic defects is generally expressed as a number of excess cases/yr/million descendants versus the average radiation dose in rems to the exposed generation during their reproductive lifetimes. The total of such effects is estimated to be between 60 and 1,500 cases/million descendants/rem of average dose to the exposed generation. These cases will be spread over several generations of descendants, with only about 20% occurring in the first descendant generation. Table 6.5 gives a breakdown of the various risk values by type.

Under proposed NRC guidelines for limiting radiation doses to the public to levels "as low as practicable" from nuclear power plant operations, the maximum doses that may be received by the most exposed members of the general public are specified as design criteria. The values are given in Table 6.6. These values constitute about 5% increase in the total radiation exposure to an individual (exclusive of medical exposures). The risk of cancer to any individual who actually receives these doses is given in Table 6.7. The risk of genetic damage to the exposed individual causing defects in his descendants is also given in Table 6.7. These additional risks should be compared to the unavoidable risks to the individual from the same diseases, also given in the Table. It can be seen that the dose from each year of maximum exposure to the radiation from the power plant produces only a very small increase in the total risk that any particular disease or genetic defect will occur.

The number of persons actually exposed to the levels of radiation given in Table 6.6 is very small in comparison to the number of persons within 50 miles of a plant who will receive smaller doses annually. By assuming that there is a linear relationship between incremental radiation dose and additional risk of effect, "population doses" and "risks to the population" can be calculated. In a calculation of this sort, the total of all doses to the members of the public is estimated, and this value is used to compute the number of cases of each disease expected to be caused in the population by the radiation doses from the power plant. In fact, the "best" estimated number of

TABLE 6.5

RISKS OF GENETIC DEFECT INDUCTION FROM RADIATION

A. Specific Genetic Damage: Effects per million live-born descendants due to 1-rem radiation dose to all individuals in one generation

Effect	Cases in First Generation	Total Cases Over All* Future Generations	Current Incidence per Million Live Births
Autosomal dominant traits	10-100	50-500	10,000
X-chromosome-linked traits	0-5	2-20	400
Recessive traits	(very few)	(very small)	1,500

B. Cytogenic (Chromosome Aberration): Effects per million live-born descendants due to 1-rem radiation dose to all individuals in a generation

Effect	Cases in First Generation	Total Cases Over All* Future Generations	Current Incidence per Million Live Births
Congenital abnormalities			
Unbalanced rearrangements	12	15	1,000
Aneuploidy	1	1	4,000
Recognized spontaneous abortions			
Aneuploidy & polyploidy	11	11	35,000
XO	3	3	9,000
Unbalanced rearrangements	72	90	11,000

C. Total of Effects, Including Genetically Linked Disease (contains values from Parts A and B): Effects per million live-born descendants due to a 1-rem radiation dose to all individuals in a generation

Disease Classification	Cases in First Generation	Total Cases Over All* Future Generations	Current Incidence per Million Live Births
Dominant diseases	10-100	50-500	10,000
Chromosomal & recessive diseases	very few	very few	10,000
Congenital anomalies	1-100	10-1,000	15,000
Anomalies expressed later			10,000
Constitutional & degenerative diseases			15,000
Total	11-200	60-1,500	60,000

---

*Assumes population is not increasing or decreasing rapidly so that each generation has the same number of individuals

TABLE 6.6

DESIGN VALUES FOR LIMITING THE HIGHEST EXPOSURE TO AN INDIVIDUAL IN THE GENERAL POPULATION TO LEVELS "AS LOW AS PRACTICABLE" (ALAP)

Method of Exposure	Organ Exposed	Design Basis Maximum Dose
Immersion in and ingestion of aqueous discharges	Whole body*	5 mrem
Immersion in and ingestion of gaseous discharges	Whole body*	5 mrem
All iodine releases	Thyroid gland	15 mrem

*A single individual is not expected to receive the maximum dose from both aqueous and gaseous plant discharges.

