Physics Cluster Questions

Three independent cases from Empires of a Shattered Sky

Name _____ Class _____ Date _____

Use the evidence in each case to make a justified decision. Show an equation before substitution, include units, and explain your reasoning. Use a calculator in degree mode. Keep unrounded values until the final answer. Each cluster is worth 20 points.

Flight manual extension

Three independent cases • 24 questions • 60 points

Use the supplied scene diagram and evidence for each cluster. Calculation spaces follow the manual’s G.U.E.S.S. format. Graphing and explanation prompts have separate response spaces.

Case	Decision
01 Across the Breach	Choose a launch angle using motion graphs and projectile evidence.
02 Catch Without Breaking	Evaluate capture forces, momentum, energy, and braking.
03 Shutdown Is Not Enough	Choose cooling equipment using thermal and electrical constraints.

CLUSTER 1 / SCENE REFERENCE

Across the Breach

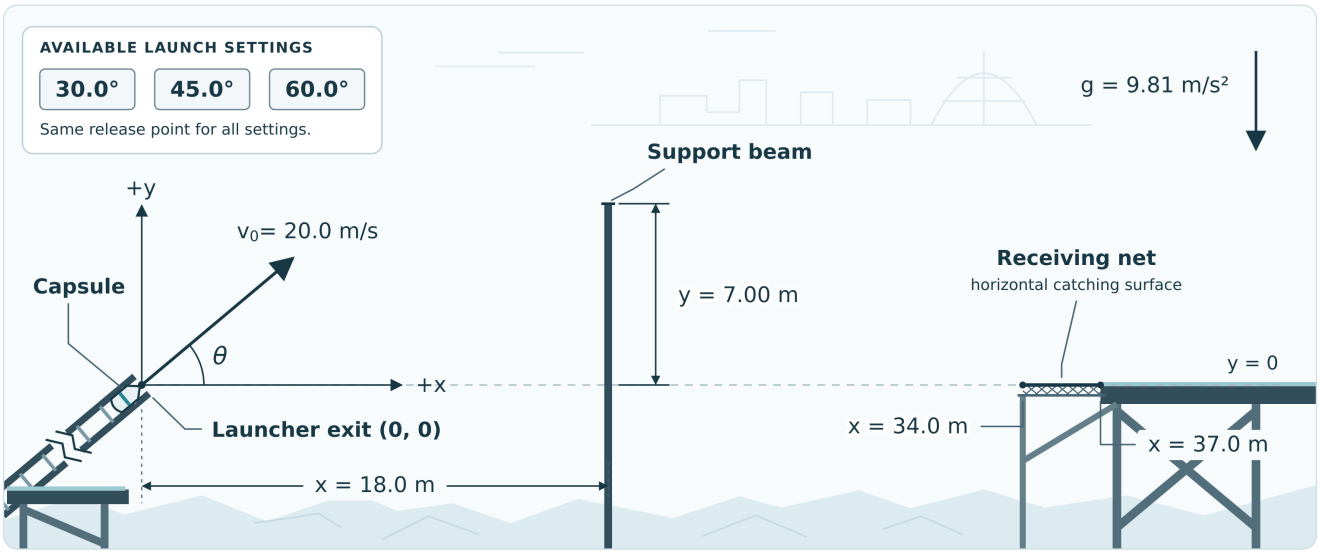
EMPIRES OF A SHATTERED SKY

Across the Breach

Codex Naviga cargo delivery · Antarctic Arcology

CLUSTER 01

Student diagram · side elevation



MODEL Ignore air resistance. Treat the beam as a vertical line.

Launch angle θ is schematic. Use the labeled values; the accelerating rail is shown with a length break.

A launcher at (0, 0) releases a capsule at 20.0 m/s. Available angles are 30, 45 and 60 degrees. A 7.00 m beam stands at x = 18.0 m. The horizontal net extends from x = 34.0 to 37.0 m at y = 0. Gravity acts down at 9.81 m/s².

