

Four Mystery Packets: Which Way Does the Energy Go?

Investigation question: Four unlabeled packets go into water. Which ones release energy to the surroundings, which absorb it, and which do neither, and what evidence tells you?

Evidence-based mystery

Groups of 4

1 session

Setup 7 · Activity 33 · Cleanup 8 min

MS-PS1-6 · practice

MS-ETS1-2 · supports

Scientific purpose

Students measure the temperature of the water before and after each of four teacher-measured packets is added, classify each change as exothermic, endothermic or close to neutral from the data, and then use their evidence to match each packet to a description on a manufacturer's spec sheet. Two of the packets fizz but move the temperature in opposite directions, which separates 'gas is produced' from 'energy is released' and makes the thermometer, not the eye, the deciding instrument.

Why this helps students with this chapter

Students arrive believing that a change which looks energetic (fizzing, foaming) must be giving off energy, and that cold is something a cold pack makes. Measuring four changes with a thermometer, including two that fizz in opposite directions and one that does almost nothing, forces the classification to rest on where the energy went. Having to identify each packet from a spec sheet turns the measurements into evidence for an argument instead of numbers in a table.

Standards connections

MS-PS1-6 (practice, characterizing the chemical processes that a warming or cooling device could use): Before students can design a pack in Lab 2 they need to know which safe processes release thermal energy and which absorb it, and how much. This lab produces that evidence with the same reagents, so it is practice toward the design PE rather than evidence of it.

MS-ETS1-2 (supports, matching measured performance to a written specification): Matching each packet to a spec-sheet description from evidence is a small version of evaluating whether a material meets a stated requirement, which students do fully in Lab 3.

Roles (rotate each session)

- **Safety captain and mixer:** Checks that everyone's goggles are on, pours the measured water, adds the packet on the timer's signal, and stirs gently with the stick. The only person who touches reagents.
- **Timer and caller:** Starts the stopwatch the instant the packet goes in and calls out 'read' every 30 seconds for three minutes.
- **Thermometer reader:** Holds the probe in the middle of the liquid without touching the cup bottom and reads the temperature aloud to one decimal place at each call.

- **Recorder:** Writes every reading and observation in the table, computes the temperature change, and leads the group's spec-sheet matching.

Materials

Item	Quantity	Per	Note
Foam cups, 8 to 12 oz	4	group	Label A, B, C, D with a marker before class. Foam slows heat loss to the table so the change is easier to see.
Digital thermometer or temperature probe reading to 0.1 °C	1	group	A kitchen instant-read thermometer works. Rinse and dry between stations.
Stopwatch or phone timer	1	group	
Graduated cylinder or kitchen measuring cup marked at 50 mL	1	group	
Room-temperature tap water	about 200 mL	group	Fill a pitcher the day before so it is at room temperature.
Packet A: calcium chloride pellets (ice-melt or pickling grade), 3 g, teacher-measured	1 packet	group	In a small labeled paper cup or folded paper. Anhydrous pellets give the largest rise; hydrated or lower-purity products warm less.
Packet B: citric acid 3 g and baking soda 3 g, pre-mixed dry, teacher-measured	1 packet	group	The dry mix is stable; it reacts only when water is added.
Packet C: table salt (sodium chloride), 3 g, teacher-measured	1 packet	group	
Station D liquid: 3% hydrogen peroxide, 30 mL, poured by the teacher into cup D	30 mL	group	Cup D holds peroxide instead of water. Students are told it is 'a clear liquid that is not plain water'.
Packet D: dry active yeast, about 1 g (a quarter teaspoon), teacher-measured	1 packet	group	
Wooden stirring sticks	4	group	
Plastic tray or baking sheet to hold the four cups	1	group	Catches foam from station D and any spills.
Safety goggles	1 pair	student	
Paper towels and a waste bucket	1 set	class	
Recording sheet and graph paper	1 set	student	

Estimated cost: 20 to 35 per class of 8 groups, excluding thermometers (an estimate; Estimate. A 10 lb bag of calcium chloride ice melt (about \$15) and a 1 lb jar of citric acid (about \$8) supply dozens of classes; baking soda, table salt, a bottle of 3% peroxide and a packet of yeast total under \$6; foam cups about \$4. Digital kitchen thermometers run \$8 to \$12 each if the room has none.)

