FE-Review
Biology

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FE Review - Biology

- Coverage
  - NCEES October 2005
    - “Afternoon Session: III. Biology”
      - 5% of afternoon “Other/General” Engineering
      - Amounts to 3 problems.
      - Topical areas:
        - » Cellular biology
        - » Toxicology
        - » Industrial hygiene
        - » Bioprocessing.

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- Coverage
  - Professional Publications Inc. “FAQ/Advice”:
    - There are a surprising number of environmental and water-treatment problems on the civil afternoon exam. If you haven't taken environmental courses, you will be lost on these.
    - The Environmental module had a surprising number of problems in US units.
    - The Environmental module should be called "civil with environmental emphasis."

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- Best “guess” of type of problems that could be on exam:
  - Cellular biology:
    - Enumeration of bacteria (MPN, Plate Count, Fecal Coliform).
    - Doubling times (log-growth phase)
  - Toxicology:
    - Dose/Response to compute excess risk.
  - Bioprocessing:
    - Activated sludge analysis/design.
  - Industrial hygiene:
    - Carcinogen exposure (tools similar to toxicology)

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Cellular Biology

- Microorganisms in Water and Wastewater
  - Animal (Eucaroytic cells)
    - Crustaceans; Worms; Rotifers
  - Plant(Eucaroytic cells)
    - Rooted aquatic; seed plants; ferns; mosses
  - Protista
    - Protozoa; Algae; Fungi (Eucaroytic cells)
    - Blue-green algae; Bacteria (Procaryotic cells)

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Cellular Biology

- Eucaroytic cells
  - Nucleus within well defined membrane
- Procaryotic cells
  - Nucleus not enclosed with membrane

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Cellular Biology

- Energy/Carbon Sources
  - Light/CO_2
    - Plants;algae;photosynthetic bacteria
    - Photoautotroph
  - Light/Organic
    - Photosynthetic bacteria
    - Photoheterotroph
  - Inorganic/CO_2
    - Bacteria
    - Chemoautotroph
  - Organic/Organic
    - Bacteria;fungi;protozoa;animals
    - Chemoheterotroph

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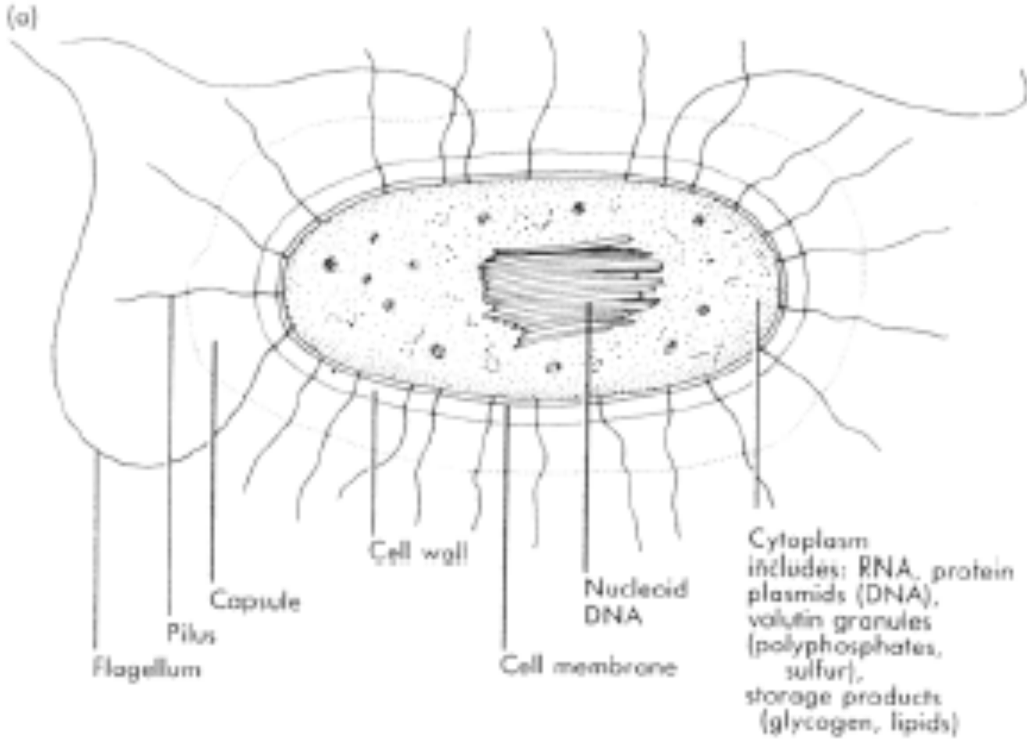
Cellular Biology

