IQRA UNIVERSITY

FINAL TERM EXAMINATION

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POWER GENERATION & UTILIZATION

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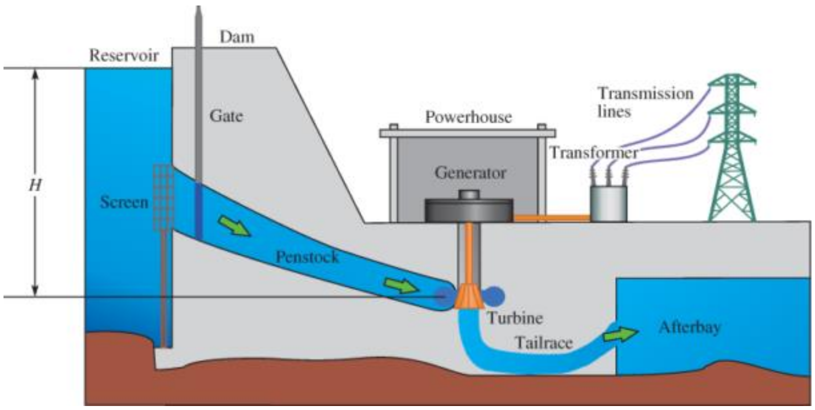
ANSWER 1(a)

HYDROPOWER PLANT

Hydropower plant uses hydraulic energy of water to produce electricity. The power obtained from this plant is termed as hydroelectric power. Nearly 16% of total power used by the world is represented by hydropower.

There are several types of hydropower plants classified on different characteristics. But for every hydropower plant some important principal components are needed and those are explained here.



ELEMENTS OF A HYDROPOWER PLANT

The major components of a hydroelectric plant are as follows.

- Forebay
- Intake structure
- Penstock
- Surge chamber
- Hydraulic turbines
- Power house
- Draft tube
- Tailrace

FOREBAY

A forebay is a basin area of hydropower plant where water is temporarily stored before going into intake chamber. The storage of water in forebay is decided based on required water demand in that area. This is also used when the load requirement in intake is less.

We know that reservoirs are built across the rivers to store the water, the water stored on upstream side of dam can be carried by penstocks to the power house. In this case, the reservoir itself acts as forebay.

INTAKE STRUCTURE

Intake structure is a structure which collects the water from the forebay and directs it into the penstocks. There are different types of intake structures are available and selection of type of intake structure depends on various local conditions.

Intake structure contains some important components of which trash racks plays vital role. Trash racks are provided at the entrance of penstock to trap the debris in the water.

If debris along with water flows into the penstock it will cause severe damage to the wicket gates, turbine runners, nozzles of turbines etc. these trash racks are made of steel in rod shape. These rods are arranged with a gap of 10 to 30 cm apart and these racks will separate the debris form the flowing water whose permissible velocity is limited 0.6 m/sec to 1.6 m/sec.

In cold weather regions, there is chance of formation of ice in water, to prevent the entrance of ice into the penstocks trash racks heated with electricity and hence ice melts when it touches the trash racks.

Other than trash racks, rakes and trolley arrangement which is used to clean the trash racks and penstock closing gates are also provided in intake structure.

PENSTOCK

Penstocks are like large pipes laid with some slope which carries water from intake structure or reservoir to the turbines. They run with some pressure so, sudden closing or opening of penstock gates can cause water hammer effect to the penstocks.

So, these are designed to resist the water hammer effect apart from this penstock is similar to normal pipe. To overcome this pressure, heavy wall is provided for short length penstock and surge tank is provided in case of long length penstocks.

Steel or Reinforced concrete is used for making penstocks. If the length is small, separate penstock is used for each turbine similarly if the length is big single large penstock is used and at the end it is separated into branches.

SURGE CHAMBER

A surge chamber or surge tank is a cylindrical tank which is open at the top to control the pressure in penstock. It is connected to the penstock and as close as possible to the power house.

Whenever the power house rejected the water load coming from penstock the water level in the surge tank rises and controls the pressure in penstock.

Similarly, when the huge demand is needed in power house surge tank accelerates the water flow into the power house and then water level reduces. When the discharge is steady in the power house, water level in the surge tank becomes constant.

There are different types of surge tanks available and they are selected based on the requirement of plant, length of penstock etc.