Safety

- Goggles on from the first packet to the last rinse. Citric acid, calcium chloride and hydrogen peroxide are all eye irritants.
- Only the safety captain touches reagents, and with dry hands. Calcium chloride pellets warm when wet and can irritate skin; if any touches skin, rinse with water for a minute.
- 3% hydrogen peroxide can sting cuts and bleach fabric. Keep it in the cup, on the tray. The yeast foam may overflow the cup; that is why the tray is there.
- Never cap or seal any cup. Stations B and D make gas; a sealed container can burst.
- Nothing is tasted, nothing is sniffed up close, and no cup is held near the face. Hands are washed at the end.
- The amounts are chosen so that no station should pass about 40 °C. If a cup feels hot, set it on the tray and tell the teacher; do not pick it up.
- Disposal: all four solutions are drain-safe in these amounts. Pour them down the sink with running water; cups and sticks go in the trash.
- No flames, no hot plates, no sealed bags. This activity has not been physically tested by the authors; pilot it before class.

Teacher preparation and setup

1. Weigh the packets the day before on a kitchen or lab balance: 3 g calcium chloride, 3 g citric acid plus 3 g baking soda mixed, 3 g salt, and about 1 g yeast per group. Fold each in paper or put it in a small labeled cup. Keep calcium chloride sealed; it pulls water from the air and clumps.
2. Pilot station A and station D yourself with your actual products. If 3 g of your calcium chloride in 50 mL warms the water less than 5 °C, raise packet A to 5 g. If the peroxide and yeast warm less than 3 °C in three minutes, use fresh peroxide (it loses strength once opened) and a fresh yeast packet.
3. Pour 30 mL of 3% hydrogen peroxide into each cup D just before class and keep the cups on the trays; do not let students pour it.
4. Print the spec sheet (it is on the recording sheet) and the data table; set a pitcher of water out the night before so it is at room temperature.
5. Write the three-minute reading schedule on the board: 0, 30, 60, 90, 120, 150, 180 seconds.

Investigation design

Independent variable	Which packet is added (A, B, C or D)
Dependent variable	Temperature of the liquid over three minutes, and the temperature change from start to finish
Controlled	Same volume of liquid in each cup (50 mL water; station D is a fixed 30 mL of peroxide); Same cup type and same tray position, so heat loss is similar; Same stirring (two gentle turns) and same reading schedule; Packet masses measured by the teacher, 3 g of solid at A, B and C
Trials	One trial per station per group; the class pools temperature changes on the board so each station has eight or more values to compare.

Comparison

Temperature change at each station compared with zero and with the other stations; fizzing stations B and D compared with each other.

Student procedure

1. Put on goggles. Set the four labeled cups on the tray. Read the spec sheet on your recording sheet so you know the four fillings you will be trying to identify.
2. The safety captain measures 50 mL of room-temperature water into cups A, B and C. Cup D already holds 30 mL of a clear liquid that is not plain water; do not add water to it.
3. For station A: the thermometer reader places the probe in the water, waits ten seconds, and reads the starting temperature. The recorder writes it in the 0 s row.
4. The timer says 'go'; the safety captain tips packet A into the water and stirs gently twice. The timer calls 'read' every 30 seconds for three minutes while the reader reads and the recorder writes. Everyone also notes what they see and hear: fizzing, foam, color change, pellets disappearing.
5. Rinse and dry the probe. Repeat steps 3 and 4 for station B (add packet B to the water) and station C (add packet C).
6. For station D: read the starting temperature of the liquid in cup D, then add packet D (the yeast) on 'go' and record for three minutes. Expect foam; keep the cup on the tray.
7. Compute the temperature change for each station (final minus starting; a drop is a negative number). Classify each station as exothermic, endothermic or close to neutral and write the evidence.
8. Plot all four stations on the one graph, temperature against time, with a different symbol for each station. Label each line with its letter.
9. Match each station to a spec-sheet filling (1 to 4). Write the evidence for each match. Then answer the analysis questions individually and compare within the group.