- Bacteria Cell



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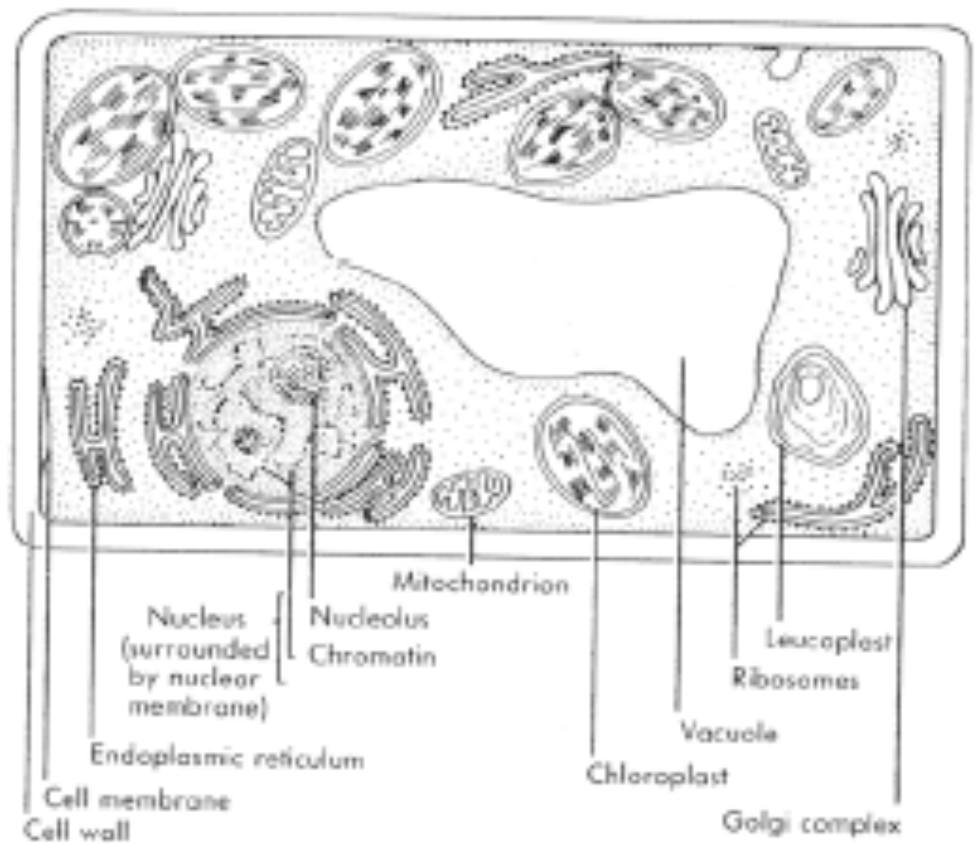
Cellular Biology

– Plant Cell



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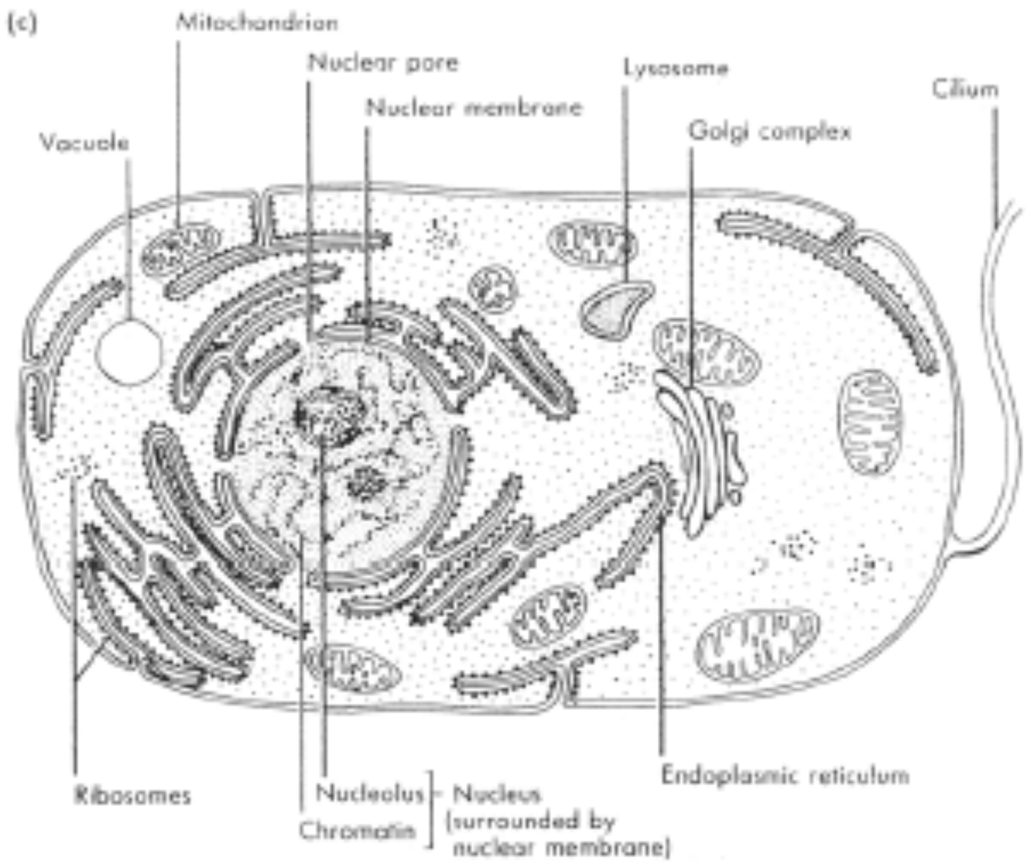
Cellular Biology

– Animal Cell



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- Bacterial Enumeration
  - Counting bacteria is standard method to determine their concentration in water and consequently their probability of causing disease.
  - Two common methods:
    - Plate count
    - Most Probable Number (MPN)
  - Both use serial dilutions.

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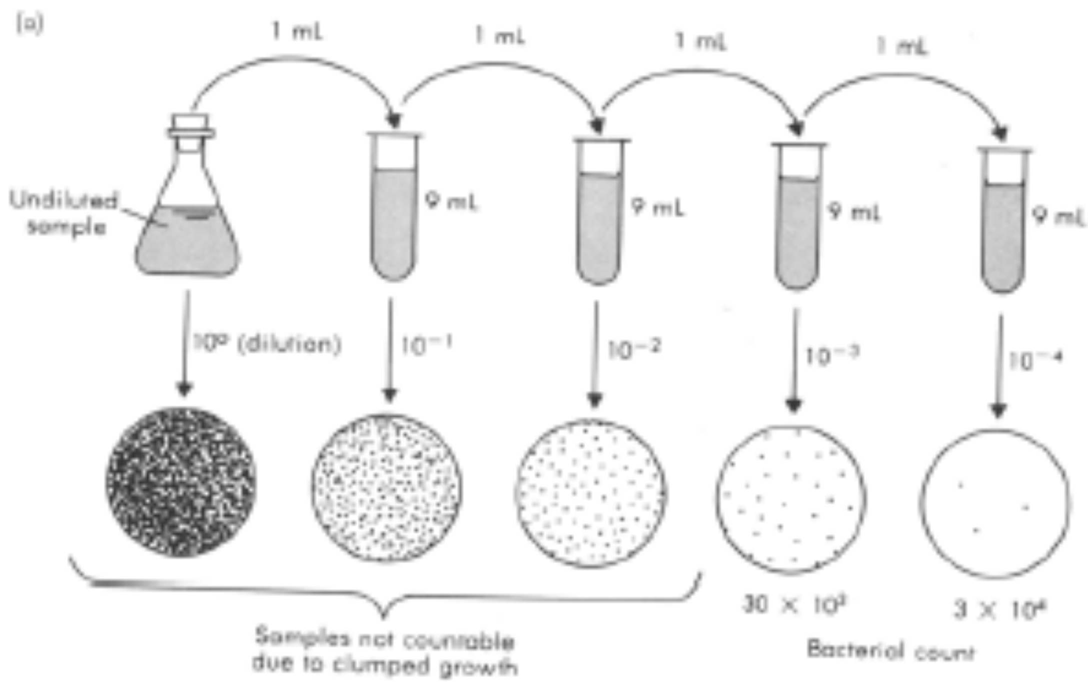
- Plate Count
  - Sample is serially diluted. Counts between 30-300 are feasible.
  - Result of viable plates are multiplied by dilution factor then reported as CFU/100mL