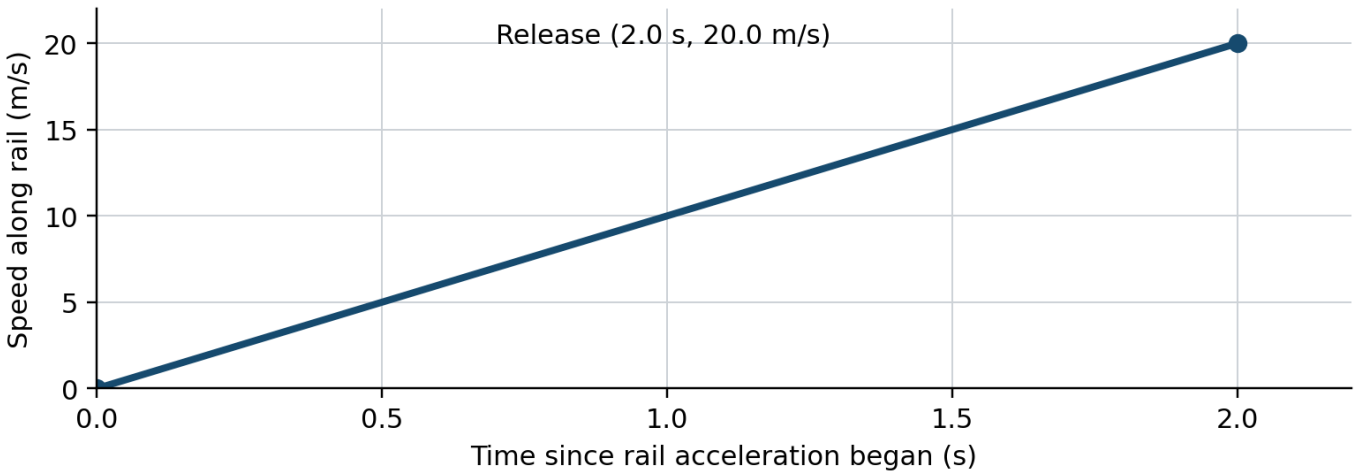
Use with questions 1.1–1.8. The graphs and tables on the following pages supply additional evidence.

Cluster 1 Across the Breach

A damaged service bridge has isolated a maintenance annex near the Antarctic Arcology. A Codex Naviga repair crew must send a protected communications module across the gap. Their delivery drone is disabled, so they use a cargo launcher with three angle settings. The capsule accelerates along a straight rail and then moves freely through the air. A raised support beam obstructs the route, and a horizontal receiving net covers a narrow landing zone on the far side. Your task is to choose a launch setting that clears the beam and reaches the net.

Model: Treat the capsule as a particle. Ignore air resistance, wind, and Earth curvature. After release, ax = 0 and ay = -9.81 m/s². The release point is (0, 0); right and up are positive. The receiving net is at y = 0. All angles are measured above horizontal.

Site or launcher measurement	Value
Available launch angles	30.0°, 45.0°, 60.0°
Speed at release for every setting	20.0 m/s
Initial speed on rail	0 m/s
Receiving net horizontal extent	x = 34.0 m to 37.0 m
Beam location and top height	x = 18.0 m; y = 7.00 m



Graph 1. The line is straight. Its time origin is the start of rail acceleration; projectile time begins again at zero at release.

Cluster 1 Motion evidence

1.1. Use Graph 1 to determine the capsule’s acceleration along the rail. Show how the graph supports your value. [2 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

1.2. Determine the distance traveled along the rail before release using a kinematics equation. Explain how the area under Graph 1 checks your result. [2 points]