Expected observations

- Station A: pellets disappear within a minute; the water warms steadily, typically by 7 to 10 °C with anhydrous pellets (less with hydrated ice-melt products), peaking by about 90 seconds; no gas.
- Station B: immediate fizzing and a hiss; the water cools, typically by 3 to 6 °C, most of it in the first minute; the fizzing slows as the baking soda is used up.
- Station C: salt dissolves slowly with no fizzing; temperature changes by about 1 °C or less, usually a slight drop (3 g of salt can cool 50 mL of water by up to about 0.9 °C).
- Station D: foam builds over a minute and may overflow; the liquid warms by several degrees over three minutes, more slowly than station A, because the breakdown continues as long as peroxide and enzyme remain in contact.

Likely difficulties

- The probe touches the cup bottom or sits in foam at station D and reads the wrong thing; coach readers to hold the probe mid-liquid and below the foam.
- Groups read station A too early and miss the peak, or read station B too late and see the water already warming back toward room temperature; keep to the 30-second schedule and use the 180 s reading

as 'final' for everyone.

- Students classify by how the cup feels rather than by the numbers; require a number in the evidence column.
- The negative sign on station B's change confuses some students; model 'final minus start' on the board with a drop.
- Old peroxide or dead yeast makes station D flat; pilot with your actual products and replace them if the rise is under 3 °C.

Structured debrief

1. Pool every group's temperature change for each station on the board. Ask what the class agrees on: A and D warm, B cools, C barely moves. Point out that the spread within a station (a few degrees) is much smaller than the differences between stations, which is why the classification holds.
2. Put stations B and D side by side: both fizzed, opposite directions. Ask students to state the rule they will carry into Lab 2: gas tells you matter left the system; only the thermometer (or light and sound) tells you which way energy went.
3. Reveal the identities: A is calcium chloride, which dissolves exothermically; B is citric acid and baking soda, a genuine reaction that makes carbon dioxide and absorbs energy; C is table salt, which dissolves with almost no energy change; D is hydrogen peroxide breaking down into water and oxygen, sped up by an enzyme in the yeast. Note that A and C are dissolving processes, not reactions in the strict sense, while B and D form new substances.
4. Return to the cold-pack question from the slides: at station B the water cooled first, then the cup, then the hand. Energy moved from hand to cup to water to the reacting system. No cold moved anywhere.
5. Preview Lab 2: the hot-pack teams will use filling A and the cold-pack teams filling B, with criteria for temperature and time, so today's data are their starting point.

Recording sheet: what students fill in

Lab 1 recording sheet: Four mystery packets

You are a quality tester at a company that makes warming and cooling packs. Four candidate fillings arrived without labels. Measure what each one does in water, then use your evidence to work out which is which.

Manufacturer's spec sheet: the four candidate fillings — **Filling 1, WarmSalt:** an ionic solid that gives out energy as it dissolves; makes no gas. **Filling 2, FizzCool:** a dry mix of an acid and a carbonate; reacts in water, makes carbon dioxide gas and takes in energy. **Filling 3, Plain:** a common salt that dissolves with almost no energy change. **Filling 4, OxyFoam:** a clear liquid that breaks down into water and oxygen gas when a catalyst is added, giving out energy. One of the four stations uses a liquid instead of water; the packet at that station is the catalyst.