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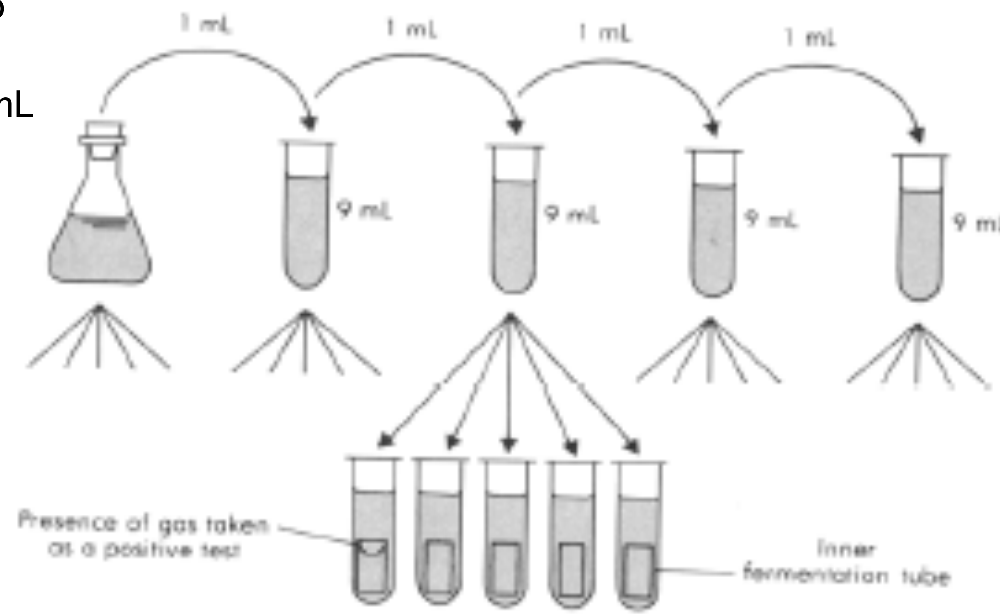
- MPN
  - Multiple serial dilutions into growth media.
  - Gas production is indicator of target organism (E. Coli).
  - Tables, Poisson distribution, or Thomas approximation used to determine MPN.
  - Results reported as MPN/100mL



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- MPN
  - Thomas approximation

$$MPN/100mL = \frac{no.\_positive\_tubes * 100}{\sqrt{(mL\_of\_sample\_in\_negative\_tubes * mL\_of\_sample\_in\_all\_tubes)}}$$

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- Example
  - Six water samples were analyzed for coliform bacteria using the five-tube lactose-fermentation technique. The results are given below. Determine the MPN of the samples.

DILUTION, mL/100 mL	NUMBER OF POSITIVE TUBES					
	Water sample					
	1	2	3	4	5	6
10.0	5	4	5	5	5	5
1.00	3	3	5	5	5	5
0.10	1	5	5	5	0	5
0.01	—	—	3	5	3	4
0.001	—	—	2	3	2	3
0.0001	—	—	1	2	1	1

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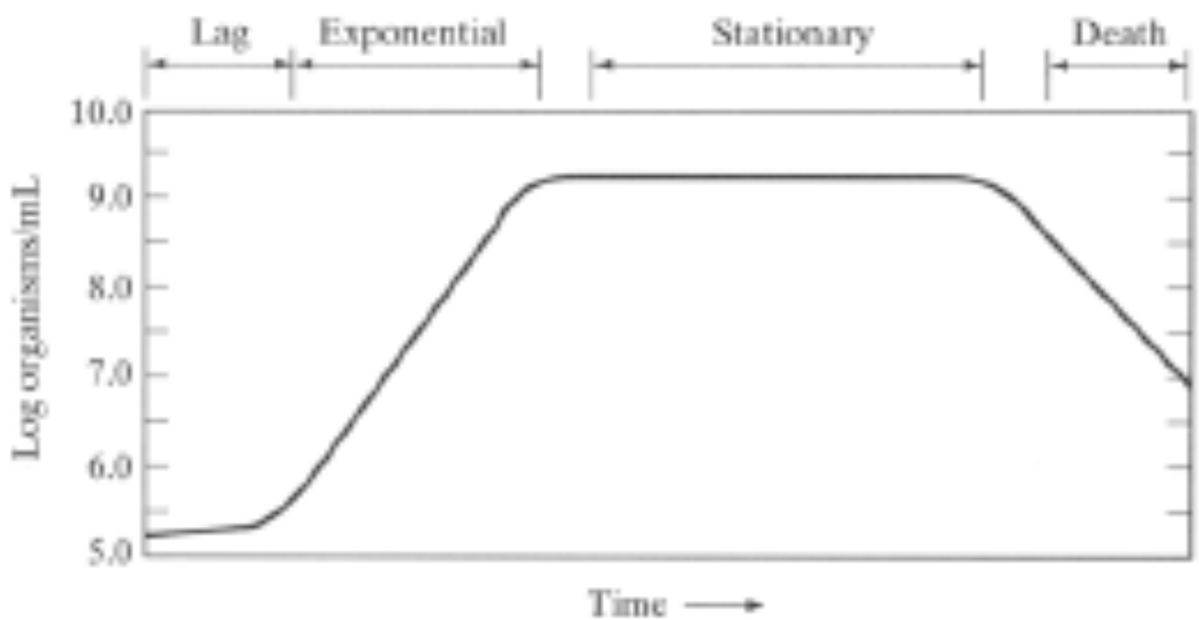
- Logistic Growth
  - Typical in bacterial populations and other short gestation populations (without significant age stratification)



