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PURGATORIO--TWO RATHER DIFFERENT VIEWS OF THE SAME EVENT

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Descriptions of the experiences of organisms entrained in a once-through cooling system usually treat either stresses from a single cause or stresses connected with a part of the system. For example, the American Nuclear Society (1974) describes pressure changes while Coutant et al. (1975) discuss the combined thermal and physical stresses within the condenser tubes. The advantage of manageable problems encourages such partial descriptions. However, since it is our purpose to consider the total

"The year class will come to order." The portly striped bass with scarred gill plates and half his dorsal fin missing flexed his back once and snapped his jaws. The fry fluttered their tails and gave the professor the kind of nervous attention that is partly respect but principally a suspicion that they may be dinner.

"This course is Advanced Survival, S 303," the professor continued.

"Its prerequisites are Elementary Survival, S 101, and Intermediate Survival, S 202.

impact, it will be useful to follow an organism through the system.

In S 101 you have learned of the natural hazards of inner space, that bounded by the bottom and the water surface. In S 202 you have learned the more common dangers arising from the bug-eyed monsters who inhabit outer space: bloodworms which conceal barbed hooks, nets, weirs, and similar devices that descend on us through the surface. Formerly, the work on survival terminated here. However, a new and more atrocious invasion, the power plant cooling system, is multiplying and, in the opinion of the faculty, you should not be allowed to continue in your customary abysmal ignorance. Since, in my youth, I was once entrained in a cooling system--and lived--I have been appointed as your instructor.

The passage begins under ambient conditions as the organism is drawn into the water moving toward the intake. This may happen at distances as far as 100

"The most insidious thing about entrainment is that you will not know that it is happening. Everything looks and feels normal. Grazing is normal.

meters. He drifts toward the intake at a gentle 15 to 30 cm/sec and may take 5 or 10 minutes to reach the screen. Aside from distant noise he sees little out of the ordinary except for an unusual number of predators.

Temperature is normal. However, off in the distance there is a bit more noise than usual. But that's all. If at the instant you detect the noise, you swim vigorously with the noise to one side of you--not away from it--you fry just may escape. However, such evasive action in response to every slight increase in noise is impractical. For a long time there is nothing much out of the way to be seen, but you will notice that predators seem to be getting unusually plentiful. Appropriate action in the face of predators was covered in S 101. Remember the school motto: 'Edere Non Ederi.'

seconds

Conditions begin to depart from normal near the intake screens. Speeds increase slightly to 30 to 60 cm/sec. Accelerations in the turbulent flow reach approximately one-tenth of the acceleration of gravity (0.1g). The shear forces near the screen may reach 20 dynes/cm^2. Neither the

"In the last few seconds as you approach the screen the noise level goes up sharply. The meshes of the screen are large enough for you to slip through quite easily, but small enough to hang up that white perch who regards you as food. There is considerable satisfaction in seeing your pursuer

shears nor the accelerations will be damaging to most entrained organisms, although ichthyoplankton large enough to be trapped against the screen would die.

During the 10 to 20 seconds required for the 10-meter passage from screen to pump disturbances increase abruptly. For a pump above water level the absolute pressure falls continuously from the intake. For example, an organism entrained from a depth of 10 meters experiences a drop from 2 atm to 0.3 atm. Velocities increase to 100 to 200 cm/sec. Turbulent accelerations reach 0.4 g to 1.6 g. Shears remain sublethal at 100 to 200 dynes/cm^2 near the surface of the conduit.

To prevent fouling, power plants inject pulses of biocide into the coolant. Those organisms directly exposed to an injection experience concentrations as great as 3 ppm of

gasping his life out flattened against the screen. But you had better look sharp! You won't be able to hang around and your troubles have really begun.

"As you enter the conduit the most disorienting sensation will be the reports from your lateral lines. As you know, these give directional pressure signals which permit you to turn away from an attacker. In the conduit you will feel yourself completely surrounded by predator. The walls go by with a rush and you will feel yourself twisted and rolled by the current. You will have the sensation that you have surfaced from 20 meters in only a few seconds. There will be thousands and thousands of others with you and those with vacuoles will begin to explode. Then there is the burning biocide; not always but too often for comfort. If you are caught directly in one of these gas

chlorine.

attacks, you and everyone around you has bought it. In my own experience, I was fortunate enough to go through just behind a gas attack but the burns were, and still are, painful.