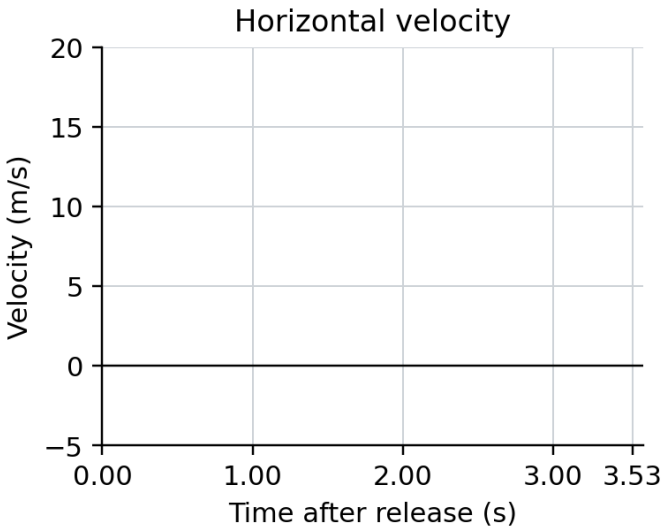
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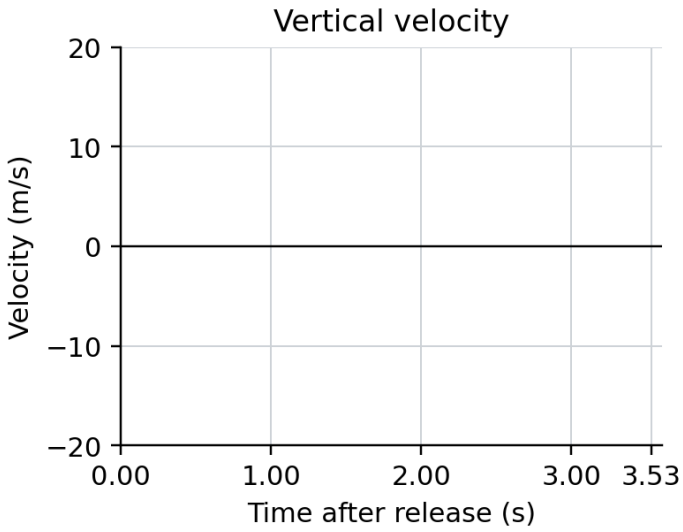
Cluster 1 Velocity graphs

1.3. For the 60.0° setting, calculate the initial horizontal and vertical velocity components. [2 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

1.4. On the axes below, sketch horizontal velocity and vertical velocity versus time for the 60.0° flight. For this item, use vx0 = 10.0 m/s, vy0 = 17.3 m/s, and a total flight time of 3.53 s. Mark when the capsule reaches its highest point. [3 points]





Cluster 1 The delivery decision

1.5. Calculate the time to return to y = 0 and the horizontal range for the 60.0° setting. Use vx0 = 10.0 m/s and vy0 = 17.3 m/s if needed. [3 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

1.6. Calculate the capsule’s height when it reaches the beam at x = 18.0 m using the 60.0° setting. State whether it clears the 7.00 m beam. [2 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

Cluster 1 Final recommendation

The crew’s model gives these results for the other settings. The predicted range assumes no obstruction.