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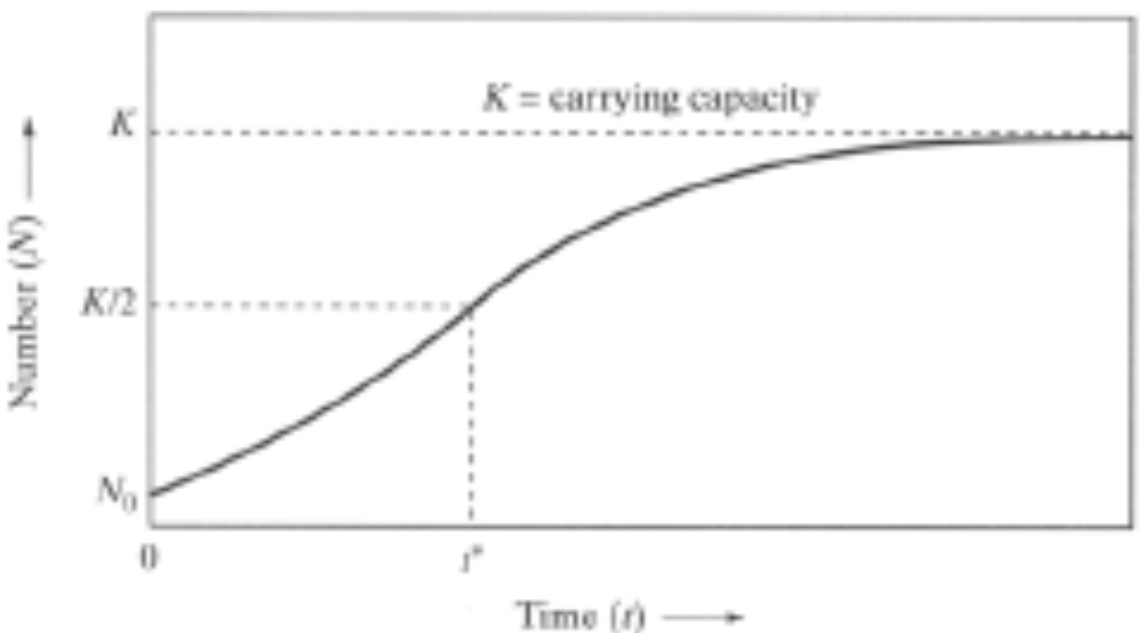
- Logistic Growth
  - Exponential phase



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- Logistic Growth
  - Model

$$\frac{dN}{dt} = rN(1 - \frac{N}{K})$$

  - Solution

$$N(t) = \frac{K}{1 + \exp(-r(t - t^{*}))}$$

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- Maximum Sustainable Yield
  - Number of individuals that can be harvested without reducing population size.
  - Slope of population model is growth rate.
  - Harvest should be at/near maximum growth rate to minimize impact to population number.
  - To maximize yield, set its slope to zero and solve for population size.

$$Y = \frac{dN}{dt}$$

$$\frac{dY}{dN} = 0 = \frac{d}{dt}[rN(1 - \frac{N}{K})] = r\frac{dN}{dt} - \frac{r}{K}(2N\frac{dN}{dt})$$

Solve for N

$$N^* = \frac{K}{2}$$

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Cellular Biology

- Example
  - A pond stocked with 100 fish shows a population doubling oevery year for the first two years, but after many years the population is stable at 4000 individuals. Assuming logistic growth what is maximum sustainable yield from this pond?

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- Exposure routes:
  - Inhalation (breathing)
  - Ingestion (eat/drink)
  - Absorption (skin)
- Distribution:
  - Blood system
  - Lymph system
- Storage:
  - Fat
  - Organs
  - Soft tissue
  - Bones
- Excretion:
  - Feces
  - Air (exhaled air)
  - Urine
  - Secretions (sweat)

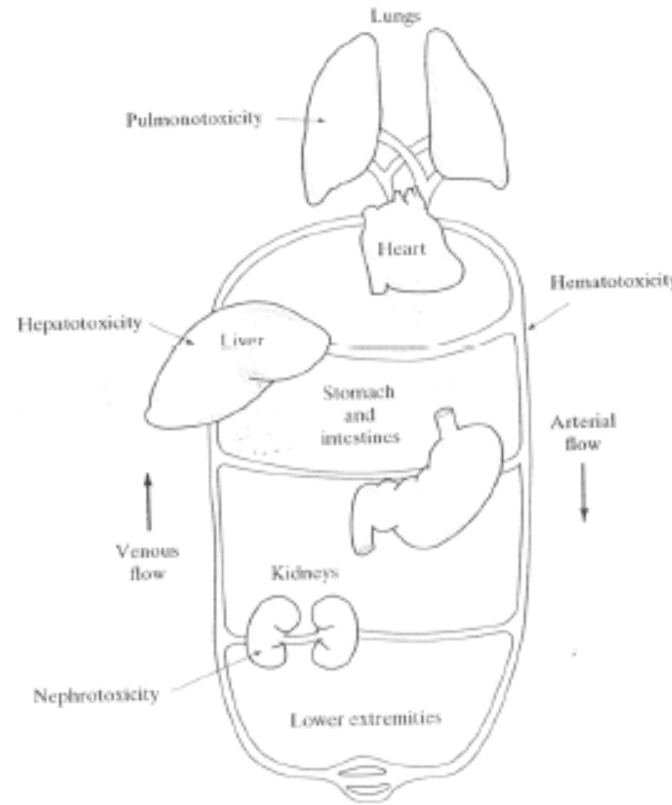

FIGURE 4.2 The circulatory system and nomenclature for toxic effects: hepatotoxicity (liver), nephrotoxicity (kidneys), pulmonotoxicity (lungs), hematotoxicity (blood). (*Source:* Based on James, 19

