Sanford Underground Research Facility

Argon Transfer Challenge

It's up to you!

Small particles. Big challenge.

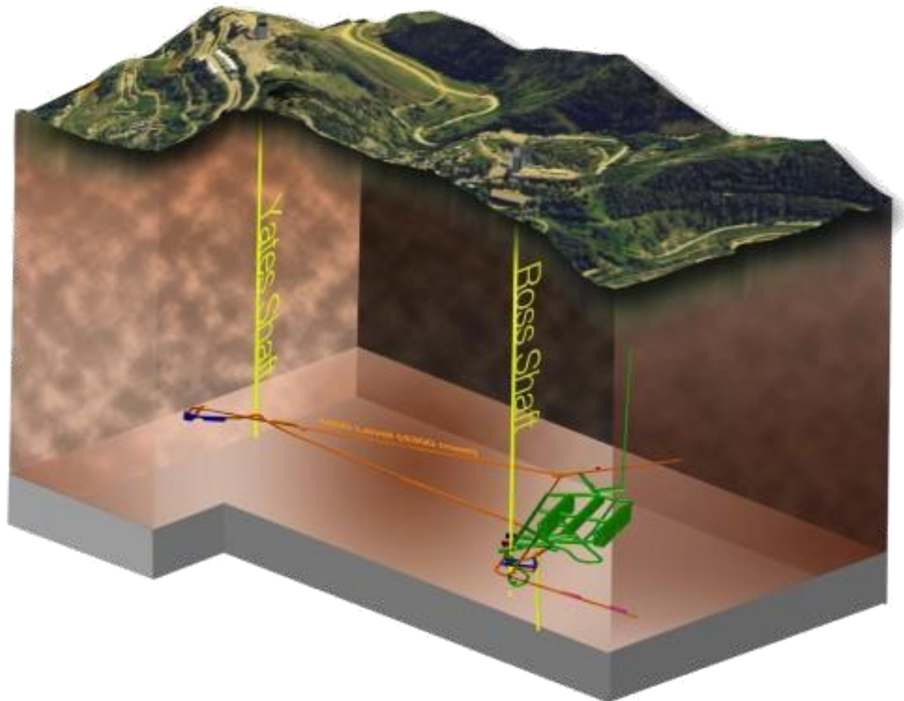
Imagine a cutting-edge science facility constructed nearly one mile underground in a former gold mine nestled in the heart of the Black Hills of South Dakota.

Hundreds of people have worked for years to excavate 800,000 tons of rock and prepare the colossal caverns that will soon house the massive particle detector modules for the Deep Underground Neutrino Experiment (DUNE).

The underground caverns are breathtaking! The cavern below is more than 500 feet long and about seven stories tall. The world's largest neutrino detectors (of their kind) will soon occupy this deep underground location at the Sanford Underground Research Facility (SURF).

Yes, preparing the caverns was an enormous effort. But what about the world's largest neutrino detectors? The detectors have also taken years to imagine, design, and construct. The scientists and engineers can proudly declare, *"These detectors are the best and by far the biggest in the world!"*

The technical term for the DUNE detectors is "Liquid Argon Time-Projection Chambers." The very first ProtoDUNE was successfully tested in 2018.



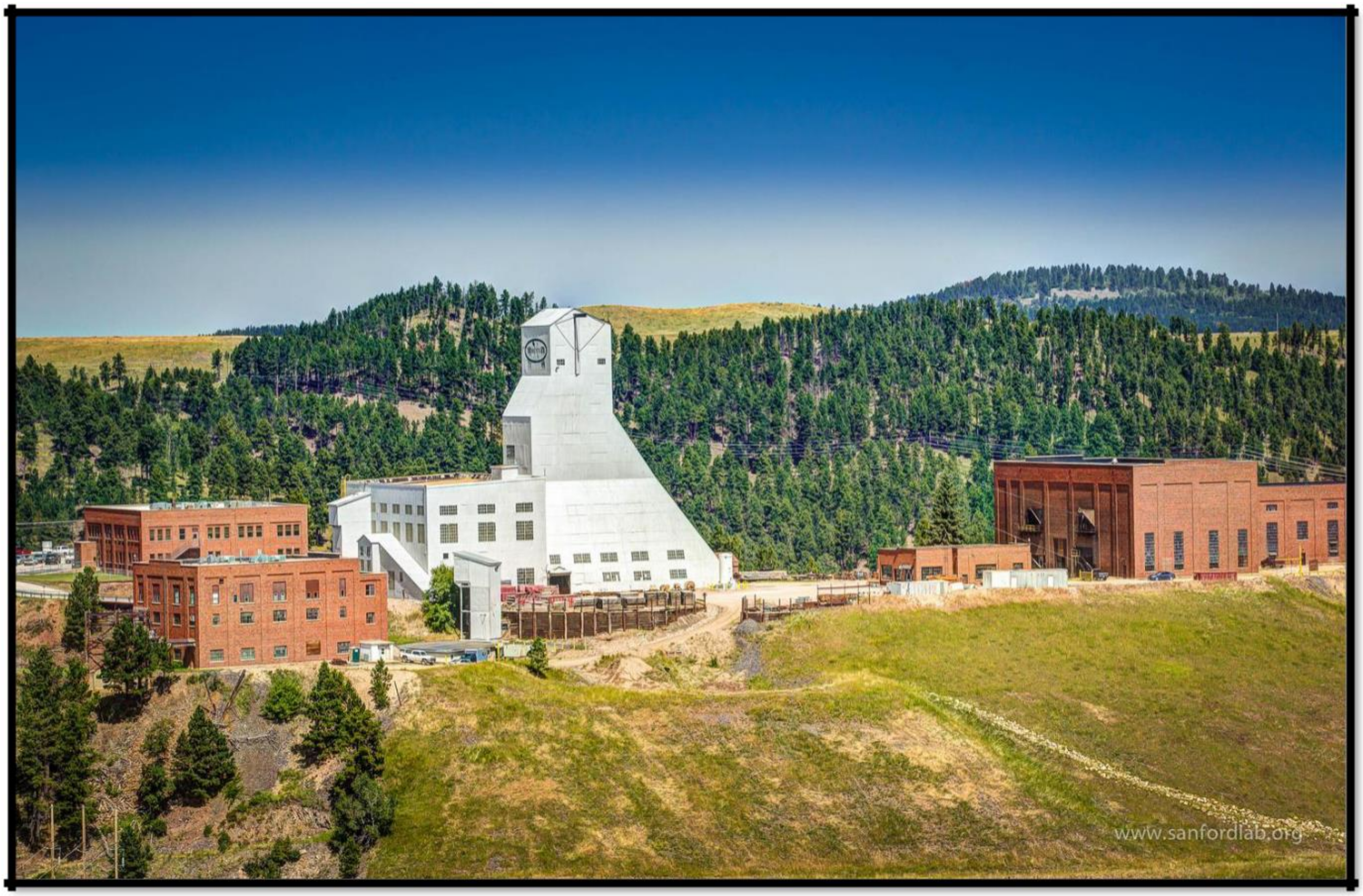
Building a ship in a bottle.

Teams from around the world are developing and constructing detector components that will be shipped to the Sanford Underground Research Facility (SURF) in Lead, South Dakota. There the detector components will be lowered 4850 feet underground, through a narrow shaft to the waiting caverns, where they will be assembled and operated while being sheltered from the cosmic rays that constantly bombard Earth's surface.
For now, the chambers wait. They are empty, except for the hopes and dreams of thousands of scientists from around the world.