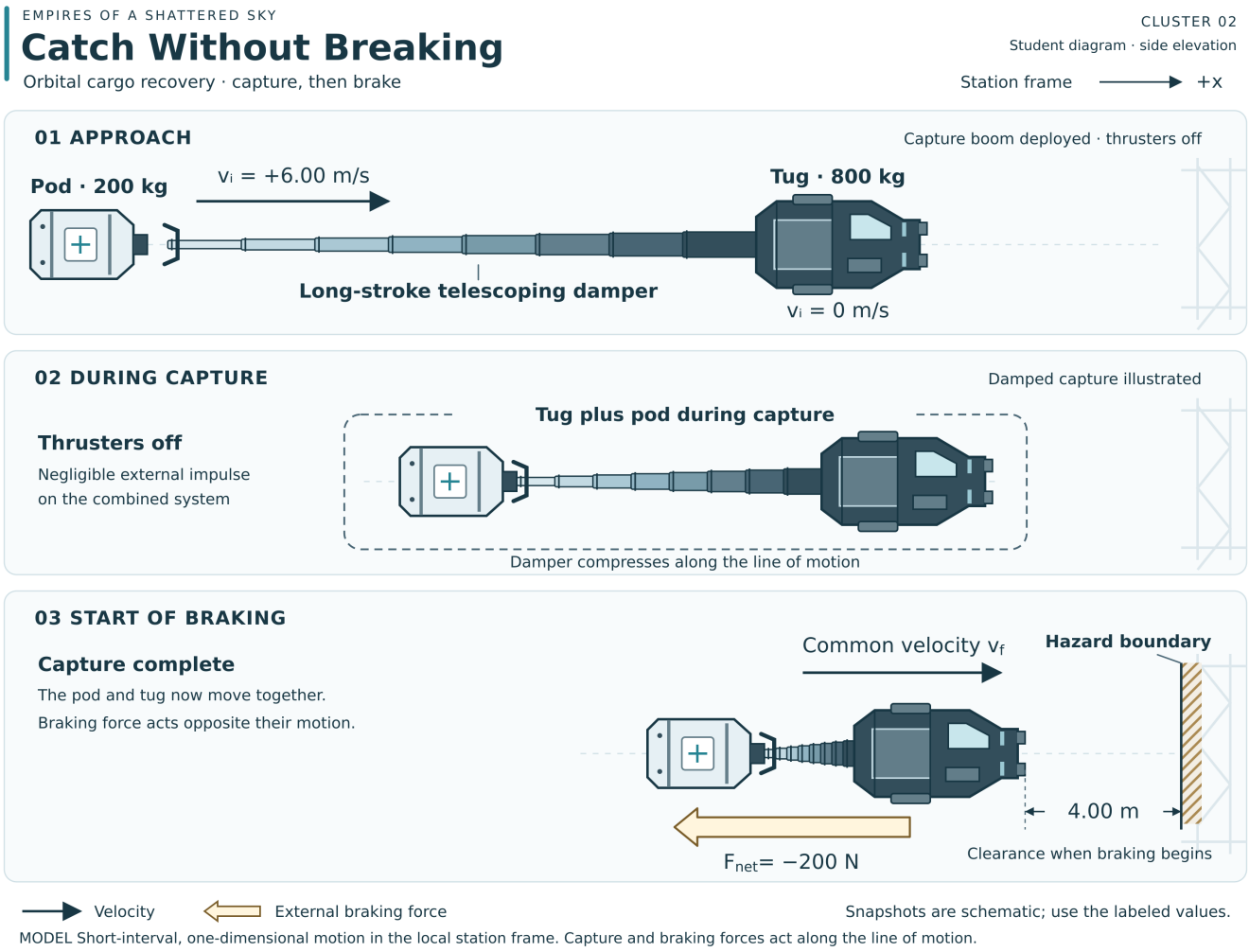
Launch angle	Predicted range	Height at x = 18.0 m
30.0°	35.3 m	5.10 m
45.0°	40.8 m	10.1 m

1.7. Recommend one of the three launch settings. Use numerical evidence to address both the beam and the receiving net. Explain why each other setting fails. [3 points]

1.8. A technician says, “At the highest point of the 60° flight, the capsule’s speed and acceleration are both zero.” Evaluate both parts of this claim. State the velocity components and acceleration there. [3 points]

CLUSTER 2 / SCENE REFERENCE

Catch Without Breaking



A 200 kg pod moving right at 6.00 m/s approaches an 800 kg tug initially at rest. Thrusters are off during capture. After capture they move together; a 200 N braking force acts left. Clearance is 4.00 m when braking begins.

Use with questions 2.1–2.8. The graphs and tables on the following pages supply additional evidence.