FE Review – Biology Toxicology

- Acute toxicity based on probable single lethal dose.
  - Sucrose (a sugar) is lethal if 1.5kg is ingested at once.
  - Botulin toxin (similar to botox) is lethal if 0.00070 mg is ingested at once.

TABLE 4.6 A conventional rating system for the acute toxicity of chemicals in humans

	Probable lethal oral dose for humans	
Toxicity rating	Dose (mg/kg of body weight)	For average adult
1. Practically nontoxic	more than 15,000	More than 1 quart
2. Slightly toxic	5,000–15,000	1 pint to 1 quart
3. Moderately toxic	500–5,000	1 ounce to 1 pint
4. Very toxic	50–500	1 teaspoon to 1 ounce
5. Extremely toxic	5–50	7 drops to 1 teaspoon
6. Supertoxic	Less than 5	Less than 7 drops

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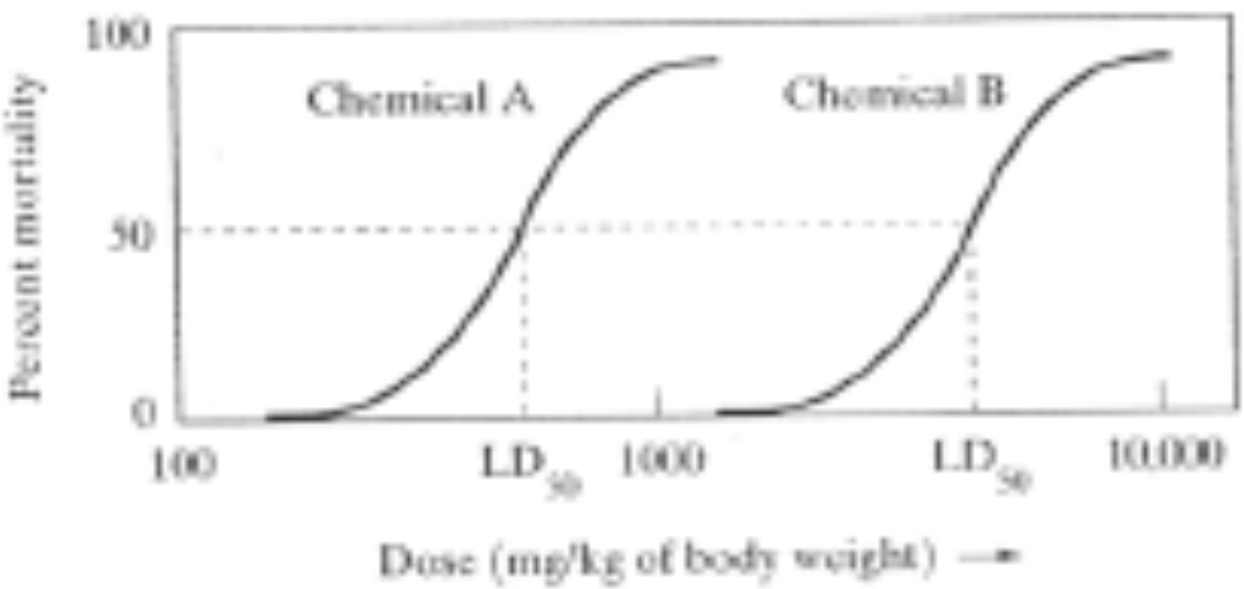
Toxicology

- Dose-Response Determined Experimentally Using Animal Models; Usually Bacteria, Fish, etc.



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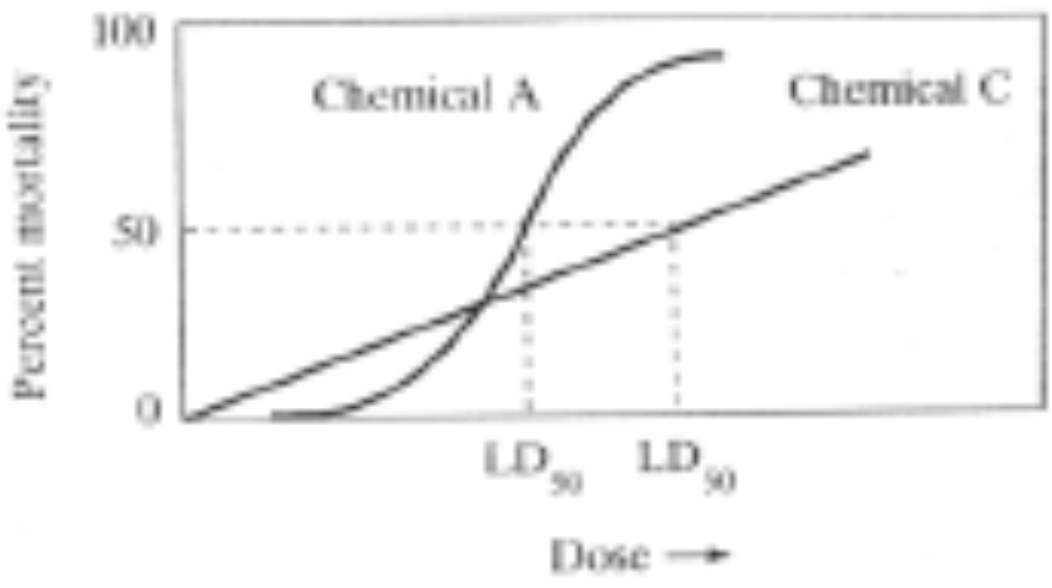
- Toxicity depends on shape of dose-response curve.