What are they waiting for? Argon! Once assembled the detectors will be filled with argon: a noble gas that will transform them into the world's largest neutrino detectors. Neutrinos interacting with the argon atoms generate electron-ion pairs and scintillation light. The ultra-pure argon will arrive in the liquid state, despite the fact that its boiling point is -185.8 degrees Celsius (-302.5 degrees Fahrenheit).

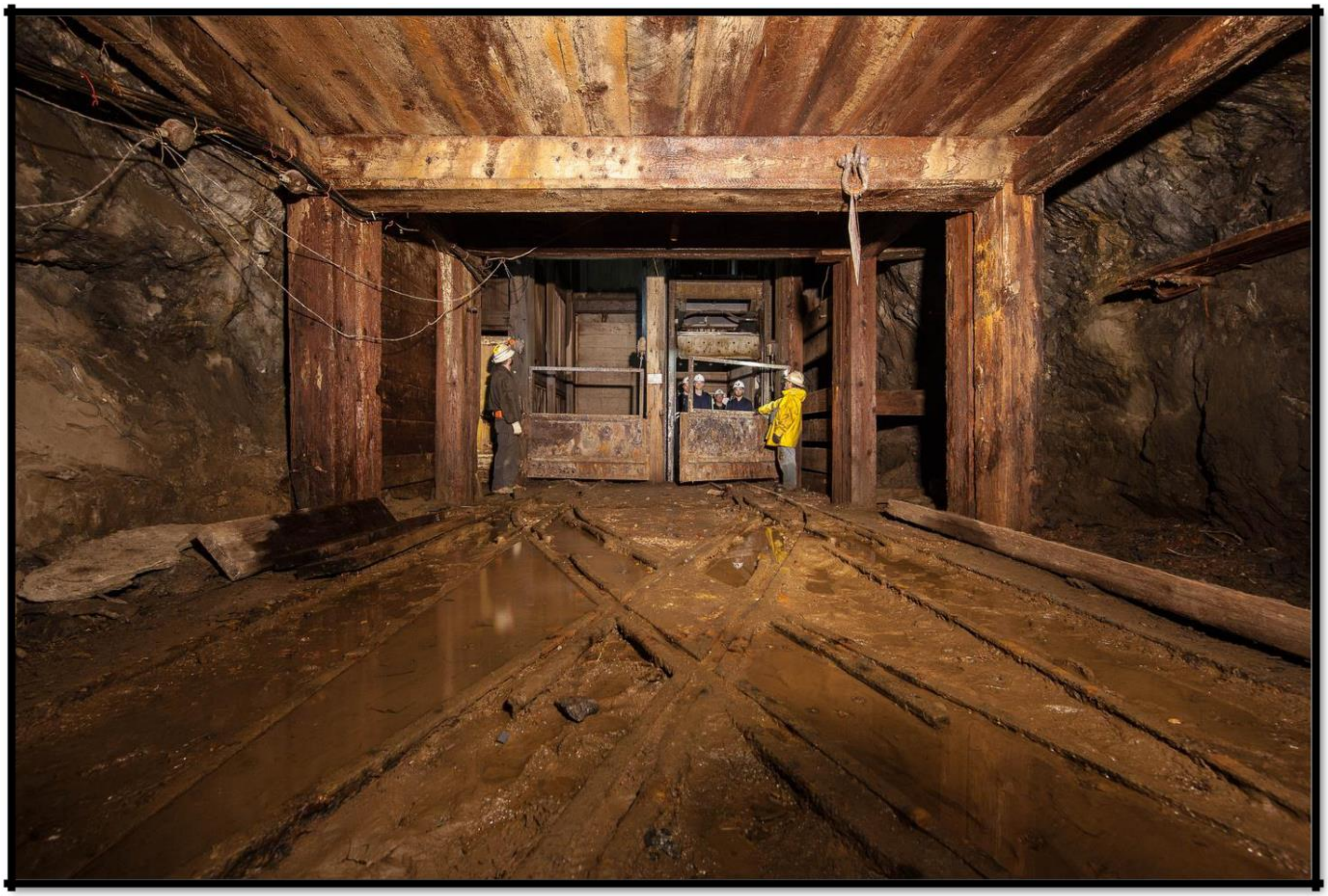
That's going to be cold. Unbearably cold.

The argon will arrive at the Sanford Underground Research Facility in liquid state, carried inside of 20-ton tanker trucks. After more than a decade of work by hundreds of people, it is up to you (and your team) to devise a plan to safely, and effectively, transport nearly 70,000 tons of argon to the underground detector chambers.



Once filled, the argon detectors hope to see light and electrons produced by rare neutrino interactions.

Solid, liquid, or gas?



Your team will work together to determine how the argon can be safely transported from the surface to the underground and the waiting detectors.

Everything in the underground facility arrives by traveling in a long, vertical shaft. A trip straight down, nearly one mile to the underground caverns. The enormous Deep Underground Neutrino Experiment (DUNE) detectors wait.

YOU ARE THE
ENGINEER.
YOU'VE GOT THIS.

70,000 TONS OF ARGON MUST BE MOVED FROM TANKER TRUCKS AT THE SURFACE OF SANFORD LAB IN THE BLACK HILLS OF SOUTH DAKOTA TO THE WAITING DETECTORS, LOCATED ONE MILE BELOW. READY, SET, GO.

Work together to meet the challenge!

Everyone on the team needs to be familiar with the Deep Underground Neutrino Experiment, DUNE. What questions do YOU have about DUNE?

Assign each team member a different role:

Team Member #1: *Become an argon expert!* Learn more about argon so that you can help your team with the engineering puzzle of transporting this vital element to the detectors underground.

Team Member #2: *Become a phase change expert!* Learn about energy transfer and phase changes so that you can advise your team about how to safely move the argon to the underground detectors.