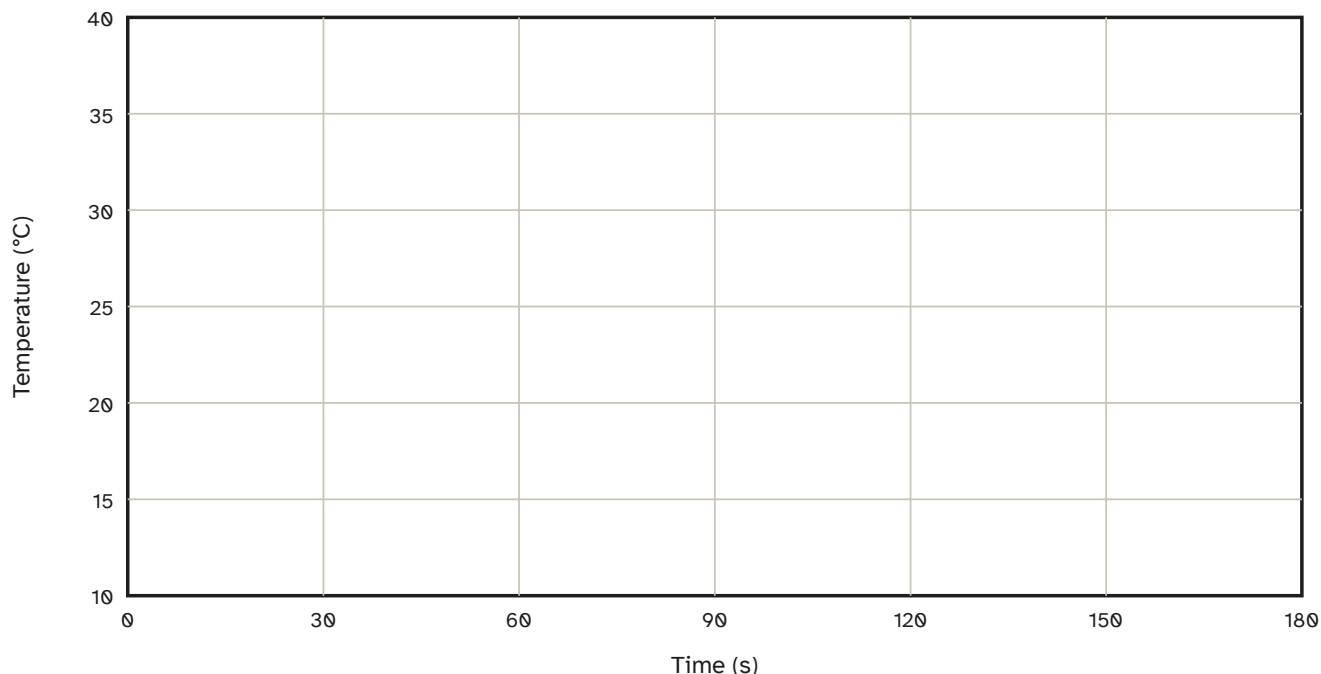
Temperature readings (°C) every 30 seconds

Time (s)	Station A	Station B	Station C	Station D
0 (before packet)				
30				
60				
90				
120				
150				
180				
Change (180 s minus 0 s)				

Observations and classification

Station	What you saw and heard	Exothermic, endothermic or neutral?	Evidence (use a number)	Spec-sheet filling (1-4)
A				
B				
C				
D				

Temperature of each station over three minutes



1. For station A, name the system and name two things in the surroundings. Which of those surroundings did your thermometer actually measure?

Answer: System: the calcium chloride and the calcium and chloride ions it becomes as it dissolves.

Surroundings: the water in the cup, the cup itself, the air, the thermometer probe, your hand. The thermometer measured the water, which is the part of the surroundings closest to the system.

Why: The boundary goes around the matter that changes. The water is the surroundings that receives the energy first, so its temperature is the evidence. Accept answers that put the water inside the system if the student explains that it is the medium the ions spread into; chemists draw it either way.

- Names the dissolving calcium chloride (or 'the pellets and what they become') as the system
- Names at least two surroundings items
- Identifies the water as what the thermometer measured

2. Two stations fizzed. Did they move the temperature in the same direction? What does that tell you about using fizzing as evidence of energy direction?

Answer: No. Station B fizzed and cooled; station D foamed and warmed. Fizzing shows that a gas is being made (matter leaving the liquid), not which way energy is flowing, so fizzing cannot be used as evidence of exothermic or endothermic.

Why: This is the lab's central contrast and the basis of a listed chapter misconception. A full answer names both stations and states the rule.

- States the two fizzing stations went in opposite directions
- Concludes that fizzing is not evidence of energy direction

-  Draw two boundary diagrams side by side: one for station A and one for station B. In each, draw a dashed boundary around the system, label the system and the surroundings, and draw an arrow showing which way energy crossed the boundary. Label each diagram exothermic or endothermic.

Answer: Two diagrams. Station A: dashed boundary around the pellets/ions; water, cup and hand labeled outside; arrow from inside to outside; labeled exothermic. Station B: dashed boundary around the citric acid, baking soda and the products (sodium citrate, carbon dioxide, water formed); water, cup and hand outside; arrow from outside to inside; labeled endothermic.

Why: The arrows are the point. Students who draw the arrow for B pointing out because 'gas came out' have confused matter leaving with energy leaving; the gas can be drawn leaving, but the energy arrow must point in.