HYDRAULIC TURBINES

Hydraulic turbine, a device which can convert the hydraulic energy into the mechanical energy which again converted into the electrical energy by coupling the shaft of turbine to the generator.

The mechanism in this case is, whenever the water coming from penstock strike the circular blades or runner with high pressure it will rotate the shaft provided at the center and it causes generator to produce electrical power.

Generally hydraulic turbines are of two types namely

- Impulse turbine
- Reaction turbine

Impulse turbine is also called as velocity turbine. Pelton wheel turbine is example for impulse turbine. Reaction turbine is also called as pressure turbine. Kaplan turbine and Francis turbine come under this category.

POWER HOUSE

Power house is a building provided to protect the hydraulic and electrical equipment. Generally, the whole equipment is supported by the foundation or substructure laid for the power house.

In case of reaction turbines some machines like draft tubes, scroll casing etc. are fixed with in the foundation while laying it. So, the foundation is laid in big dimensions.

When it comes to super structure, generators are provided on the ground floor under which vertical turbines are provided. Besides generator horizontal turbines are provided. Control room is provided at first floor or mezzanine floor.

DRAFT TUBE

If reaction turbines are used, then draft tube is a necessary component which connects turbine outlet to the tailrace. The draft tube contains gradually increasing diameter so that the water discharged into the tailrace with safe velocity. At the end of draft tube, outlet gates are provided which can be closed during repair works.

TAILRACE

Tailrace is the flow of water from turbines to the stream. It is good if the power house is located nearer to the stream. But, if it is located far away from the stream then it is necessary to build a channel for carrying water into the stream.

Otherwise the water flow may damage the plant in many ways like lowering turbine efficiency, cavitation, damage to turbine blades etc.

This is because of silting or scouring caused by unnecessary flow of water from power house. Hence, proper design of tailrace should be more important.

ANSWER 1 (b)

GIVEN THAT

Available volume at pond age

$V = 5 \times 10^5 \ m^3$

Available head

h = 100m

Hydraulic efficiency

85% 0.85

Electrical e efficiency

0.94

Therefore: Overall efficiency

0.85 x 0.94= 0.80

USING

$E = npghV = 0.8 \times 1000 \times 9.81 \times 100 \times 5 \times 10^5$

E = 3.92 x 10^ 11 W-s

ANSWER 2 (a)

TYPES OF HYDROPOWER TURBINES

1. Impulse Turbine
2. Reaction Turbine

IMPULSE

The steam velocity is very high and therefore turbine speed is very high.

REACTION

The steam velocity as well as pressure is utilized

TYPE OF TURBINE SELECTED FOR PROJECT IS BASED ON

- Height of standing water "head"
- Flow of water
- Volume of water
- How deep the turbine must be set
- Efficiency
- Cost

IMPULSE TURBINE

- The impulse turbine generally uses the velocity of the water to move the runner. The water stream hits each bucket on the runner.
- An impulse turbine is generally suitable for high head, low flow applications.
- In impulse turbine, at inlet , only kinetic energy available. But in reaction turbine, at inlet kinetic energy as well as pressure energy both are available

TYPES OF IMPULSE TURBINES

1. Pelton Turbine
2. Cross-flow Turbine
3. Reaction Turbine

REACTION TURBINE

- A reaction turbine develops power from the combined action of pressure and moving water. The runner is placed directly in the water stream flowing over the blades rather than striking each individually.
- Reaction turbines are generally used for sites with lower head and higher flows than compared with the impulse turbines.

TYPES OF REACTION TURBINES

- Propeller Turbine
- Francis Turbine
- Kinetic Turbine

PROPELLER TURBINE

- A propeller turbine generally has a runner with three to six blades in which the water contacts all of the blades constantly. Picture a boat propeller running in a pipe.
- The pitch of the blades may be fixed or adjustable.