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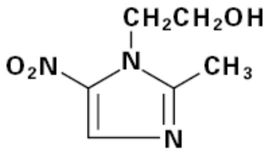
Toxicology

- Carcinogens
  - Compounds that cause certain types of responses are declared carcinogens.
  - Many compounds that have therapeutic value are carcinogens.
  - Example (From PDR):
    - Metronidazole is an oral synthetic antiprotozoal and antibacterial agent, 1-(beta-hydroxyethyl)-2-methyl-5-nitroimidazole, which has the following structural formula:



    - Metronidazole tablets contain 250 mg or 500 mg of metronidazole. Inactive ingredients include cellulose, FD&C Blue No. 2 Lake, hydroxypropyl cellulose, hydroxypropyl methylcellulose, polyethylene glycol, stearic acid, and titanium dioxide.
    - Metronidazole has been shown to be carcinogenic in mice and rats (see PRECAUTIONS.) Unnecessary use of the drug should be avoided. Its use should be reserved for the conditions described in the INDICATIONS AND USAGE section.
  - Carcinogenic responses are on the next table.

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- Carcinogenic response types:

TABLE 4.7 Glossary of Carcinogenesis Terminology

Acute toxicity	Adverse effects caused by a toxic agent occurring within a short period of time following exposure
Benign tumor	A new tumor composed of cells that, though proliferating in an abnormal manner, do not spread to surrounding, normal tissue
Cancer	An abnormal process in which cells begin a phase of uncontrolled growth and spread
Carcinogen	Any cancer-producing substance
Carcinoma	A malignant tumor in the tissue that covers internal or external surfaces of the body such as the stomach, liver, or skin
Chronic toxicity	Adverse effects caused by a toxic agent after a long period of exposure
Initiator	A chemical that initiates the change in a cell that irreversibly converts the cell into a cancerous or precancerous state
Malignant tumor	Relatively autonomous growth of cells or tissue that invade surrounding tissue and have the ability to metastasize
Mutagenesis	Alteration of DNA in either somatic or germinal cells not associated with the normal process of recombination
Mutation	A permanent, transmissible change in DNA that changes the function or behavior of the cell
Neoplasm	Literally, new growth, usually of an abnormally fast-growing tissue
Oncogenic	Giving rise to tumors or causing tumor formation
Pharmacokinetics	The study of how a chemical is absorbed, distributed, metabolized, and excreted
Promoter	A chemical that can increase the incidence of response to a carcinogen previously administered
Sarcoma	A cancer that arises from mesodermal tissue (e.g., fat, muscle, bone)
Teratogen	Any substance capable of causing malformation during development of the fetus
Toxicity	A relative term generally used in comparing the harmful effect of one chemical on some biological mechanism with the effect of another chemical

Source: Based on Williams and Burson, 1985.

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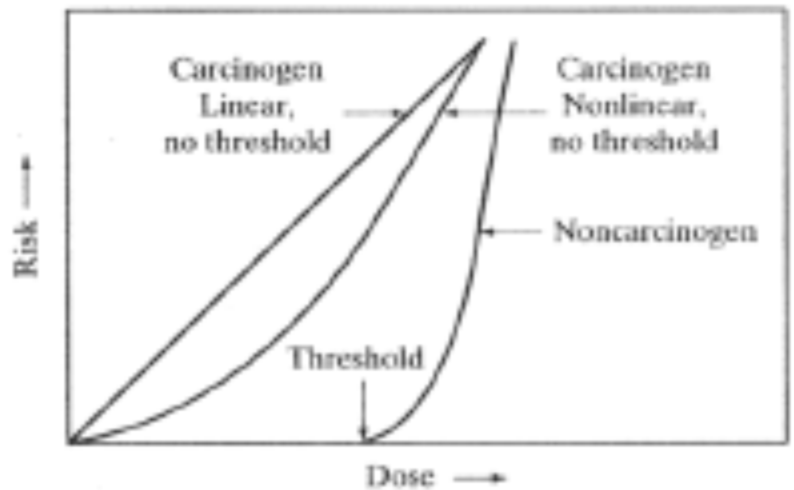
- Dose-Response assessment
  - If carcinogen, NO THRESHOLD DOSE
  - If non-carcinogen, THRESHOLD DOSE
  - Scaling factor used to scale model response to human response.



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- Dose-Response assessment
  - Carcinogens:
    - Need to compute CDI (Chronic Daily Intake). (Average daily dose is lifetime dose for a 70-year lifetime)

$$CDI(mg/kg-day) = \frac{\text{average\_daily\_dose}(mg/day)}{\text{body\_weight}(kg)}$$

    - Need to look-up potency factor. (Table)
    - Compute Excess Risk (Incremental lifetime risk)

$$Excess\_Risk = Potency\_Factor * CDI$$

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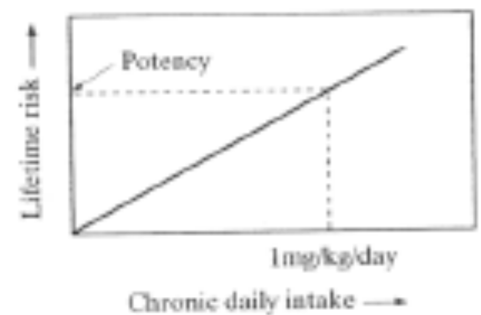
- Potency Factor Table