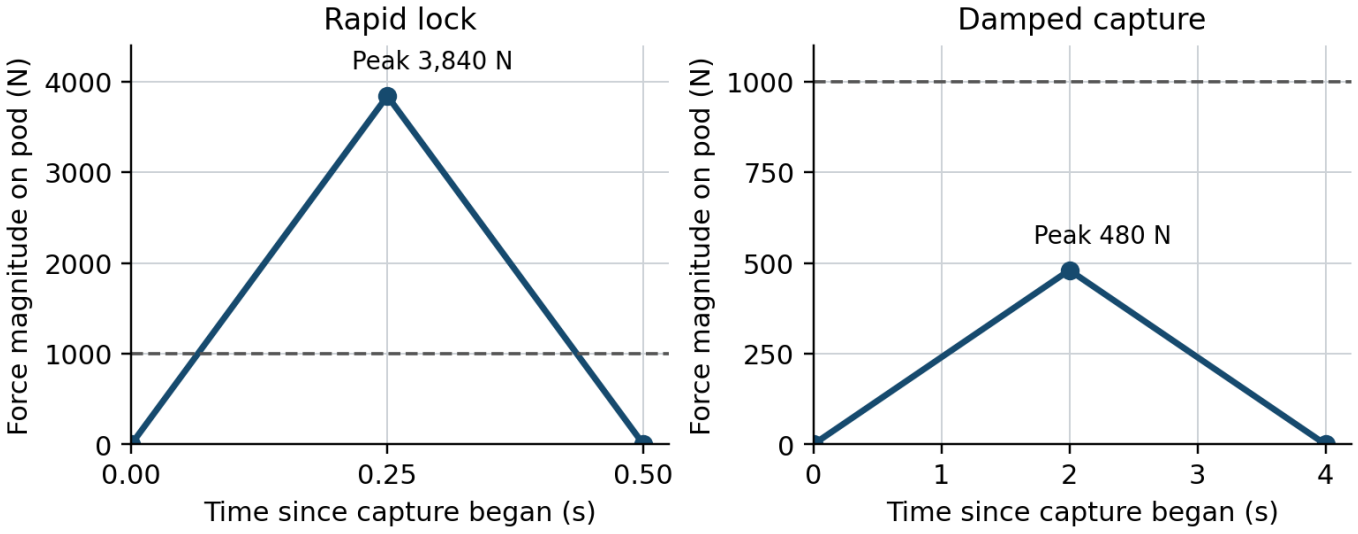
Cluster 2 Catch Without Breaking

Name _____ Class _____ Date _____

A cargo pod has broken loose near a Codex Naviga orbital transfer station. A recovery tug waits ahead of it with its capture system aligned through both centers of mass. The pilot can use a rapid locking mechanism or a damped mechanism that gradually brings the tug and pod to a common velocity. Thrusters remain off during capture. After capture, the pilot uses a braking thruster to stop both objects relative to the station. Choose a capture method and evaluate whether the combined system can stop safely.

Model: Use a local frame moving with the station over this short interaction. Motion is one-dimensional; right is positive. Neglect external impulse and differences in gravitational acceleration during capture. Ignore rotation. After capture the tug and pod remain connected. Thruster propellant loss is negligible.

Measured or specified quantity	Value
Pod mass and initial velocity	200 kg; +6.00 m/s
Tug mass and initial velocity	800 kg; 0 m/s
Maximum allowable coupling force	1,000 N
Net braking force after capture	-200 N
Clear stopping distance at start of braking	4.00 m



Graph 2. Each pulse is a straight-sided triangle. Both graphs show the magnitude of the force on the pod; its direction is left. The dashed line is the coupling limit. The two panels use different time and force scales.

Cluster 2 Capture analysis

2.1. Before capture, the pod has no propulsion and negligible net force in the local model. Explain why its velocity does not fall to zero. Identify the relevant Newton’s law. [2 points]

2.2. During capture, compare the force exerted by the tug on the pod with the force exerted by the pod on the tug. Compare their acceleration magnitudes and support the comparison using their masses. [2 points]

Cluster 2 Momentum and impulse

2.3. Use conservation of momentum to calculate the common velocity immediately after capture. State the condition that allows you to conserve the tug-and-pod system’s momentum during this interaction. [3 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

2.4. Use the area under either force-time pulse to determine the impulse on the pod. Include its sign in the stated coordinate system. [2 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

Cluster 2 Equipment and braking decisions

2.5. Which original capture mechanism stays within the coupling’s force limit? Support your answer with both peak forces and the specified limit. [2 points]