During the next split-second within the pump the most severe shocks occur. There is an almost instantaneous jump in pressure of about 1.5 atm. Entrainment into the boundary layer of the impeller where viscous stresses reach 10^3 to 10^4 dynes/cm^2 is a strong possibility. These stresses are an order of magnitude greater than the stresses experienced elsewhere in the system and exceed lethal levels for striped bass eggs and larvae (Morgan et al., 1976). Direct collision with the impeller will occur for some 3.5% of the entrained organisms. The impact velocity will be 1600 cm/sec, the equivalent of a fall from a height of over 15 meters. Battle (1944) showed trauma in

"The experiences of the next second pass belief. You are wrenched and twisted and bounced about until you feel you will break. Around you you will see many of your fellows with eyes dangling out, with heads cut off, and with snapped spines. Quite a few of them will be smashed to death against the impeller blades.

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Teleostean eggs for falls of only 0.6 meters, terminal velocity 240 cm/sec.

The next 4 to 5 seconds are spent in transit to the water box. Conduit conditions are equivalent to those ahead of the pump.

"The lot of you--the dead, the dying, and the living--will be spat out into comparative quiet. At least it will be no worse than it was before--although you will be.

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In the water boxes velocities increase to as much as 250 cm/sec. The irregular geometry of the boxes increases the turbulent intensity and accelerations of 10 g are common. Shear at the walls of the box can exceed 200 dynes/cm^2.

"But, once again, you are carried along with a rush and the twisting and churning increases. You are spun and dropped. And the worst is yet to come.

The animal is forced into one of a multitude of 12-meter long, 2.3-cm I.D. condenser tubes. For the 2 to 8 seconds spent in the tube, heat absorbed from condensing turbine steam will raise the body temperature by some 11°C. The velocities remain quite high, 200 to 600 cm/sec. Turbulence induces

"Ahead is hell! Dozens of small openings lie before you and into one or another of them you go willy nilly. The twisting, rolling, and accelerations become even more intense. But the worst is the heat. It is worse than anything you can imagine or than you will ever experience in this world. Breathing! All you can do is

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accelerations of 2 g to 14 g. Shear forces over 500 dynes/ cm^2 exist near the tube walls. Biocide levels have dropped below 2 ppm and there is commonly an uptake of copper and other heavy metals from the tube walls.

gasp and wonder where your next breath is coming from-- if you should live long enough to take it. And it goes on and on and on. About the only solace I have to offer is that the burning from the gas attack is easing off just a little. However, you won't find that much comfort since you will begin to taste copper, lead, and zinc in the water.

The second or so spent in the exit water boxes usually finds the organism subjected to the lowest absolute pressures of the journey, 0.3 atm, while other physical conditions are comparable to those found in the entrance water box.

"Again you will find yourself rushed from depth to surface and then flung into outer space. The sound of exploding bodies reaches a drumfire. Fragments and broken bodies are all around you. You will be fortunate if you are alive to see it, although it may not strike you that way. The shambles is worse than Pickerel's Charge at Gettysburg.

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Exit conduits range in length from 100 to 500 meters and require transit times of 50 to 250 seconds. In this segment the mechanical conditions are similar to those in

"Then follows the long, long trek through the desert. The water is running more smoothly, but the heat and the suffocation go on for what seems like forever.

the upstream conduits. However, the temperature remains high, rarely falling more than 1°C while biocide levels fall to their exit values of 0.5 ppm.

The burning from the gas attack has definitely begun to abate.

How long the surviving creatures remain exposed to thermal and biocidal stresses after discharge ranges from seconds to hours depending upon whether a diffuser, multi-port jet, weir, or canal forms the outfall.

"At long last you're out--but not yet in the clear. All around you is the senseless carnage wrought by the monsters from outer space and you are feeling none too lively. Further, the brotherhood of fish is not a doctrine that applies at mealtimes. Many of your relatives and 'friends' will be gathered around to welcome you with gently smiling jaws.

An organism passing through a once-through cooling system of a power plant experiences a sequence of stresses: physical, thermal, and chemical. No answer can be given to the question, "How many organisms survive entrainment?" or to the question, "How can survival be maximized?" by evaluating a single stress. Even if a single stress were

"What practical advice can S 303 offer you? Like most theoretical courses, very little beyond, 'Don't get entrained.' However, when the bomb goes off it's always nice to know how the thing works.

limiting under a given set of conditions, there is no assurance that it will remain so when conditions are changed.

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