TABLE 4.9 Toxicity data for selected potential carcinogens

Chemical	Category	Potency factor oral route $(mg/kg\text{-}day)^{-1}$	Potency factor inhalation route $(mg/kg\text{-}day)^{-1}$
Arsenic	A	1.75	50
Benzene	A	2.9×10^{-2}	2.9×10^{-2}
Benzol(a)pyrene	B2	11.5	6.11
Cadmium	B1	—	6.1
Carbon tetrachloride	B2	0.13	—
Chloroform	B2	6.1×10^{-3}	8.1×10^{-2}
Chromium VI	A	—	41
DDT	B2	0.34	—
1,1-Dichloroethylene	C	0.58	1.16
Dieldrin	B2	30	—
Heptachlor	B2	3.4	—
Hexachloroethane	C	1.4×10^{-2}	—
Methylene chloride	B2	7.5×10^{-3}	1.4×10^{-2}
Nickel and compounds	A	—	1.19
Polychlorinated biphenyls (PCBs)	B2	7.7	—
2,3,7,8-TCDD (dioxin)	B2	1.56×10^{5}	—
Tetrachloroethylene	B2	5.1×10^{-2}	$1.0 - 3.3 \times 10^{-3}$
1,1,1-Trichloroethane (1,1,1-TCA)	D	—	—
Trichloroethylene (TCE)	B2	1.1×10^{-2}	1.3×10^{-2}
Vinyl chloride	A	2.3	0.295

Source: U.S. EPA http://www.epa.gov/iris



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- Problem 1
  - Drinking water disinfected with chlorine produces chloroform ($CHCL_3$) as a by-product. Suppose a 70kg person drinks 2 liters of water per day for 70 years that has a chloroform concentration of 0.10mg/L
    - What is the cancer risk for this person?

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- Problem 2
  - Drinking water disinfected with chlorine produces chloroform (CHCL3) as a by-produce. Suppose a 70kg person drinks 2 liters of water per day for 70 years that has a chloroform concentration of 0.10mg/L
    - If a city of 500,000 also drinks the same amount of water, how many excess cancers can be expected (using the 70 year lifetime)?

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- Problem 3
  - Drinking water disinfected with chlorine produces chloroform (CHCL3) as a by-produce. Suppose a 70kg person drinks 2 liters of water per day for 70 years that has a chloroform concentration of 0.10mg/L
    - Compute the cancer death rate (deaths/100,000/year) caused by the chloroform with the U.S. death rate of 193/100,000/year.
    - Is the chloroform death rate detectable?

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- Problem 4
  - Compute the concentration of chloroform in drinking water that would result in a 10^{-6} risk for a "standard person-lifetime".

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- The CDI calculation is adjusted for intermittent exposures when warranted. Generic equation is:
  - Inhalation

$$CDI(mg/kg-day) = \frac{Concentration(mg/m^3)*Intake\_Rate(m^3/day)*Exposure(days/life)}{\text{body\_weight}(kg)*70(yr/life)*365(days/life)}$$

  - Drinking Water

$$CDI(mg/kg-day) = \frac{Concentration(mg/L)*Intake\_Rate(L/day)*Exposure(days/life)}{\text{body\_weight}(kg)*70(yr/life)*365(days/life)}$$

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- Exposure type/duration

TABLE 4.10 Example EPA Exposure Factors Recommended for Risk Assessments

Land use	Exposure pathway	Daily intake	Exposure frequency, days/year	Exposure duration, years	Body weight, kg
Residential	Ingestion of potable water	2 L (adult) 1 L (child)	350	30	70 (adult) 15 (child)
	Ingestion of soil and dust	200 mg (child) 100 mg (adult)	350	6 24	15 (child) 70 (adult)
	Inhalation of contaminants	20 m^3 (adult) 12 m^3 (child)	350	30	70
Industrial and commercial	Ingestion of potable water	1 L	250	25	70
	Ingestion of soil and dust	50 mg	250	25	70
	Inhalation of contaminants	20 m^3 (workday)	250	25	70
Agricultural	Consumption of homegrown produce	42 g (fruit) 80 g (veg.)	350	30	70
Recreational	Consumption of locally caught fish	54 g	350	30	70

Source: U.S. EPA (1991).

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- Problem 5
  - Occupational Exposure: Estimate the excess risk for a 60-kg worker exposed to a carcinogen during a 5-day work week, 50 weeks per year over a 25 year working career. The worker breathes 20 cubic meters of air daily. The carcinogen has a potency factor of $0.02(mg/kg\text{-}day)^{-1}$ and average concentration in the factory air of $0.05 mg/m^3$

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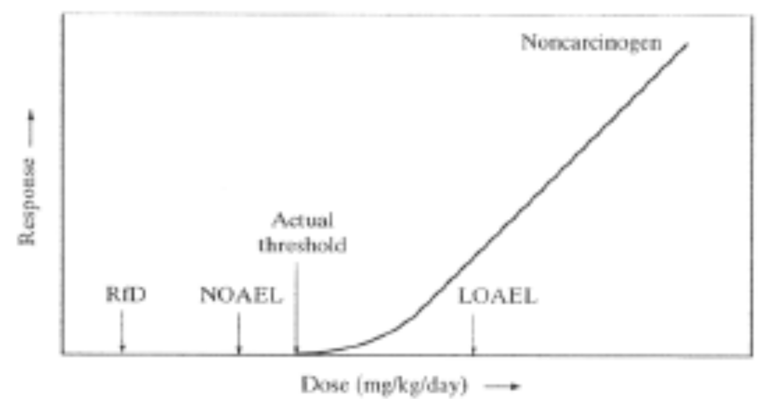
- Noncarcinogenic response
  - Compute a hazard quotient.
  - Hazard index is sum of hazard quotients for all likely exposures.
  - Hazard indices less than 1 are thought of indicate “no significant risk of system toxicity” (i.e. a surrogate for “probably safe”)

$$HQ_i = \frac{average\_daily\_dose(mg/kg-day)}{RfD_i(reference\_dose)}$$

$$HI = \sum_{i=1}^{N} HQ_i$$



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- Noncarcinogenic response, Reference Dose

TABLE 4.11 Oral RfDs for chronic noncarcinogenic effects of selected chemicals.