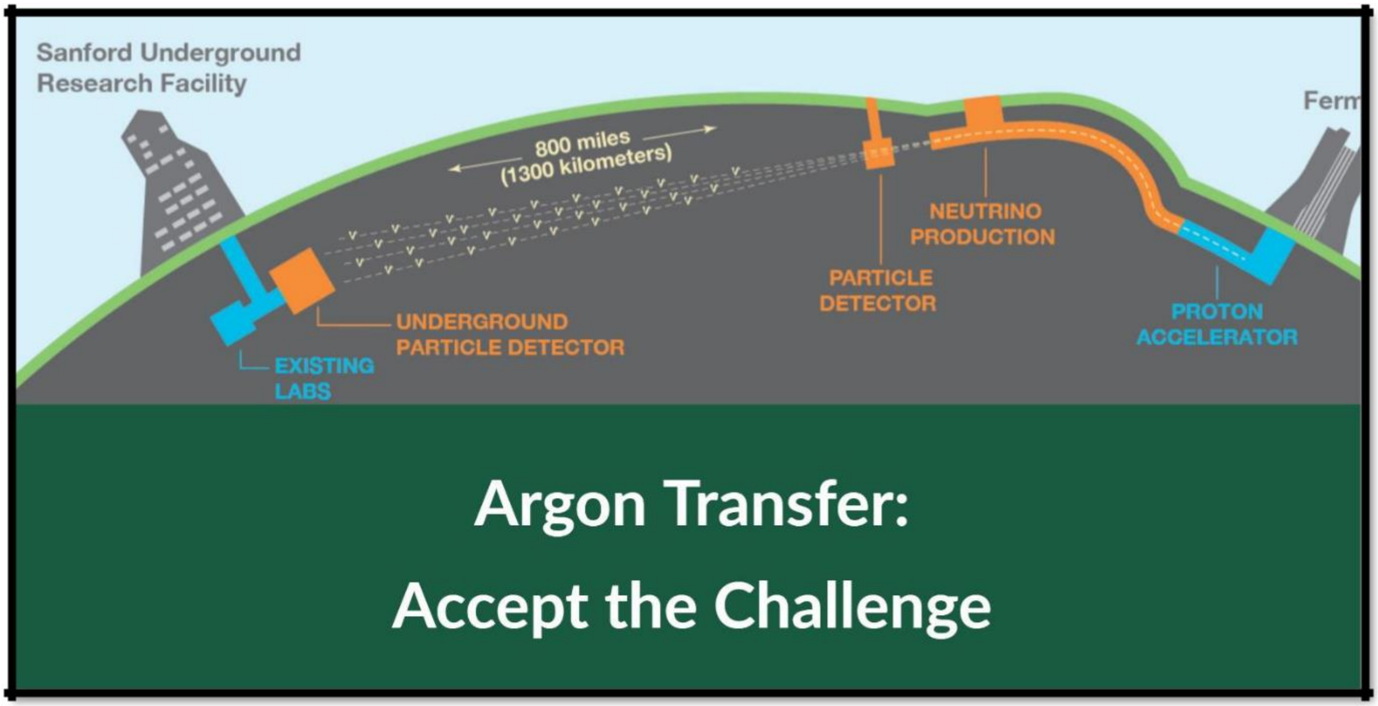
Team Member #3: *Become the matter-transfer expert!* Learn more about the Sanford Underground Research Facility (SURF) and the physical challenges of moving materials to the underground spaces.

As a team, design a detailed plan to safely move the argon from the surface to the underground detectors. You must convince the DUNE scientists and the engineers that your plan will work. The goal is clear: safely transport the argon to the waiting detectors.

Create a multimedia presentation, a journal report, or a digital model of your system.

(optional physical model)

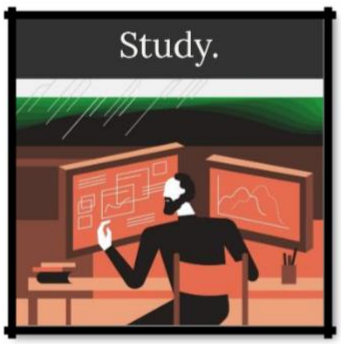
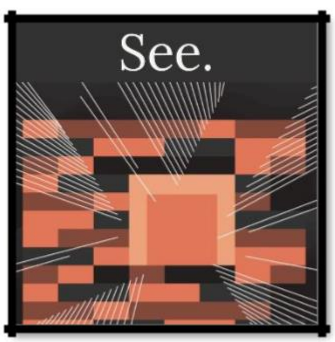
Water will be much easier than argon to find and use for testing your system design. Try to figure out a way to move 50.0 mL of water from one container to another by using only phase changes (adding or removing energy from the system).



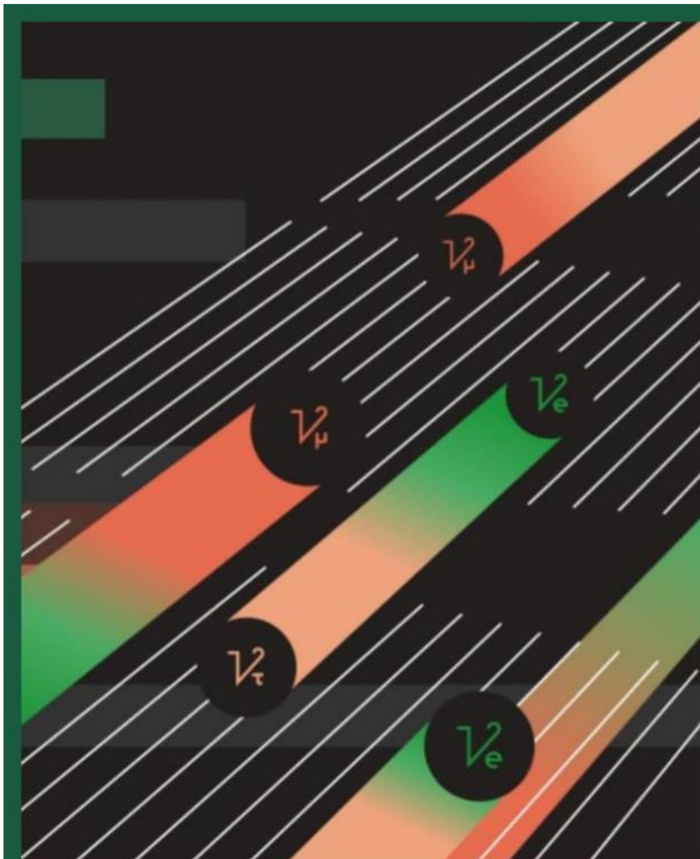
Study the system and learn the logistics of the Deep Underground Neutrino Experiment (DUNE).

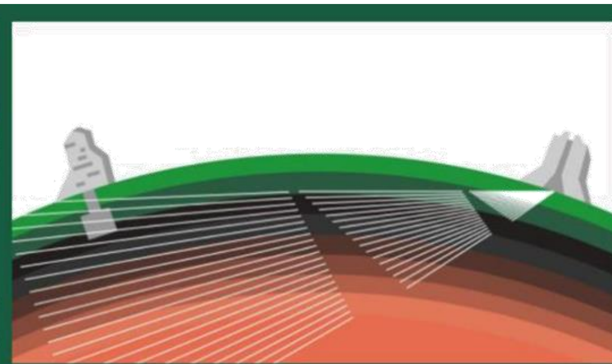
DUNE is one of the largest international science collaborations, ever. Over 1,400 people, from more that 200 institutions, in more than 35 countries are saying, “*Count me IN!*” when it comes to exploring the most abundant particle in our universe, the neutrino. One of the coolest things about DUNE (other than the temperature) is that the experiment itself stretches over vast distances. The neutrinos will be produced using a particle accelerator at Fermilab, near Chicago, Illinois. The neutrinos will travel about 800 miles to Lead, South Dakota where detectors filled with argon will record the rare interaction of neutrinos. Scientists from all over the world will analyze the interactions hoping to unlock answers to some of the most puzzling scientific questions in the universe.

DUNE Resources

	The first place to start in your quest to know as much as possible about the **D**eep **U**nderground **N**eutrino **E**xperiment, DUNE, is the experiment's website. Browse the site, keeping a close eye out for connections to South Dakota! DUNE
	These Fermilab web pages are loaded with tons of important information that will help you better understand the DUNE experiment. Overview and Technology
	Every time you watch this video created by DUNE, you will learn something new. Really. The video is just two minutes long, so you will need to listen closely and maybe hit "replay" a time or two. Video

Use the resources above to complete page 1 of the Team Notebook with your team. Then, think about your own interests and questions about the Deep Underground Neutrino Experiment. Finally, determine which person on your team will serve as Team Member #1, #2 and #3.