2.6. Calculate the total kinetic energy before and immediately after capture, then account for the change. Use a common final velocity of +1.20 m/s for this item. [3 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

Cluster 2 Stopping and refinement

2.7. Starting at +1.20 m/s after capture, calculate the acceleration and stopping distance under the -200 N net braking force. Decide whether the available 4.00 m is sufficient. Show your equations. [3 points]

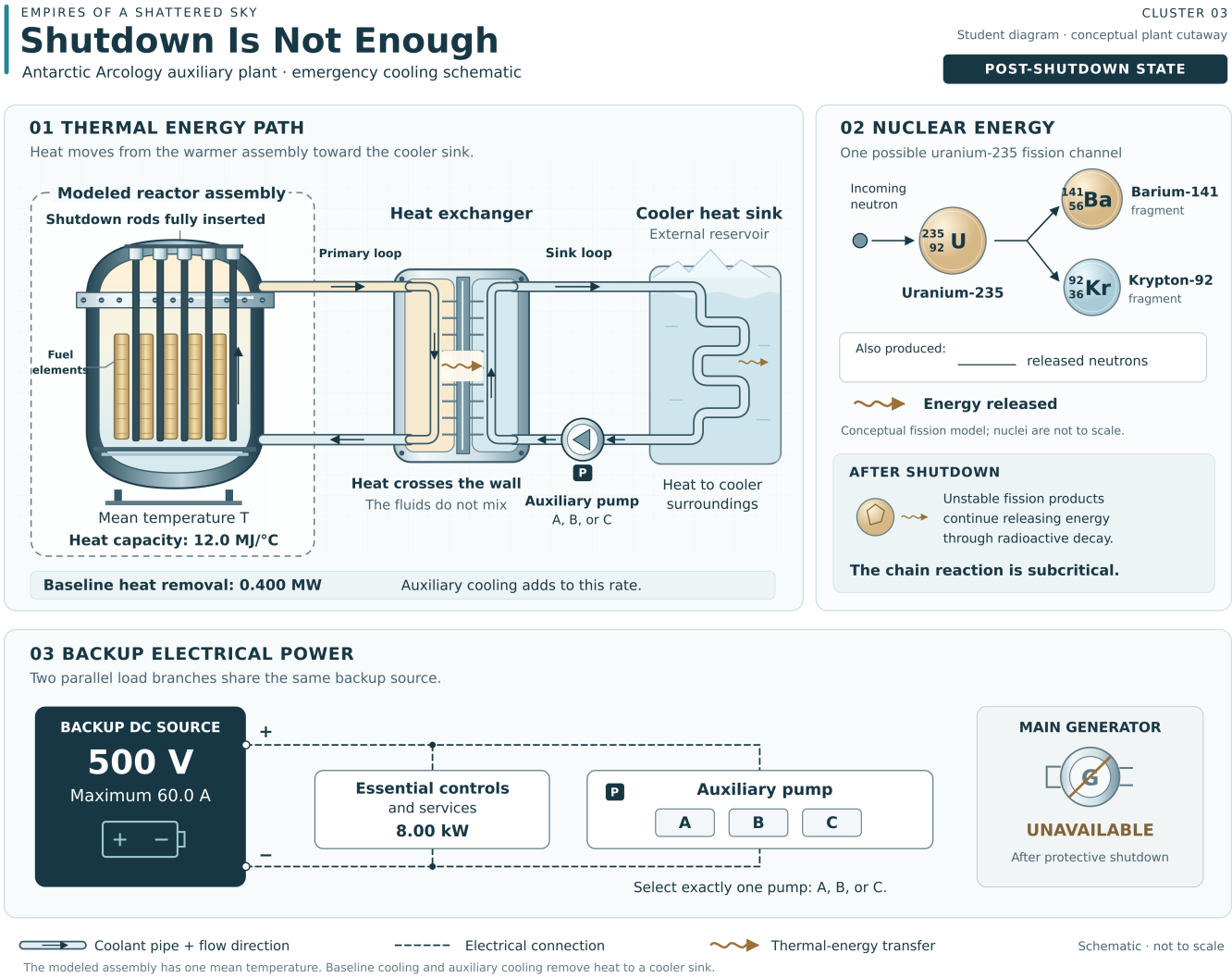
G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