TYPES OF PROPELLER TURBINES

1. Bulb Turbine
2. Straflo Turbine
3. Tube Turbine
4. Kaplan Turbine

TURBINE PROPERTIES & SELECTION

Head Classification	Turbine Type	
	Impulse	*Reaction*
High (>50m)	• Pelton • Turgo	
Medium (10-50m)	• Crossflow • Turgo • Multi-jet Pelton	• Francis (spiral case)
Low (<10m)	• Crossflow • Undershot waterwheel	• Propeller • Kaplan • Francis (open-flume)

Table 1
Operational ranges of different turbines (ESHA, 2004)

Type of turbine	Head range (m)	Acceptance of flow variation	Acceptance of head variation	Maximum efficiency (%)
Kaplan/propeller	2-40	High	Low	91-93
Francis	25-350	Medium	Low	94
Pelton	50-1 300	High	High	90
Cross-flow	2-200	High	Medium	86
Turgo	50-250	Low	Low	85

SELECTION OF TURBINES

- Net Head
- Range of Discharge through turbine
- Rotational Speed
- Cost
- Francis is slow runner will be used in high head schemes, where Kaplan , Propeller and bulb are used in low head schemes with high speeds.
- The available energy therefore depends on the head of the water above the turbine and volume of water flowing through it .
- Turbines can also be selected on the basis of their output power and rated discharge.

KAPLAN/ FRANCIS DECISION

- **KAPLAN**
  - Smooth operation to low flow
  - Higher efficiency over a wide range
  - May result in a single unit instead of two Francis
  - Higher specific speed and rotational speed (smaller generator).

- **FRANCIS**
  - Less expansive

FRANCIS/ PELTON DECISION

- **PELTON**
  - Less excavation cost
  - Better for erosive water
  - Better part load efficiency
  - Less sensitive to head variation
  - Wide operating range
  - Lower maintenance cost

- **FRANCIS**
  - Higher specific speed and rotational speed (smaller generator)
  - Higher peak efficiency

SPECIFIC SPEED FOR DIFFERENT TURBINES

Type of Turbine	Specific Speed (rpm)	Reference (source)
Pelton Wheel (single jet)	$n_s = \frac{85.49}{(h)^{0.243}}$	Siervo and Lugaresi, 1978
Francis	$n_s = \frac{3763}{(h)^{0.854}}$	Schweiger and Gregory, 1989
Kaplan	$n_s = \frac{2283}{(h)^{0.486}}$	Schweiger and Gregory, 1989
Cross-flow	$n_s = \frac{513.25}{(h)^{0.505}}$	Kpordze and Warnick, 1983
Bulb	$n_s = \frac{1520.6}{(h)^{0.2837}}$	Kpordze and Warnick, 1983

ANSWER 2 (b)

GIVEN DATA
HEAD: **h = 190 m**
DISCHARGE: **q = 2.2 m³/s**
Overall efficiency: ***n* = 85% or 0.85**

At a head of 190 meters, a single jet pelton wheel turbine seems most suitable. Therefore from table 11.3, the specific speed can be calculated by using:

$$n_s = \frac{85.49}{(h)^{0.243}}$$

$$n_s = \frac{85.49}{(190)^{0.243}} = 23.88$$

The output power can be obtained by using:

$$P = \text{npqgh Watts}$$

$$P = 0.85 \text{ x } 1000 \text{ x } 2.2 \text{ x } 9.81 \text{ x } 190 = 3485.5 \text{ kW}$$

Using equation, we have:

$$n = n_s \frac{h^{\frac{5}{4}}}{\sqrt{P}}$$

$$n = 23.88 \frac{(190)^{\frac{5}{4}}}{\sqrt{3485.5}} = 285.32 \text{ rpm}$$

An alternator rated at 50 Hz frequency with synchronous speed approach 285.32 rpm but not greater is to be selected. The number of poles required computed by using:

$$N_s = \frac{120 \text{ f}}{P}$$

Or

$$P = \frac{120 \text{ x } 50}{285.32} = 21.02 \text{ poles}$$

Selecting 24 poles alternators will rotate at 250 rpm at 50 Hz seems just right a turbine will have a diameter which can be determine by using equation. Equation

$$D = 38.567 \frac{\sqrt{h}}{n} = 38.567 \frac{\sqrt{190}}{250} = 2.12 \text{ m}$$