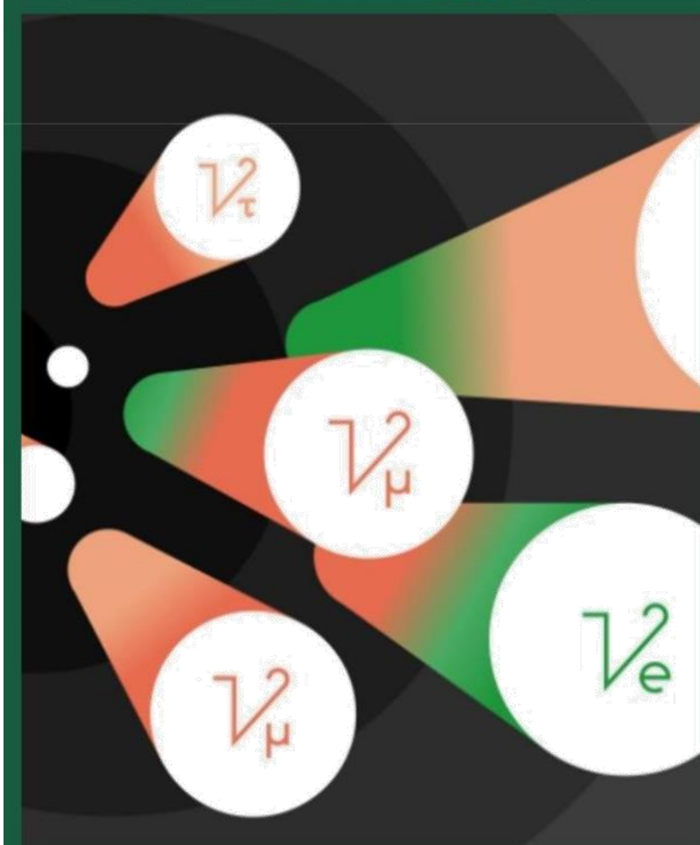


TEAM MEMBER #1

BECOME

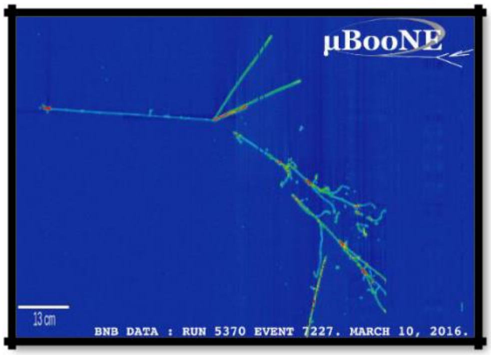
AN ARGON EXPERT

LEARN MORE ABOUT ARGON
SO THAT YOU WILL
UNDERSTAND
THE ENGINEERING
PUZZLE OF
TRANSPORTING THIS VITAL
ELEMENT TO THE
UNDERGROUND LAB.



Team Member #1: Become an Argon Expert!

Learn more about argon so that you will understand the engineering puzzle of transporting this vital element to the detectors underground.



There are over one hundred elements on the periodic table. Only one will serve the detector systems for the Deep Underground Neutrino Experiment-- **argon!**

Argon is the celebrity in the biggest neutrino experiment, ever. What makes argon the top choice for this experiment?

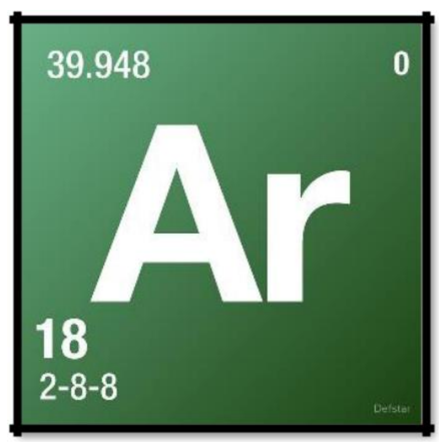
For one thing, **argon makes tracks.** Charged particles are produced when a neutrino bumps into an argon atom, and those charged particles bump into neighboring argon atoms and produce a signal.

Secondly, **argon releases light**! When a neutrino bumps into an argon atom, the argon electrons get excited. Those excited argon electrons release their extra energy as light when they fall back to a lower energy state.

There are many reasons that convinced the scientists to choose argon for the Deep Underground Neutrino Experiment. As you learn more about argon, remember to look for its unique properties.

You will need to give advice to your team about how to choose the best containers to hold and to transport the argon as it travels underground. Should it travel as a solid? A liquid? A gas?

If you are looking for information about an element, like argon, start with a periodic table. You can start by clicking the Argon symbol on this page to visit an online periodic table, loaded with great information.

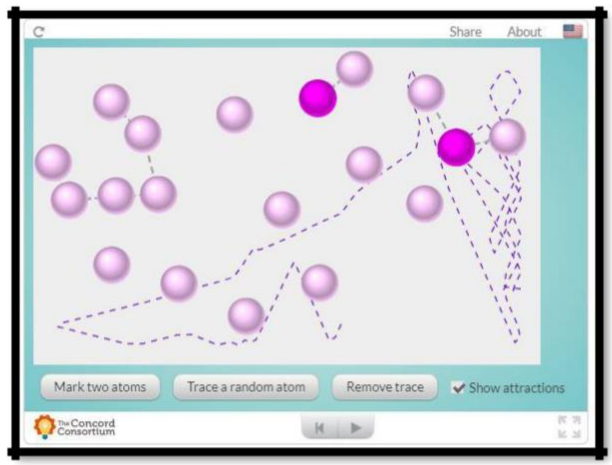


Team Member #1: Become an Argon Expert!

Think about what you will need to know about argon in order to help your team. **Make a list of your questions about argon,** asking, "What do I need to know in order to safely contain, transport, and handle argon?

You can learn a lot from the folks who made the decision to use argon: the scientists who are a part of the DUNE experiment! Check out Fermilab and be sure to read this article. **Look for answers to your own questions**, and keep on asking yourself, *"What do we need to know about argon to safely move it from one place to another?"*

Investigate the phases of argon.