- Boundary encloses only the reacting matter and its products
- Energy arrow out for A, in for B
- Both diagrams labeled with the correct term

Analysis questions: answer key

3. Station A's water went from 22.0 °C to 31.5 °C in 90 seconds and then stopped rising. Calculate the temperature change and the average change per 30-second interval during the rise. Show your work.

Answer: Change = 31.5 °C – 22.0 °C = +9.5 °C. The rise took 90 s, which is three 30-second intervals, so the average change per interval = 9.5 °C ÷ 3 ≈ 3.2 °C per 30 s.

Why: Final minus start, then divide by the number of intervals during the rise (not the full 180 s, since the prompt says the rise stopped at 90 s). Accept 3.17 or 'about 3 °C per 30 s' with the division shown.

Also acceptable: Accept a rate expressed per second (about 0.11 °C/s) or per minute (about 6.3 °C/min) if the arithmetic is shown.

4. Explain how you matched station B to its spec-sheet filling. Give two separate pieces of evidence and say which one could not have been replaced by just looking.

Answer: Station B fizzed (gas was made) and the temperature fell by several degrees (energy was absorbed). The only filling on the spec sheet that both makes gas and takes in energy is Filling 2, FizzCool. The temperature drop is the evidence that could not have been replaced by looking: fizzing is visible, but the direction of energy flow needs the thermometer, because station D also fizzed and warmed.

Why: A full answer uses two independent lines of evidence and recognizes that the thermometer reading was the deciding one because the other fizzing station went the other way.

- Cites gas production
- Cites a measured temperature drop
- Identifies the temperature drop as the evidence that required measurement

5. Station C changed by about one degree or less. Does dissolving always involve an energy change? Use what you know about separating particles and about water surrounding them to explain why the change can be nearly zero.

Answer: No; the size and direction of the energy change depend on the substance. Separating the particles of a solid from one another takes energy in, and water molecules surrounding and attaching to the separated particles gives energy out. For table salt those two amounts are nearly equal (separating costs slightly more), so the net change is close to zero: a slight cooling. For calcium chloride the surrounding step gives out much more than the separating step costs, so it warms; for some salts, such as ammonium chloride in a cold pack, the separating step costs more, so it cools.

Why: This is the dissolving version of the bond-breaking and bond-forming model: pay in to separate, get paid when water attaches. Students need not know enthalpy values; the pattern of 'two amounts, compare them' is the target.

- States that separating particles takes energy in
- States that water surrounding the particles gives energy out
- Explains near-zero change as the two amounts nearly cancelling

6. Write a word equation for station B that includes the word 'energy' on the correct side. The reactants are citric acid and baking soda (sodium bicarbonate); the products are sodium citrate, carbon dioxide and water. Then do the same for station D, where hydrogen peroxide becomes water and oxygen. Explain how you decided where to put 'energy' each time.

Answer: Station B: citric acid + sodium bicarbonate + energy → sodium citrate + carbon dioxide + water. Station D: hydrogen peroxide → water + oxygen + energy (the yeast's enzyme speeds it up but is not used up, so it is not written as a reactant). Decision: at B the surroundings cooled, so energy entered the system and belongs with the reactants; at D the liquid warmed, so energy left the system and belongs with the products.

Why: The placement rule from slide 16 applied to the lab's own data. Accept 'catalyst' or 'yeast' written above the arrow for D; do not accept yeast as a reactant without a note, though do not penalize heavily since the lab did not teach catalysts.

- Energy with the reactants for B
- Energy with the products for D
- Justifies each placement with the measured temperature direction

7. At station B, the cup felt cold to the recorder's hand after two minutes. Describe the direction of thermal energy flow between the hand, the cup, the water and the reacting system. Is anything called 'cold' moving?

Answer: Thermal energy flows from the warmer things to the cooler things: from the hand into the cup wall, from the cup into the water, and from the water into the reacting system, which is absorbing energy as citric acid and baking soda react. The hand feels cold because energy is leaving it. Nothing called cold moves anywhere; only energy moves, and it moves in one direction, toward the system.

Why: This is the chapter's first listed misconception. The chain hand → cup → water → system is the full-credit picture; the essential statement is that the hand loses energy.

- States that energy flows out of the hand
- Describes the direction toward the reacting system
- States explicitly that cold is not a substance that moves

8. You must choose one filling for a cooling pack and one for a warming pack to be sold in a camping store. Which do you pick for each, and what is one reason, based on your data or on safety, that you rejected the other exothermic filling for the warming pack?