TABLE 6.7

RISKS (ACCUMULATED ANNUALLY) TO INDIVIDUALS AND DESCENDANTS OF INDIVIDUALS EXPOSED TO ALAP RADIATION LEVELS

	Additional Risk Due to Radiation	Normal Risk Level
*Risk of Cancer (assuming 10 mrem)	$\frac{2}{1,000,000}$	$\frac{1,520}{1,000,000}$
Risk of Thyroid Nodule (assuming 15 mrem)	$\frac{3}{1,000,000}$	$\frac{\sim 10,000}{1,000,000}$
*Risk of Genetic Defect in Children (assuming 10 mrem)	$\frac{0.07 \text{ to } 1.4}{1,000,000}$	$\frac{60,000}{1,000,000}$
*Risk of Genetic Defect in Any Descendants (assuming 10 mrem)	$\frac{0.4 \text{ to } 10}{1,000,000}$	$\frac{60,000}{1,000,000}$

*Assuming the individual receives maximum dose from both the gaseous and aqueous releases (contrary to NRC assumptions).

TABLE 6.8

RADIATION "POPULATION DOSES" FROM POWER PLANTS IN AND NEAR MARYLAND

Plant/Unit	On-Line Date	Total Annual Dose to Population Within 50 Miles	Fraction of 50-Mile Population in Md.	Dose to Maryland Citizens Over Next Ten Years
Calvert Cliffs				
Unit 1	1975	17 person-rem	1.0	153 person-rem
Unit 2	1977			
Peach Bottom				
Unit 2	1975	83 person-rem	0.5	415 person-rem
Unit 3	1975			
Summit				
Unit 1	1981	42 person-rem*	0.15	16 person-rem
Unit 2	1984			
Fulton				
Unit 1	1984	36 person-rem	0.5	18 person-rem
Unit 2	1986			
Douglas Point				
Unit 1	1985	13 person-rem	0.35	0 person-rem
Unit 2	1987			
TOTALS:		191 person-rem		602 person-rem

*Includes an estimated 19 person-rem due to airborne tritium releases, which was not included in AEC dose predictions.

such cases is less than one, so that it is probable that no additional cases of cancer or genetic disease will be induced in Maryland's population by the operation of nuclear power plants over the next ten years.

Predictions of population doses from five existing and proposed nuclear power plants in and near Maryland over the next ten years are given in Table 6.8. The number of cases of various diseases which are predicted to be induced by this radiation exposure are given in Table 6.9. Since the "expectation numbers" are all less than one, the values are actually probabilities that one additional person in the exposed population will suffer a disease. The "population dose" concept says nothing about which person might suffer the given effect. The total probability that some person will be affected is divided among the exposed individuals in proportion to the dose they receive. The risk to any specific individual should not be greater than the values given in Table 6.7 for the risk to most exposed individuals.

TABLE 6.9

PROBABLE NUMBER OF CASES OF SOMATIC AND GENETIC EFFECTS INDUCED IN MARYLAND RESIDENTS BY THE OPERATION OF NUCLEAR POWER PLANTS IN AND NEAR MARYLAND OVER THE NEXT TEN YEARS (1975 - 1984)

Cancers		0.1
Genetic Dominant Diseases (0.02 to 0.20)		~0.1
Chromosomal and Recessive Diseases, Congenital Anomalies, Anomalies Expressed Later, Constitutional and Degenerative Diseases	(0.004 to 4.0)	~0.2

Identical Effects Expected in Maryland's Population Over the Next Ten Years From Other Causes (Not Identified)

Cancers	60,000 deaths
Genetic Dominant Disease	40,000 cases
Chromosomal and Recessive Diseases	40,000 cases
Congenital Anomalies	60,000 cases
Anomalies Expressed Later	40,000 cases
Constitutional and Degenerative Disease	60,000 cases

Health effects of ten years' operation of all five plants on the total population within 50 miles are about three times greater than those calculated above for Maryland citizens alone (cf. Table 6.8). At this time, such numbers would be best estimates for the total impact of these plants over the 1985-1994 time span. However, much will be learned over the next several years which will probably allow better estimates.