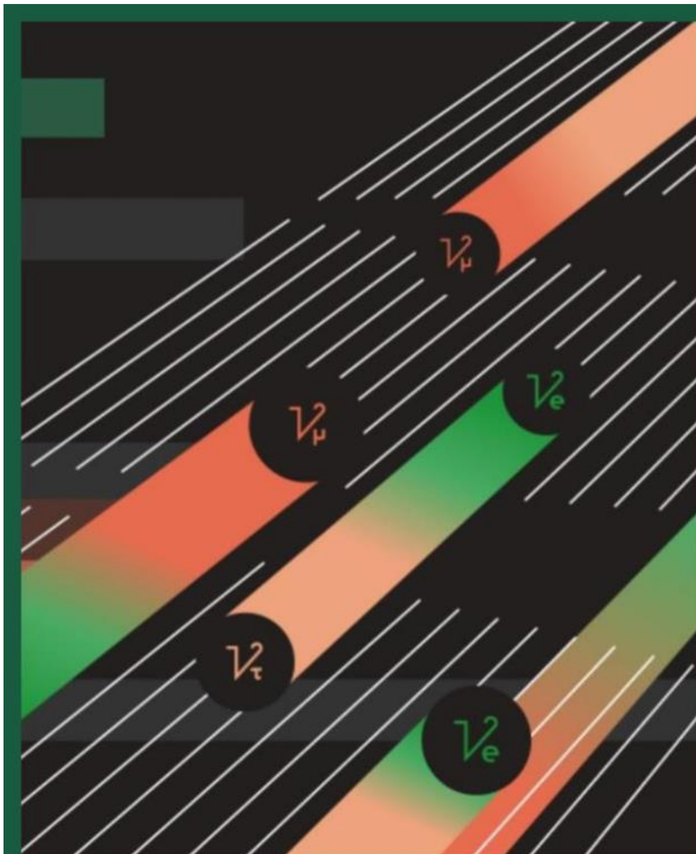


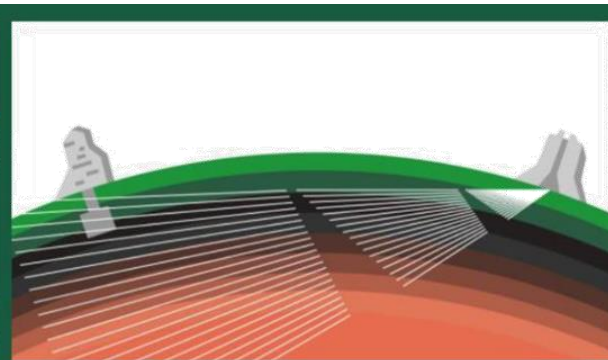
Complete the online simulation. Pay close attention to the questions about how the particles fill **containers**. Argon has no charge, and very weak "Van der Waals" attractions. That means that argon atoms do *not* interact with each other very much, because they do not have much attraction to each other. Answer the questions on the four pages, and then take a screenshot to share with your team.

Make a claim. Give evidence. Explain your Reasoning.

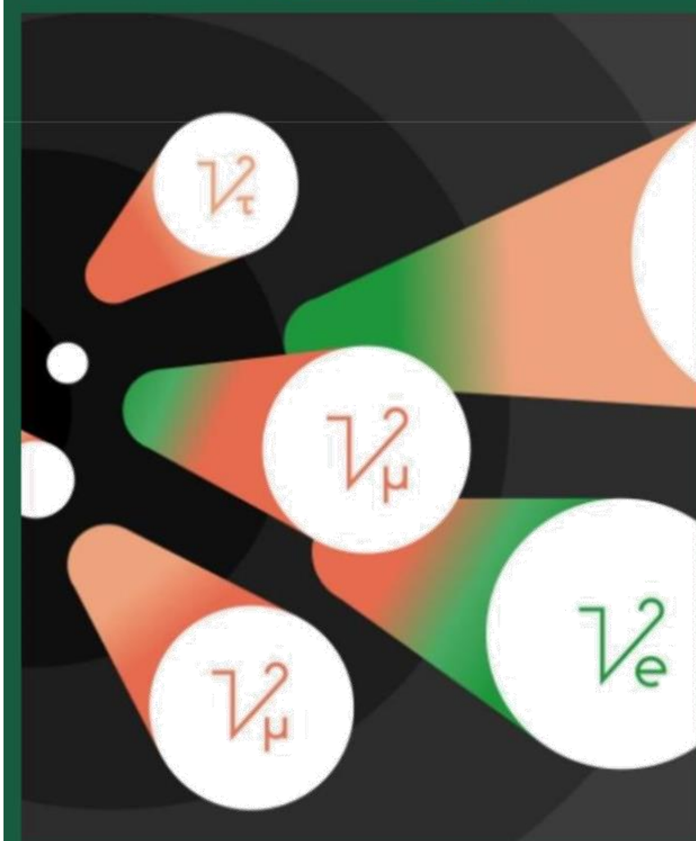
You will use your digital investigation to help your team decide how to contain the argon as it is stored and moved. Be ready to show your team how to use the simulation and explain your claim.

Claim: Argon can be stored and transported in _________state by using containers like…
Evidence: I found the following evidence to support my claim…
Reasoning: This evidence supports my claim because…





TEAM MEMBER #2
BECOME A PHASE
CHANGE EXPERT!



LEARN ABOUT
ENERGY TRANSFER
AND PHASE CHANGES
SO THAT YOU CAN
MAKE A PLAN TO MOVE
THE ARGON TO THE
UNDERGROUND
DETECTOR.

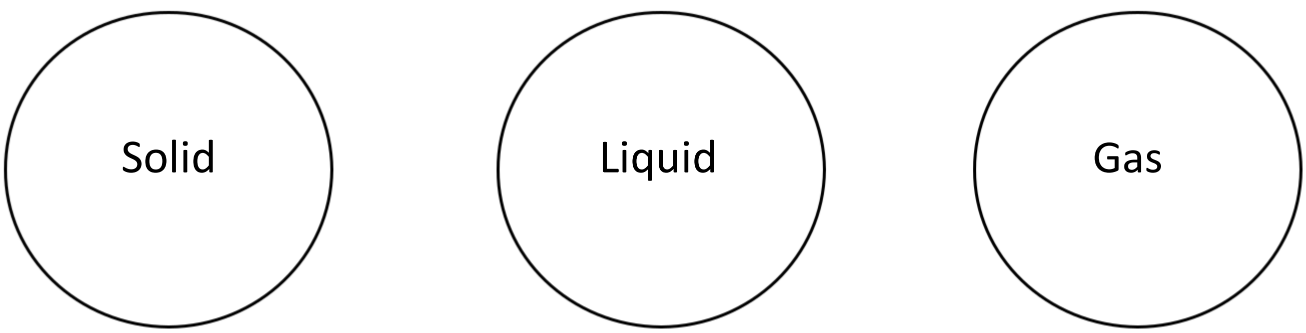
Team Member #2: Become a Phase Change Expert!

The argon will arrive at Sanford Underground Research Facility (SURF) in huge tanker trucks, transported as a cryogenic liquid. The trucks have special compartments that keep the argon in the liquid state. **What exactly is happening to the argon atoms in those tanker trucks?**

Every atom matters.

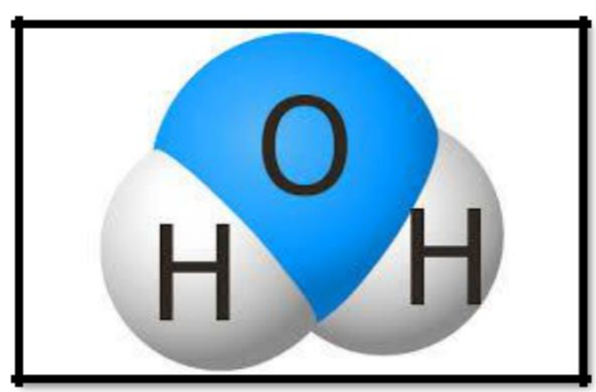
Argon is expensive, and every atom counts. You will need to know what is happening to the argon atoms as they move from the tankers to the underground neutrino detectors.

What do you know right now about solids, liquids, and gases? In your *Team Notebook* draw argon atoms inside each circle to represent the atoms' positions and movements as a solid, a liquid, and a gas.



Every atom moves.