2.8. An engineer proposes a symmetric triangular capture pulse lasting 2.00 s while keeping the impulse magnitude at 960 N·s. Calculate the required peak force, check the coupling limit, and explain why the common final velocity would remain the same as for the original captures. [3 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

CLUSTER 3 / SCENE REFERENCE

Shutdown Is Not Enough



After shutdown, residual heat passes from the reactor assembly through a heat exchanger to a cooler sink. Heat capacity is 12.0 MJ/°C and baseline removal is 0.400 MW. A 500 V source limited to 60.0 A supplies parallel essential services of 8.00 kW and one pump A, B or C. The main generator is unavailable. The fission inset leaves the released-neutron count blank.

Use with questions 3.1–3.8. The graphs and tables on the following pages supply additional evidence.

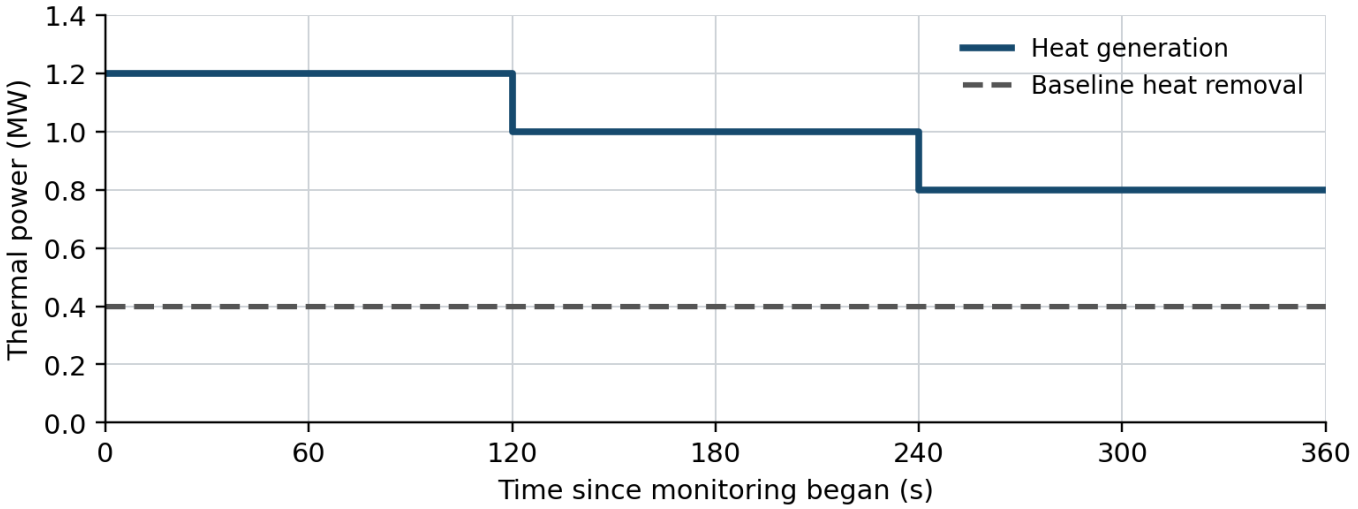
Cluster 3 Shutdown Is Not Enough

Name _____ Class _____ Date _____

An equipment fault at an auxiliary fission plant serving the Antarctic Arcology causes an unintended power increase and disrupts normal cooling. The protective shutdown stops the sustained chain reaction. The main generator is unavailable, but the reactor assembly continues to warm. An engineering crew has a backup electrical supply and three auxiliary pumps. You must explain the continuing heat production and choose a pump that removes enough heat without overloading the backup supply.

Science briefing: A critical reactor has a self-sustaining chain reaction; the term does not itself mean overheating. Shutdown makes the chain reaction subcritical. Unstable fission products continue to decay and release energy. The remaining heat must still be transferred to cooler surroundings.