The jet diameter can be calculated as

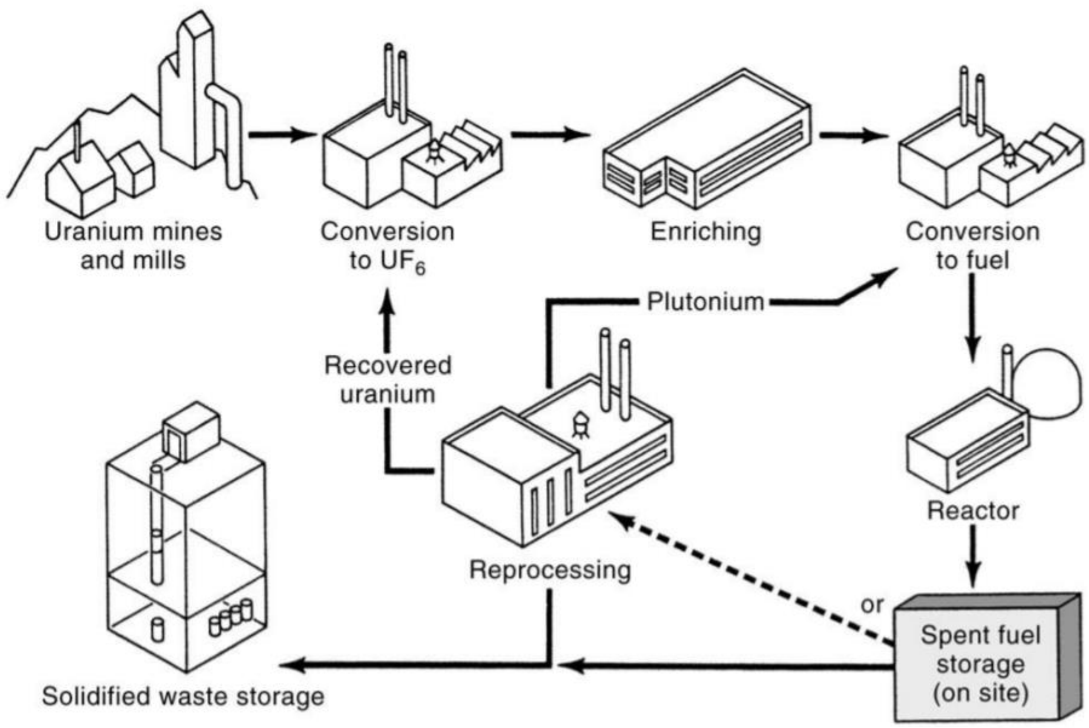
$$q = \frac{\pi dj^2}{4} vj$$

The jet velocity is vj = $\sqrt{2gh}$ = $\sqrt{2x9.81x190}$ = 61.05 m/s. Therefore the jet diameter from equation is

$$dj = \sqrt{\frac{4q}{\pi v_j}} = \sqrt{\frac{4 \text{ x } 2.2}{3.14 \text{ x } 61.05}} = 0.214 \text{ m or } 21.4 \text{ cm}$$

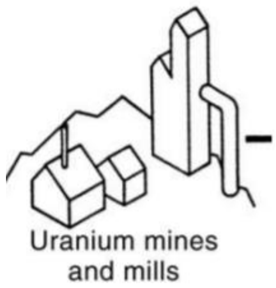
Thus turbine will have a standard diameter of 2 meters defined as the diameter of the circle describing the buckets center line and the diameter of the jet 20 cm.

ANSWER 3



MINING AND MILLING

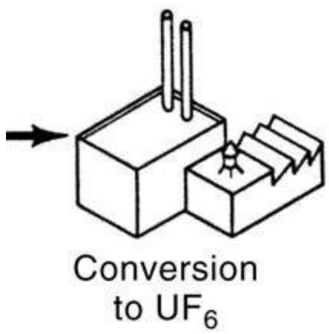
- Uranium is usually mined by either surface (open cut) or underground mining techniques, depending on the depth at which the ore body is found.
- From these, the mined uranium ore is sent to a mill which is usually located close to the mine.



- At the mill the ore is crushed and ground to a fine slurry which is leached in sulfuric acid to allow the separation of uranium from the waste rock.
- It is then recovered from solution as uranium oxide (U308) concentrate.
  - Sometimes this is known as "yellowcake“

CONVERSION

- Because uranium needs to be in the form of a gas before it can be enriched, the U308 is converted into the gas uranium hexafluoride (UF6) at a conversion plant.