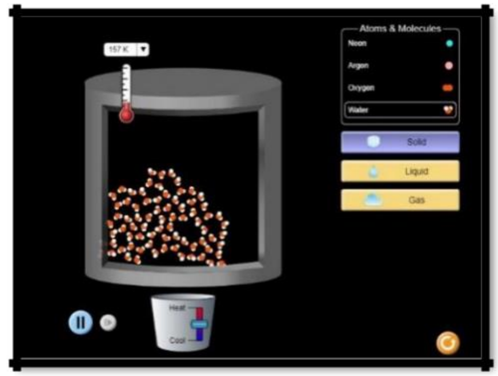
Think about solids, liquids, and gases. Start with something familiar, like water. What are the water molecules doing when they change from ice, to liquid water, to steam? **Click the water molecule** to see what a few other people know about water and phase changes.



Team Member #2: Become a Phase Change Expert!

Sometimes it helps to see it. You will need to be sure that your team understands the **movement of the particles** (atoms or molecules) in a substance as it changes from solid, to liquid, to gas. You will learn how adding or removing energy (heat) from a substance causes a change in the movement of the particles.

Investigate Phase Changes.



Work with the phase changes simulation to explore particle movement. What happens when you change the temperature of the argon sample? What happens when you change the temperature of a sample of water? Is it the same, or different?

Next, use the phase change simulation to explore effects of changing both the temperature and the pressure in samples of argon and water. Try the argon and the water, looking for differences and similarities between the atoms of argon and the water molecules.

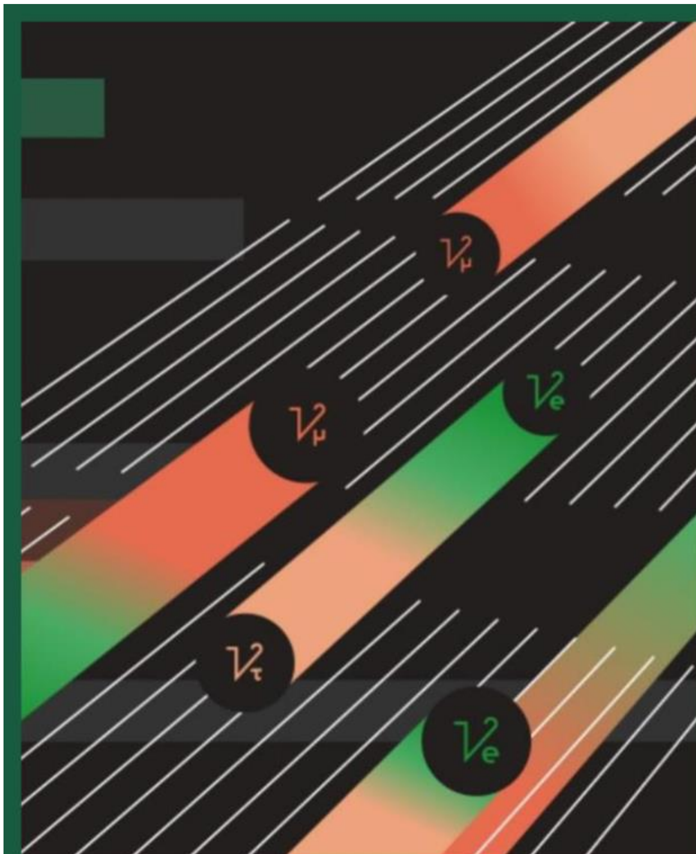
Make a Claim. Give evidence. Explain your reasoning.

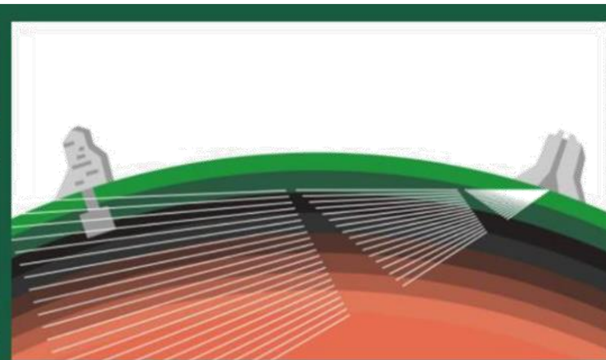
You will use your digital investigation to help your team move argon using phase changes and energy transfer. Be ready to show your team how to use the simulation to explain your claim.

Claim: Adding (or removing) energy from argon can cause a phase change because it can cause the argons atoms to…

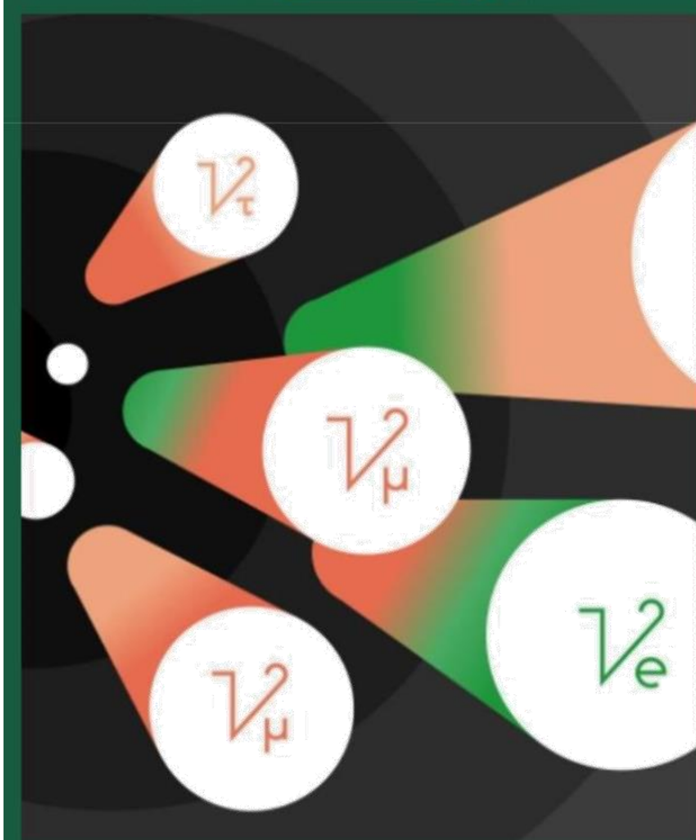
Evidence: I have found evidence to support my claim including…

Reasoning: This evidence supports my claim because…





TEAM MEMBER #3
BECOME A MATTER
TRANSPORT EXPERT



LEARN ABOUT
LIQUID AND GAS
PARTICLES AND MAKE
PLANS TO MOVE
LARGE QUANTITIES
OF ARGON.

Team Member #3: Become a Matter Transport Expert!

There are many ways to use energy to move something. Imagine you wanted to move a **solid** object from one place to another. A solid can be pushed, rolled, pulled, or hauled using forces.

Now, think about the details of the Deep Underground Neutrino Experiment. The scientists and engineers must devise a way to move 70,000 tons of argon in either **the liquid, solid, or gas state** to a colossal cavern one mile underground! That is a huge, huge puzzle to solve!

Ask Questions.

First things first. Think about the DUNE experiment, and the job of moving argon to the underground detectors.