One other point to consider is that radiation dose to the public from gaseous power plant effluents probably extends more than 50 miles beyond the reactor site. Calculations are terminated at that distance because the meteorological assumptions governing dispersion and time of travel (and therefore, radioactive decay over distance) do not remain constant over large distances. Estimates of average per capita dose, which are based on estimates of annual average radioactive effluent dispersions over large distances, have been made for the Upper Mississippi Valley in the year 2000 A. D. (19). These values are in general agreement with the values shown in Figure 6.4. The value given in the Figure for 1980 is 0.05 mrem/person, which would amount to a population dose of 200 person-rem/yr for Maryland's four million residents, or about 2,000 person-rem over a ten year period. Again, this value is about three times higher than that used for the health effect calculations given in Table 6.9.

It should be noted that the expectation values for number of cases of radiation effects will exceed one as the number of reactors and number of years of reactor operation are increased. The point at which this occurs has no real significance in terms of societal decisions. The important concept is that, measured against other societal risks of the same type, the risks from normal operations of nuclear power plants are exceedingly small. They are expected to be smaller than the public health risks due to burning coal or oil in power plants, although the data on the health effects of SO_2, NO_x and particulates are not as yet well enough documented to support a precise comparison. However, the probable number of cases of somatic and genetic effects due to the operation of nuclear power plants in Table 6.9 can be compared to the adverse health effects associated with various urban sulfate concentrations in Table 4.9. It appears probable that chemical atmospheric pollutants are the greater risk to public health.

E. Risk from Accidents

Any discussion of cumulative risks and impacts of nuclear power plants must necessarily address a question that has been thoroughly impressed on the mind of the public -- that of the risk of inadvertent irradiation due to a nuclear accident. Usually, risk estimates are derived from experience; the number of accidents or accident-related events (e.g., deaths) per million units of some activity (e.g., passenger-miles) is tabulated from records, and the same accident rate is assumed to extend into the future. This procedure cannot be used for catastrophic failure of nuclear power plant systems, however, because no such events have yet occurred.

Until recently, no techniques were available to calculate even the probability that such an event would occur. Calculations, therefore, tended to center on the consequences resulting if such an event occurred. Thus, no actual risk estimates were available for such events because risk is the product of both the probability and the consequences of an accident.

In order to provide a measure for such a risk, the AEC-sponsored Reactor Safety Study (20) extended "fault-tree" analysis techniques to make actual risk estimates for nuclear reactor accidents. Fault-tree analysis uses failure rates of system components, taken from power plant operational data, to compute the probability of failure for a system built with these components. The technique is relatively new, and has had a record of uneven success when applied to other industries. Opponents of the nuclear power industry have criticized the Reactor Safety Study on the basis that fault-tree analysis techniques have been in error in some other applications. However, this study must be considered a step in the proper direction and the best available source for risk estimates at this time. The final draft report of the Reactor Safety Study has been distributed to interested parties for comment, with the final version scheduled for the fall of 1975. It is expected that the risk estimates in this final version will be about a factor of three higher than those indicated in the draft version.

The study has verified that the major contribution to overall risk from nuclear power plants is an accident where the reactor core melts (after the chain reaction has been stopped) due to failure of all of the cooling systems. Accidents where the core melts because the fission chain reactions cannot be controlled were found to be so improbable that they made no significant contribution to the total risk.

Prior to the Reactor Safety Study, it had been thought that, should the reactor core ever melt, all of the gaseous fission products contained in it would be released to the environment. This was termed a "Class 9" accident and labeled "non-credible" by the AEC. The probability of such an event was estimated to be one-in-a-million to one-in-ten-million per year of reactor operation, without any good basis for the estimate. The term "non-credible" was therefore taken to mean that the accident was so improbable as not to require special power plant design to contain the consequences within regulatory limits. However, a more reasoned opinion has come out of the Reactor

Safety Study, which analyzed the effect on the power plant structure following core-melt. It now appears that the most probable course of events following total core-melt does not result in serious injury to the public. The most probable set of consequences is given in Table 6.10. It was also calculated that the probability of this melt-down event is significantly greater than had previously been believed amounting to about one chance in 17,000 per year of reactor operation.