ENRICHING

- Need to enrich uranium to at least 3% for a power plant
- Two Methods of Enriching
- Gaseous Diffusion Method

- UF6 (hexafluoride) gas heated
- U-238 is heavier than U-235
- Hexafluoride Gas can be separated into two streams
  - Low velocity U-238
  - High Velocity U-235

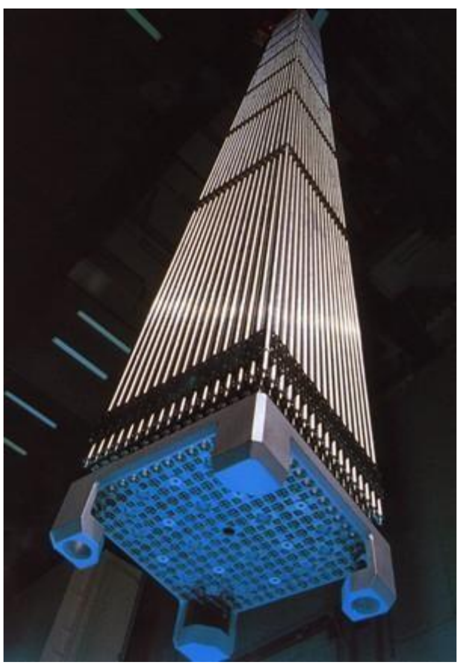
- Centrifuge Method
  - Gas spun in centrifuge
  - Lighter U-235 will separate from heavier U-238

FUEL CONVERSION

- Enriched Uranium transported to a fuel fabrication plant where it is converted to uranium dioxide (UO2) powder and pressed into small pellets.
- These pellets are inserted into thin tubes, usually of a zirconium alloy or stainless steel, to form fuel rods.
- The rods are then sealed and assembled in clusters to form fuel assemblies for use in the core of the nuclear reactor.

FUEL PACKING IN THE CORE

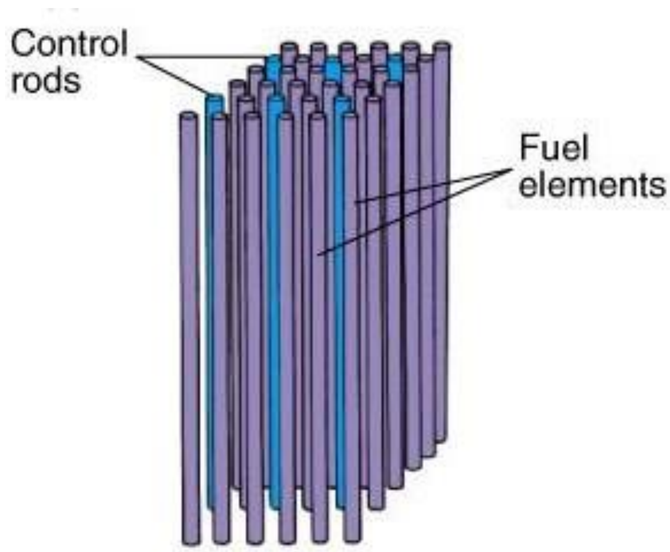
- Rods contain uranium enriched
- Need roughly 100 tons per year for a 1000MW plant



THE REACTOR CORE

- The reactor core consists of fuel rods and control rods

  - Fuel rods contain enriched uranium
  - Control rods are inserted between the fuel rods to absorb neutrons and slow the chain reaction
- Control rods are made of cadmium, which absorb neutrons effectively



MODERATORS

- Neutrons produced during fission in the core are moving too fast to cause a chain reaction
  - Note: This is not an issue with a bomb, where fissile uranium is so tightly packed that fast moving neutrons can still do the job.
- A moderator is required to slow down the neutrons
- In Nuclear Power Plants water or graphite acts as the moderator

LIGHT VS HEAVY WATER

- 99.99% of water molecules contain normal hydrogen (i.e. with a single proton in the nucleus)
- Water can be specially prepared so that the molecules contain deuterium (i.e. hydrogen with a proton and a neutron in the nucleus)
- Normal water is called light water while water containing deuterium is called heavy water
- Heavy water is a much better moderator but is very expensive to make

BOILING WATER REACTOR (BWR)

- Heat generated in the core is used to generated steam through a heat exchanger
- The steam runs a turbine just like a normal power plant