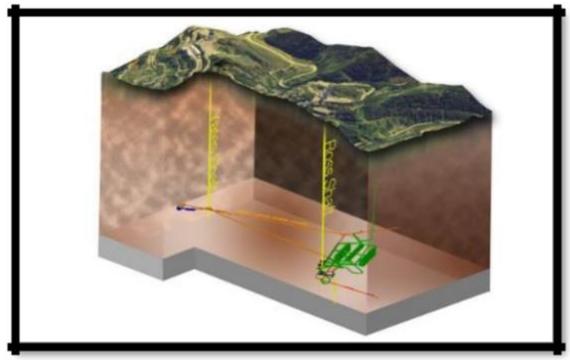
- What are your questions about moving argon as a **solid**?
- What are your questions about moving argon as a **liquid**? As a **gas?**
- What are your questions about moving argon straight down a shaft, **one mile deep**?

Find Some Answers.

The scientists and engineers working with the DUNE collaboration are the first people (ever!) to move so many tons of a noble gas (argon) to a vessel one mile underground. To get there, everything must travel through either the Yates or the Ross shaft.

The cages travel slowly down the shaft. Watch this video to get an idea of the space that the argon must travel. Moving the argon down such a shaft will be much more challenging than transporting the argon on the surface. Read this article, looking for answers to the questions that you are asking.

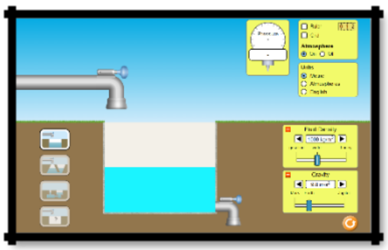
Team Member #3: Become a Matter Transport Expert!

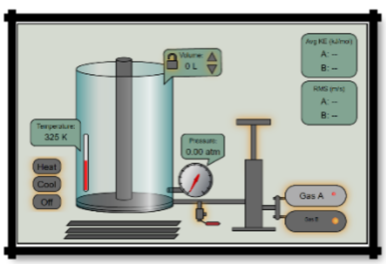


What will happen to the argon atoms as they travel straight down the mile-deep shaft?

Investigate pressure.

Explore the difference between atoms in the gas and liquid phases, paying close attention to the way that the pressure in the sample changes under different conditions.





As you work with the online simulations (linked above) think about how pressure impacts argon as it moves down the very deep, vertical shaft at Sanford Underground Research Facility.

How does the pressure change in a liquid at various heights in a container? How does the pressure change in a gas at various heights in a container?

Use a model to show the particles of solid, liquid, and gas in the containers to explain your observations about the effects of pressure.

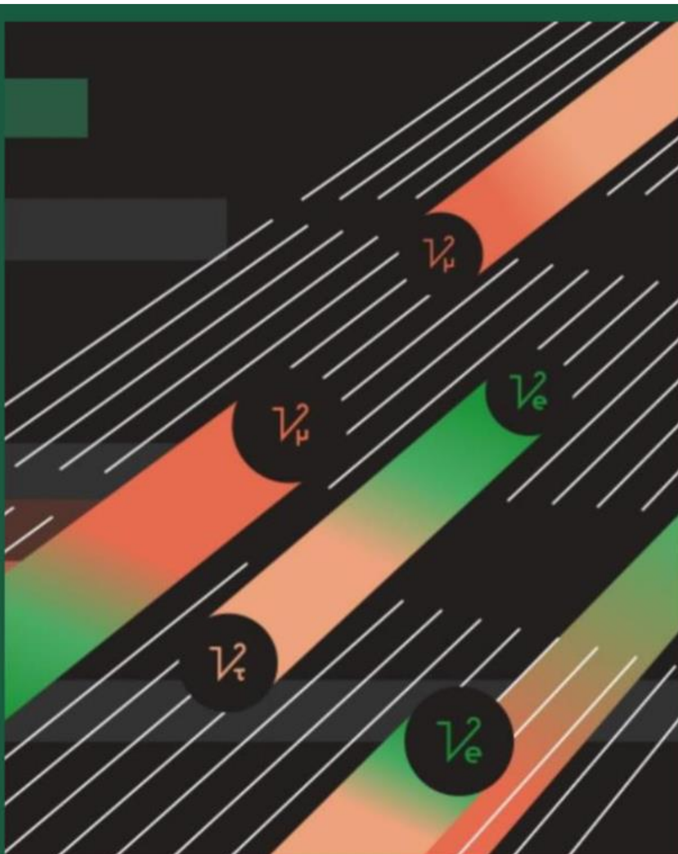
Make a Claim. Give evidence. Explain your reasoning.

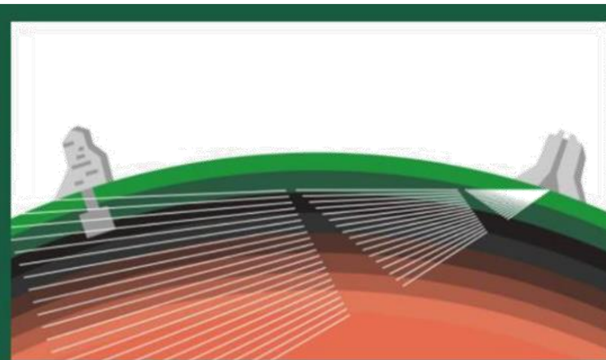
You will use your investigation to help your team make an informed decision about transporting argon down the shaft. What phase(s) makes the most sense at each step of your plan to account for pressure? Be ready to show your team the simulations to explain and support your claim.

Claim: We should transport argon down the shaft as a __________ (solid, liquid, or gas).

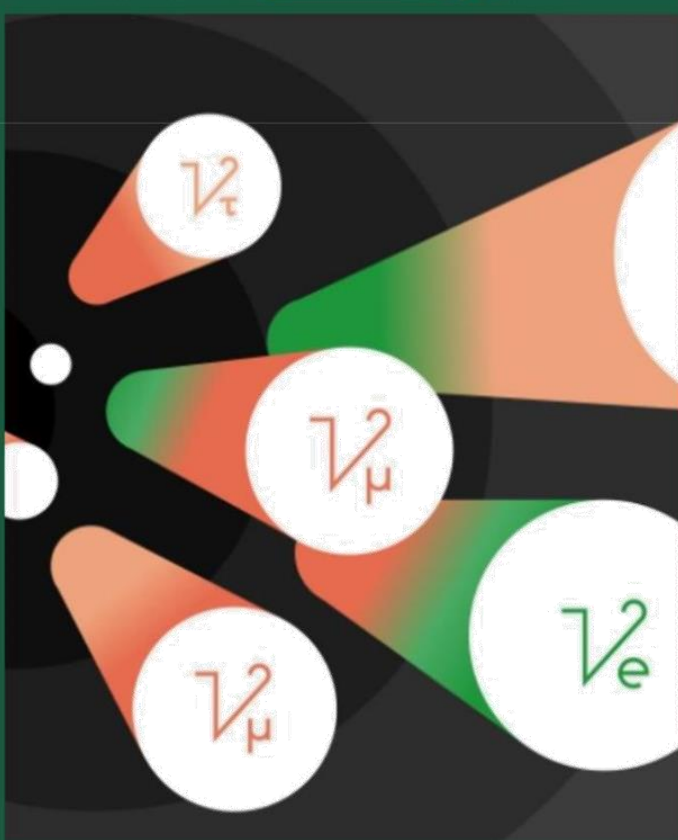
Evidence: I have found evidence to support my claim including…

Reasoning: This evidence supports my claim because…



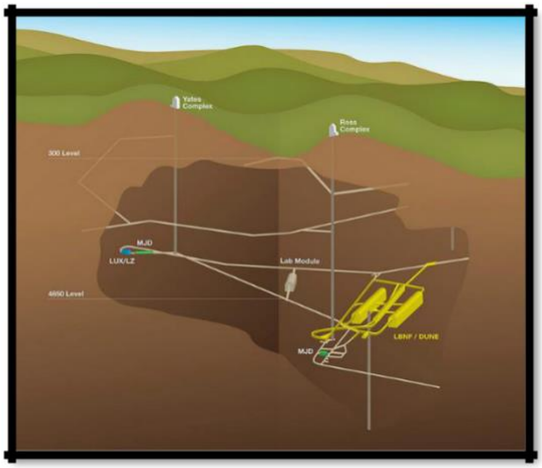


FULL TEAM MEET THE CHALLENGE!