Chemical	RfD (mg/kg-day)
Acetone	0.100
Arsenic	0.0003
Cadmium	0.0005
Chloroform	0.010
1,1-dichloroethylene	0.009
cis-1,2-Dichloroethylene	0.010
Fluoride	0.120
Mercury (inorganic)	0.0003
Methylene chloride	0.060
Phenol	0.600
Tetrachloroethylene	0.010
Toluene	0.200
1,1,1-Trichloroethane	0.035
Xylene	2.000

Source: U.S. EPA. http://www.epa.gov/iris

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- Problem 6
  - A drinking water contains 1.0mg/L toulene and 0.01 mg/L tetrachloroethylene. A 70 kg adult drinks 2L per day for 10 years of this water. Does the hazard index for this exposure suggest the exposure level was safe?

FE Review – Biology
Bioprocessing

- Fermentation
- Waste treatment
- Digestion

FE Review – Biology Bioprocessing

- Waste treatment is good example, and likely topic.

TYPE	COMMON NAME	USE*
Aerobic processes		
Suspended growth	Activated sludge process	
	Conventional (plug flow)	Carbonaceous BOD removal (nitrification)
	Continuous-flow stirred-tank	Carbonaceous BOD removal (nitrification)
	Sequencing batch reactor	Carbonaceous BOD removal (nitrification)
	Step aeration	Carbonaceous BOD removal (nitrification)
	Pure oxygen	Carbonaceous BOD removal (nitrification)
	Modified aeration	Carbonaceous BOD removal (nitrification)
	Contact stabilization	Carbonaceous BOD removal (nitrification)
	Extended aeration	Carbonaceous BOD removal (nitrification)
	Oxidation ditch	Carbonaceous BOD removal (nitrification)
	Suspended-growth nitrification	Nitrification
	Aerated lagoons	Carbonaceous BOD removal (nitrification)
	Aerobic digestion	
	Conventional air	Stabilization, carbonaceous BOD removal
	Pure oxygen	Stabilization, carbonaceous BOD removal
	High-rate aerobic algal ponds	Carbonaceous BOD removal
Attached growth	Trickling filters	
	Low-rate	Carbonaceous BOD removal (nitrification)
	High-rate	Carbonaceous BOD removal
	Roughing filters	Carbonaceous BOD removal
	Rotating biological contactors	Carbonaceous BOD removal (nitrification)
	Packed-bed reactors	Nitrification
Combined processes	Trickling filter-activated sludge	Carbonaceous BOD removal (nitrification)
	Activated sludge-trickling filter	Carbonaceous BOD removal (nitrification)
Anoxic processes		
Suspended growth	Suspended-growth denitrification	Denitrification
Attached growth	Fixed-film denitrification	Denitrification

FE Review – Biology Bioprocessing

- Waste treatment is good example, and likely topic.

TYPE	COMMON NAME	USE*
Anaerobic processes		
Suspended growth	Anaerobic digestion	
	Standard rate, single stage	
	High rate, single stage	Stabilization, carbonaceous BOD removal
	Two stage	
	Anaerobic contact process	Carbonaceous BOD removal
Attached growth	Anaerobic filter	Carbonaceous BOD removal, stabilization (denitrification)
	Anaerobic lagoons (ponds)	Carbonaceous BOD removal (stabilization)
Aerobic/anoxic or anaerobic processes		
Suspended growth	Single stage nitrification-denitrification	Carbonaceous BOD removal, nitrification, denitrification, phosphate removal
Attached growth	Nitrification-denitrification	Nitrification, denitrification
	Land treatment	
	Slow rate	Carbonaceous BOD removal (nitrification, denitrification)
	Rapid infiltration	
	Overland flow	
Combined processes	Facultative lagoons (ponds)	Carbonaceous BOD removal
	Maturation or tertiary ponds	Carbonaceous BOD removal (bacterial decay, nitrification)
	Anaerobic-facultative lagoons	Carbonaceous BOD removal
	Anaerobic-facultative-aerobic lagoons	
On-site systems	Septic tank-leach fields	Treatment and disposal of wastewater from individual residences and other buildings in areas not served with sewers
	Septic tank-mounds	
	Septic tank-evapotranspiration	

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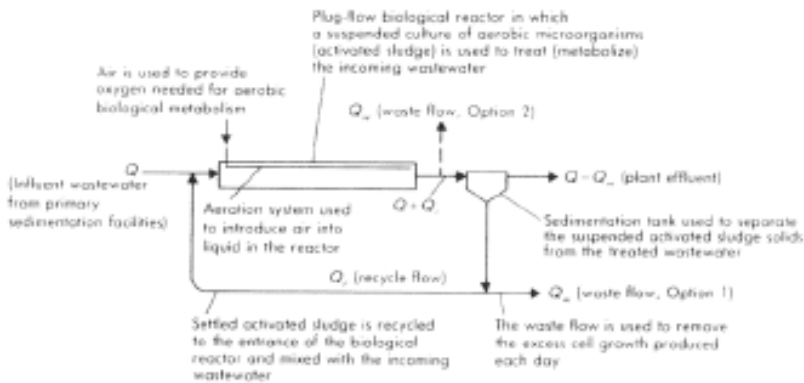
- Activated Sludge Process.
  - Typical process diagram
  - Common configurations are:
    - PFR (shown)
    - CSFSR (Continuous flow, stirred)
    - SBR (Sequence batch)



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- Activated Sludge Process.
  - Typical process parameters are in tables (pg 159 NCEES supplied reference).
  - Typical problems might involve
    - Computing biomass (substrate-limited growth model)
    - Computing sludge age
    - Computing sludge volume index

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- Example problem
  - Compute the sludge age for activated sludge process with following operating parameters
    - Q=2 cu.m./sec
    - Qw=0.015 cu.m/sec
    - Qr=0.50 cu.m/sec
    - Va=43,000 cu.m.
    - Vs=7,000 cu.m.
    - Xe=20 g/cu.m.
    - X=2000 g/cu.m.

    (Variables are on pg 159 NCEES Suppliment; Va= areation basin volume, Vs=settling tank volume)

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