Answer: Cooling pack: Filling 2, FizzCool (station B), the only one that absorbed energy. Warming pack: Filling 1, WarmSalt (station A, calcium chloride), because it warmed the most and fastest and made no gas. Reasons to reject Filling 4, OxyFoam (station D): it produces oxygen gas and foam, so a sealed pack could burst and would need venting; it warmed more slowly; and a liquid plus a catalyst is harder to store and activate than a dry salt and a water bubble.

Why: Students must use both data and a safety or practicality argument. Any one of the rejection reasons earns credit if it is tied to the observations.

- Chooses B for cooling with the temperature evidence
- Chooses A for warming with the temperature evidence
- Gives a data-based or safety-based reason for rejecting D

9. Your group measured each station once. The class table shows station A's change ranged from +7.0 °C to +10.5 °C across groups. Give two reasons the values might differ and explain why pooling the class data makes the classification more trustworthy than one cup alone.

Answer: Possible reasons: slightly different starting water temperatures, water volumes or packet masses, pellets that absorbed moisture before use, a probe touching the cup bottom or read at a different moment, differences in stirring, a cup closer to a cold window. Pooling helps because one cup's error could push a value up or down, but eight or more cups give a range and a typical value; if every group's station A is positive and every station B is negative, the classification does not depend on any single measurement.

Why: Measurement variation and the value of replication. Full credit needs two plausible causes and a statement that the pattern across groups is stronger than one value.

- Two plausible sources of variation
- Explains that the class pattern is more reliable than one measurement

Individual evidence of learning

Each student submits their own completed data table, observation and classification table, graph, boundary drawings and written answers to q1 through q9. The classification table and q4 are the primary evidence for reading energy direction from data; the boundary drawings and q7 are the evidence for the system-and-surroundings model.

Assessment criteria

Criterion	Proficient looks like
Data collection	All seven readings recorded for each station to 0.1 °C, changes computed with the correct sign, and all four lines plotted and labeled on one graph.
Classification from evidence	Each station is classified using a measured temperature change, with fizzing explicitly excluded as evidence of direction; B and D are correctly placed in opposite categories.
System-and-surroundings model	Boundary drawings place the reacting matter inside and the water, cup and hand outside, with the energy arrow pointing out for A and in for B.

Equation and direction	Word equations in q6 place energy with the reactants for B and with the products for D, with the placement justified by the measured direction.
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Accessibility adaptations

- Assign the recorder or timer role to students who should not handle reagents; the lab works with one pair of hands on the cups.
- Use a thermometer with a large digital display or a talking thermometer; allow readings to be called to a partner who records.
- Provide a data table with the 0 s row and the sign rule ('final minus start; a drop is negative') pre-printed, and a graph with the axes already scaled.
- Offer a bilingual card for exothermic, endothermic, system, surroundings and evidence, and accept q4 and q7 as recorded spoken answers.
- Students with a chemical sensitivity or respiratory condition can sit away from station D's foam and complete the classification from the group's data.

Low-cost alternative

Run the four stations as a single teacher demonstration under a document camera with one probe thermometer, with students calling the times and recording the readings. Table salt and baking soda alone (without citric acid) give a smaller but still measurable cooling for station B if citric acid is unavailable; vinegar (30 mL in place of water) with 3 g baking soda also cools by a few degrees.

Model limitations

A cup of water is a stand-in for a pack: the pack's own water, plastic and your hand are the real surroundings, and the cup loses energy to the air faster than a sealed pouch would, so the measured changes are smaller than a pack would show. Stations A and C are dissolving processes rather than chemical reactions in the strict sense, which the debrief says plainly. The temperature change depends on the amounts, so '+9 °C' describes this cup, not calcium chloride in general. This activity has not been physically tested by the authors; the expected changes are estimates from the reagents' known behavior and should be piloted.

Teacher notes

Expect the classification to be unanimous even when the sizes vary; that agreement is the lesson. If a group's station B barely cooled, the baking soda was probably old or the water warm; the sign still should be negative. For q6, some students will write 'yeast' as a reactant at D; use it to introduce the word catalyst without assessing it. Keep the pooled class table for Lab 2, where the hot-pack teams start from station A's result and the cold-pack teams from station B's.