Other, more serious, accidents were identified and calculated to have smaller probabilities of occurrence. The most serious accident identified which made any significant contribution to overall risk is also tabulated in Table 6.10. The probability of this accident ever occurring, however, is calculated to be one chance in one billion per year of reactor operation. This is not to say that more serious accidents are impossible; it merely indicates that they are so improbable that the risk value calculated for them (probability times consequence) is too small to contribute significantly to the overall risk (the sum of risks from all possible accidents).

TABLE 6.10

CONSEQUENCES OF THE MOST LIKELY CORE-MELT ACCIDENT
(Probability = 1/17,000 per year of reactor operation)

Fatalities	<1
Injuries	<1
Latent Fatalities	<1
Thyroid Nodules	4
Genetic Defects	<1
Property Damage	$100,000
Initial Evacuation Area	<0.1 square miles
Area Requiring Decontamination	<0.1 square miles

Consequences of the Most Serious Core-Melt Accident
With Probability Great Enough to Significantly Contribute
to Overall Risk (Probability = 1/1,000,000,000
per year of reactor operation)

Fatalities	2,300
Injuries	5,600
Latent Fatalities	3,200
Thyroid Nodules	84,000
Genetic Defects	3,200
Property Damage	$6,200,000,000
Initial Evacuation Area	400 square miles
Area Requiring Decontamination	31 square miles

Source: Reference 20 (Draft)

Figure 6.5 shows graphically the risk of having 100 reactors, designed, sited, and operated as now required by the NRC, operating in the United States. The Figure also shows the risk from other natural and human-caused risks, so that the nuclear accident risk is placed in perspective. In order to use the Figure properly, a consequence value (number of deaths) should be selected on the horizontal axis, and the probability of an accident occurring which will cause at least that number of deaths can then be found by moving upward to the curve of interest (e.g., reactors or dam failures), and then reading the corresponding probability value on the vertical axis.

The public risk from nuclear power reactor accidents can also be expressed on a per capita basis. The risk value is then one chance in 300 million per year of reactor operation for all those persons living within 20 miles of a power reactor. For comparison, Table 6.11 gives this value and other risk values for U. S. Residents.