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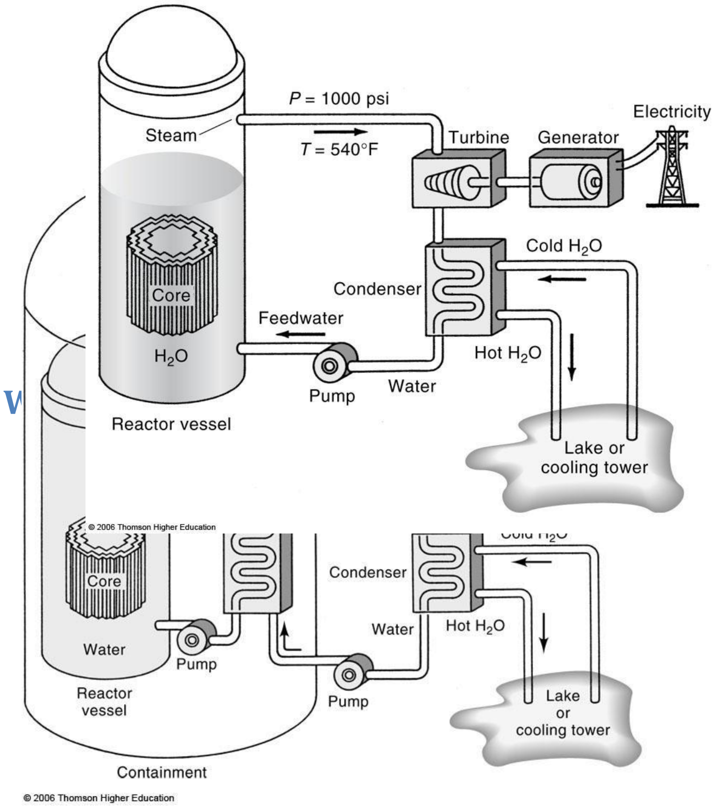


- Water in the core heated top 315°C but is not turned into steam due to high pressure in the primary loop.
- Heat exchanger used to transfer heat into secondary loop where water is turned to steam to power turbine.
- Steam used to power turbine never comes directly in contact with radioactive materials.

PWR VS BWR

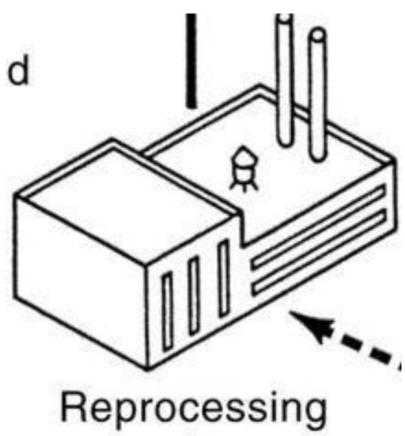
Table 14.2 LIGHT WATER REACTOR FUEL DATA

	BWR	PWR
Electrical output (MWe)	1000	1000
Initial load (tons of uranium oxide)	135	80
Fuel rods per assembly	50	200
Fuel assemblies per core	750	180
Number of control rods	180	45

Source: WASH-1250, U.S. Department of Energy.

URANIUM REPROCESSING

- Spent fuel still contains approximately 96% of its original uranium, of which the fissionable U- 235 content has been reduced to less than 1%.
- Spent fuel comprises waste products and the remaining 1% is plutonium produced while the fuel was in the reactor
- Reprocessing extracts useable fissile U-238
- Most of the spent fuel can be reprocessed.
- Federal law prohibits commercial reprocessing because it will produce plutonium (which can be used both as a fuel and in constructing bombs)



NUCLEAR WASTE DISPOSAL

- In the U.S., no high-level nuclear waste is ever disposed of--it sits in specially designed pools resembling large swimming pools (water cools the fuel and acts as a radiation shield) or in specially designed dry storage containers.
- Spent nuclear fuel must be isolated for thousands of years
- After 10,000 years of radioactive decay, according to EPA standards, the spent nuclear fuel will no longer pose a threat to public health.

Table 14.6 ANNUAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH A 1000-MWe POWER PLANT*

Impact	Coal	Nuclear (LWR)
Land use (acres)	17,000	1900
Water discharges (tons)	40,000	21,000
CO_2 emissions (tons)	6×10^6	0
Air emissions (tons)	380,000	6200
Radioactive emissions (curies)	1	28,000
Occupational health:		
deaths	0.5–5	0.1–1
injuries	50	9
Total fatalities (public and worker)	2–100	0.1–1

*Includes extraction, processing, transportation, and conversion. Strip-mined coal.
Source: WASH-1250 and *Ann. Nuclear Energy,* 13, 173 (1986).