DESIGN A PLAN TO MOVE THE ARGON INTO THE UNDERGROUND DETECTORS. YOU MUST CONVINCE THE DUNE SCIENTISTS THAT YOUR PLAN WILL WORK. THE GOAL IS CLEAR: SAFELY TRANSPORT THE ARGON TO THE WAITING DETECTOR CHAMBERS.

Full Team: Meet the Challenge!



Each team member has learned important information about argon, phase changes, energy transfer, a what happens in the shaft.

It is time to share what you have learned to solve this engineering puzzle. Your team must design a plan to move 70,000 tons of argon into the underground detector. You will need to show the **argon atoms** and the **energy transfer(s)** in your design.

Ask Questions.

- How will the argon be *contained* at each stage? How will you be sure not to lose any of the argon atoms?
- How will you use cooling and heating (*energy transfer)* to cause the argon to change phases during the transport to the underground detector?
- What *state* will the argon be (solid, liquid, or gas) at each stage in the transport? Your design must include the tanker trucks, the transfer at the surface, within the mile-deep shaft, and (finally) into the detectors underground.

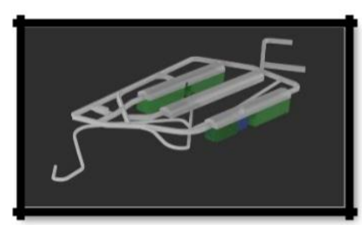
Plan your transport system.

Work with your team to answer each of the questions. Be sure to **use evidence** from your research to design the best possible plan to transport the argon.

Draw a model of the system that shows the argon atoms at each stage of the journey. Use labels to show energy transfer (heating or cooling) for each step of the system.

Your team can create the model using an [online drawing tool](), or use paper.



Communicate your plan.

Work with your team to create a presentation that explains your plan to other people. Identify the role each member will have during the presentation. Who is speaking, when, and on what points?

Choose any format for your presentation.
Here are some ideas.

- Poster Paper
- PowerPoint
- Google Slides
- Canva
- Prezi

Check with your teacher before you begin. They may have subscriptions or access to other great tools.

Remember: Your plan must include details about the state of the argon and the energy transfers in (or out) of the system to cause the phase changes. Use your model to show the particles of argon in each step.

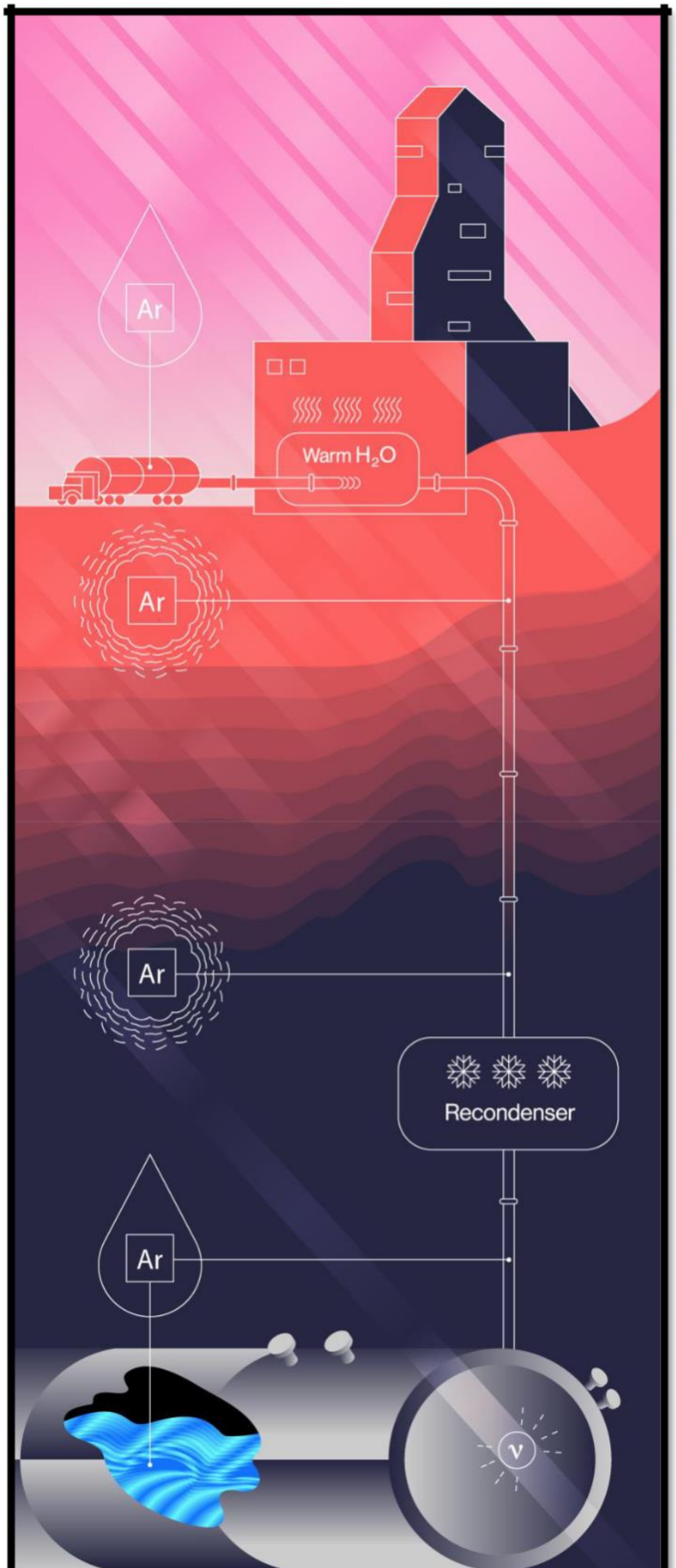
Share your plan with classmates and teacher. Be prepared to answer questions!

Test your plan (optional)

Want to try it out? Water will be much easier than argon to find and use for testing a system that can move a substance using phase changes. Devise a way to move 50.0 mL of water from one container to another by adding or removing energy from the system.

You will need to gather supplies from your classroom or home. Do you need some ideas? Watch a few videos to see how other people have approached this challenge. Video #1 Video #2

Compare. Research. Reflect.



The work to create a plan to get the tons of argon to the underground detectors is still underway. Many scientists and engineers are a part of this effort.

Read the full article from Symmetry Magazine to see how the scientists and engineers are proposing to tackle this huge engineering puzzle. Then answer the following questions.

What aspects of this plan are similar to your ideas?

What is different?

Where do the phase changes occur?

What is used to cause the argon to become a gas?

What is used to cause the argon to become a liquid?