TABLE 6.11

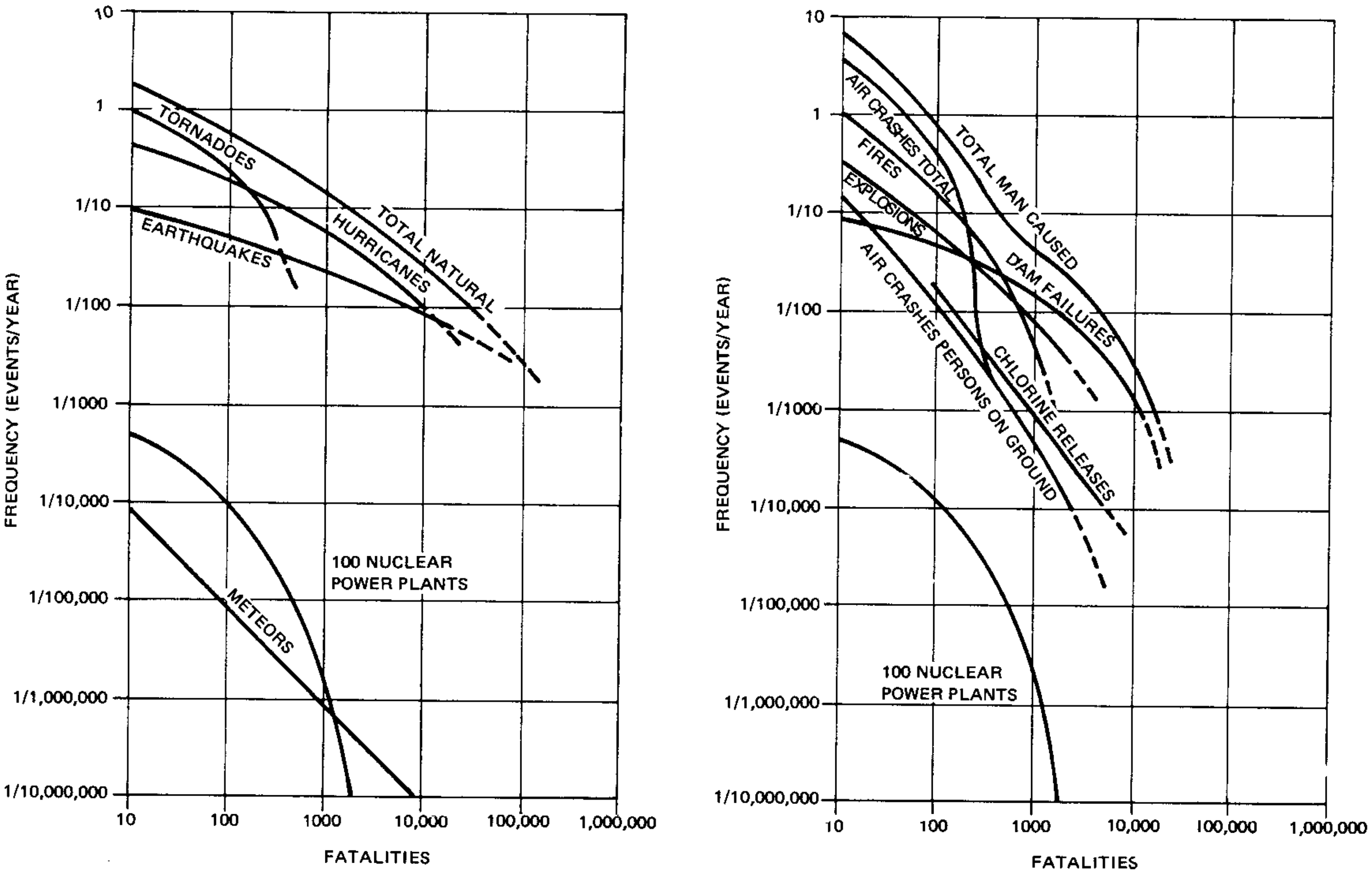
RISK OF FATALITY BY VARIOUS CAUSES

Accident Type	Total Number	Individual Chance Per Year
Motor Vehicle	55,791	1 in 4,000
Falls	17,827	1 in 10,000
Fires and Hot Substances	7,451	1 in 25,000
Drowning	6,181	1 in 30,000
Firearms	2,309	1 in 100,000
Air Travel	1,778	1 in 100,000
Falling Objects	1,271	1 in 160,000
Electrocution	1,148	1 in 160,000
Lightning	160	1 in 2,000,000
Tornadoes	91	1 in 2,500,000
Hurricanes	93	1 in 2,500,000
All Accidents	111,992	1 in 1,600
Nuclear Reactor Accidents (100 reactors)	0	1 in 300,000,000

Source: Reference 20 (draft)

FIGURE 6.5

FREQUENCY OF ACCIDENTS VS NUMBERS OF FATALITIES


NUCLEAR POWER PLANTS COMPARED TO NATURAL EVENTS

NUCLEAR POWER PLANTS COMPARED TO MAN CAUSED EVENTS

An individual residing just outside the exclusion zone of a nuclear plant would correctly assume that his own individual risk is higher than the per capita value cited. The Reactor Safety Study does not address this individual risk directly. However, analysis of data provided in the draft report leads to a risk estimate of approximately one chance in a million of fatality for any such individual during each year of reactor operation. This estimate has been verbally supported by the Project Director of the Reactor Safety Study (21). However, this particular risk estimate is most sensitive to the revisions that are contemplated for the final report.

As with the risk calculations for normal reactor operations, the total risk from accidents from all nuclear power plants in the country will grow as the number of reactors grows. (Since design improvements are continually being made, the total risk will probably grow more slowly than the number of reactors.) Again, the point at which the total risk from nuclear power plants reaches some given value (e.g., equivalent to the risk from dam failures) has no real significance for societal decision-making. As the number of reactors grows, the benefits from the reactors also grow. It is the ratio of total additional benefits to total additional adverse effects (including risk of death) which should govern the decision as to whether each new reactor is built. The risk of death due to reactor accident has now been estimated to be a very small value, a value smaller than many risk values which have historically been neglected as inconsequential in performing benefit/disbenefit analyses for other industries. However, public perception of public risk is not completely related to the numerical value of that risk. The possible magnitude of consequences from a single accident is also a key factor in public risk perception. In that respect, the Reactor Safety Study is reassuring, in that events of equal consequence are shown to be more likely for non-nuclear accidents than for power reactor accidents.