Quantity	Scenario value
Normal thermal power before the fault	20.0 MW
Normal electrical output before the fault	6.00 MW
Mean assembly temperature at monitoring time t = 0	305 °C
Effective heat capacity C of modeled assembly	12.0 MJ/°C
Maximum permitted mean temperature in this scenario	320 °C



Graph 3. Monitoring begins shortly after shutdown. Use constant heat generation of 1.20 MW for 0–120 s, 1.00 MW for 120–240 s, and 0.800 MW for 240–360 s. Baseline heat removal is 0.400 MW throughout. These are simplified interval averages.

Cluster 3 Nuclear and cooling evidence

Thermal model: Treat the reactor assembly as one uniform-temperature system with constant heat capacity. There is no phase change. The listed heat-removal rates include all modeled cooling and are net of pump heating. Use $\Delta E = (P_{generated} - P_{removed})\Delta t$ and $\Delta T = \Delta E/C$. Here 1 MW = 1 MJ/s. The heat sink remains cooler than the assembly.

At t = 120 s, exactly one auxiliary pump can start and remain on until t = 360 s. Its additional heat removal adds to the 0.400 MW baseline. Rates are constant over this short interval. The backup source maintains 500 V and can supply at most 60.0 A. Essential controls and services require 8.00 kW continuously. Treat the listed currents as steady operating currents; ignore start-up transients.

Pump	Supply voltage	Current	Additional net thermal removal
A	500 V	20.0 A	0.300 MW
B	500 V	40.0 A	0.700 MW
C	500 V	70.0 A	1.10 MW

Nuclear model data: A uranium-235 nucleus has 92 protons; barium has 56 protons and krypton has 36. A neutron has mass number 1 and charge 0. One possible fission channel is represented below; mass numbers appear after the element names.

neutron + uranium-235 → barium-141 + krypton-92 + ____ neutrons + released energy

3.1. Complete the neutron count in the model and show conservation of total nucleon number. Describe the nuclear change and explain how the released neutrons can sustain a chain reaction. [3 points]

3.2. Explain why the statement “The reactor is no longer critical, so it cannot continue producing heat” is incorrect. Identify the source of heat after shutdown. [2 points]

Cluster 3 Energy and temperature predictions

3.3. Use Graph 3 to calculate the net thermal energy added to the assembly from 0 to 120 s with baseline cooling only. Explain what the area between the two lines represents. [2 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

3.4. With baseline cooling only, calculate the temperature at each time below. Show your work and determine whether the 320 °C limit is exceeded during the modeled 360 s. [3 points]

Monitoring time	Mean assembly temperature
0 s	305 °C
120 s	_____
240 s	_____
360 s	_____

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

Cluster 3 Electrical power

3.5. Before the fault, what percentage of the reactor’s thermal power became electrical output? At steady operation, how much thermal power was not converted to electricity and had to be rejected to the surroundings? Use the normal-operation values, not the post-shutdown graph. [2 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

3.6. Use P = IV to complete the electrical-power table. Include the essential 8.00 kW load. Show the backup source’s maximum power and identify every option that exceeds it. [3 points]

Pump	Pump electrical power	Total with essential loads
A	_____	_____
B	_____	_____
C	_____	_____

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

Cluster 3 The cooling decision

3.7. Choose the pump that meets both requirements from 120 to 360 s: total electrical demand stays within the backup supply’s capacity, and total heat removal is at least the heat-generation rate throughout that interval. Cite numerical evidence for both requirements. [2 points]

3.8. For a separate check, assume Pump B starts at 120 s when the assembly is at 313 °C. Build an interval-by-interval energy calculation to predict the temperature at 240 s and 360 s. Explain how the result follows from the balance of heat generation and heat removal. [3 points]

G / U Givens and unknowns
E Equation before substitution
S / S Substitute and solve with units

All measurements and equipment specifications are fictional instructional data. Use the scene diagrams, graphs, and stated model together.