F. Conclusions

In considering the available data on risk from normal operations and accidents, there is no valid reason for governmental prohibition of the nuclear power industry from competing in the economic marketplace for its most cost-effective share of future electrical generating capacity. It appears, given a continuation of existing NRC regulatory policy towards design, siting and operation of nuclear power plants, that radiological risks are insignificant in comparison to the benefits of a nuclear reactor.

G. REFERENCES

Chapter 6

1. "Cost Comparison Dry-Type and Conventional Cooling Systems for Representative Nuclear Generating Plants," TID-26007, prepared by R. W. Beck Assoc. for USAEC Division Reactor Development and Technology, Denver (March 1972).

2. 10 CFR 50

3. Hull, Andrew P., "Comparing Effluent Releases from Nuclear and Fossil-Fueled Power Plants," Nuclear News, April 1974, p. 51.

4. Forbes, Ian A., et al., "The Nuclear Debate: A Call to Reason," A position paper, June 17, 1974, Boston, Mass.

5. Atomic Industrial Forum, No. 45, August 1974, p. 4.

6. Personal communication from A. Keneke to S. M. Long, May 31, 1973.

7. "Proposed Regulatory Guide - Population Distribution Around Nuclear Power Plant Sites," part of published AEC staff working report on population density around nuclear power plant sites, April 9, 1974.

8. "Technical Report on a Technique for Consideration of Population in Site Comparisons," USAEC, October 1974.

9. "Environmental Radioactivity Monitoring Program," Quarterly and Annual Reports by the State of Maryland, Radiation Laboratory Section, 1974.

10. "Nuclear Power in Maryland," Governor's Task Force on Nuclear Power Plants, Annapolis, Md., December 1969.

11. "Final Environmental Statement Related to Operation of Calvert Cliffs Nuclear Power Plant, Units 1 and 2," Docket No. 50-317 and 50-318, USAEC Directorate of Licensing, Washington, D. C., April 1973.

12. "Report on Releases of Radioactivity in Effluents and Solid Waste from Nuclear Power Plants for 1972," USAEC, August 1973.

13. Klement, A. W., Jr., C. R. Miller, R. P. Minx and B. Shlein, "Estimates of Ionizing Radiation Doses in the United States 1960-2000," ORP/GSD 72-1, Spec. Studies Group, Division Criteria and Stands., EPA, Rockville, Md., August 1972.

14. "X-Ray Exposure Study (XES) - Revised Estimates of 1964 and 1970 Genetically Significant Dose," Pre-release Report, HEW, Bureau of Radiological Health, February 4, 1975.

15. "Environmental Report, Construction Permit Stage, Douglas Point Generating Station, Units 1 and 2," Appendix 2-B, Vol. 3, PEPCO, 1973.

16. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiation, Division of Med. Science, NAS/NRS, Washington, D. C., November 1972.

17. *Engineering for Resolution of the Energy - Environmental Dilemma*, National Academy of Engineering, Washington, D. C., 1972.

18. Goldman, M. I., et al., "Effects of Estimated Radioactive Effluents from the Calvert Cliffs Nuclear Power Station," NUS-TM-S-87, 1969.

19. "The Potential Radiological Implications of Nuclear Facilities in the Upper Mississippi River Basin in the Year 2000. (The Year 2000 Study)," WASH 1209, Div. of Reactor Development and Technology, USAEC, January 1973.

20. Rasmussen, N. C., "Reactor Safety Study: Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants," Draft Report prepared for Atomic Energy Commission, WASH-1400, August 20, 1974.

21. Personal communication from Dr. N. C. Rasmussen to Dr. S. M. Long, January 3, 1975.