SANFORD UNDERGROUND RESEARCH FACILITY

Argon Transfer Challenge (grades 6-12)

Performance Task	
Overview	*Meet DUNE, the Deep Underground Neutrino Experiment*
Team Member Investigations	*Team Member #1: Become an Argon Expert*
	Team Member #2: Become a Phase Change Expert
	Team Member #3: Become a Matter Transport Expert
Engineering Design Challenge	*Solving an Engineering Puzzle: Argon Transfer for DUNE*

SCIENCE PHENOMENON

The anchoring phenomena is the use of energy transfer to cause phase changes, which can in turn be used to move substances from one place to another.

ENGINEERING PROBLEM

A new international mega-science project, DUNE (Deep Underground Neutrino Experiment) requires 70,000 tons of argon for their neutrino detectors. Scientists and engineers must design a solution to answer the question, *"How can we safely transport 70,000 tons of argon to a detector in a cavern nearly one mile underground?"*

Performance Expectations

MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

MS-PS3-3 Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*

Crosscutting Concepts

Cause and Effect

Energy and Matter

Science and Engineering Practices

Developing and Using Models

Constructing Explanations and Designing Solutions

Argon Transfer Design Challenge

Students work both individually, and with other students, to learn about a new international mega-science experiment-- the Deep Underground Neutrino Experiment (DUNE).

Students explore a variety of resources to learn about the construction of the some of the largest neutrino detectors in the world-- containing 70,000 tons of argon--to be located nearly one mile underground at the Sanford Underground Research Facility (SURF) in South Dakota.

Students will learn:

- 800,000 tons of rock has been excavated to create the colossal caverns that will soon house the massive particle detector modules for the Deep Underground Neutrino Experiment (DUNE).
- Once assembled, the detectors will be filled with argon- a noble gas that will transform them into the world's largest neutrino detectors.
- Argon is a pure substance that exists in the gas state at room temperature and pressure.
- The argon will need to be safely transported from tankers on the surface to the underground cavern, and the waiting detectors.

Students will work as a team to devise a plan to safely move argon from the surface to the detectors located nearly one mile below the earth's surface. Each member of the team will choose a role and work on a specific aspect of the engineering problem.

Team Member #1 will gather information about the element, argon. The student will use an online simulation to investigate the phases of argon and how the particles fill containers.

Team Member #2 will use a computer model to predict the positions and movements of particles of a pure substance (specifically, argon and water) in the liquid and gas states. The student will use an online simulation to investigate the connection between phase changes and energy.

Team Member #3 will ask questions about what is happening to the argon atoms as they are moved from the surface to the underground. The student will use online simulations to investigate changes in pressure in gases and liquids in various containers.

The full team will work together to make predictions, and draw conclusions, about phase changes and the thermal energy transfers that must occur in order to transport the argon from the tanker truck on the surface, down a nearly mile long vertical shaft, and then to the detector tanks underground. The team will create a digital presentation of the system they design to transport the argon. The presentation will demonstrate the students' conceptual models for the states of matter, as well as their understanding of energy transfer during phase changes.

Design Challenge

	Argon Transfer Design Challenge
Overview and Standards	**Overview** Students will learn about the Deep Underground Neutrino Experiment (DUNE) which includes building enormous argon detectors nearly one mile underground in Lead, South Dakota. Students will ask questions and complete online investigations to learn about the challenge of transporting 70,000 tons of argon to detectors beneath the earth's surface. Students will work as a team to create a plan to transport the argon from tanker trucks at the surface to the waiting detectors underground at Sanford Underground Research Facility (SURF). **MS-PS1-4** Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed. CCC: Cause and Effect SEP: Developing and Using Models **MS-PS3-3** Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. CCC: Energy and Matter SEP: Constructing Explanations and Designing Solutions
Background Information	In middle school, students begin to understand that solids, liquids, and gasses are all made of particles that are in constant motion. In a solid, atoms are not freely moving, but continue to vibrate in close proximity to neighboring particles. In a liquid, the particles are in contact with one another. In a gas, the particles are widely separated and come into contact with one another only when they happen to collide. Students should be able to draw models of the particles in each state, accurately reflecting both proximity and movements. Phase changes (changes of state) occur when the temperature or the pressure of a system is varied. Students use the term "heat" and associate heat energy with the transfer of thermal energy into and out of the systems that they design. Students explore how adding or removing thermal energy can cause a change in phase (physical state) of a substance. This will help students to explain that thermal energy is directly proportional to the seemingly random motion of particles in a substance. Students should learn that adding thermal energy to a system causes particles to move faster, and farther away from each other. Removing thermal energy from a system causes particles to move slower, and closer together.

Design Challenge

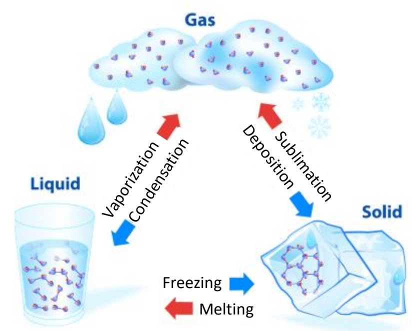
Prior Knowledge	In elementary school, students learned that matter can be divided and subdivided into smaller and smaller units. These particles are too small to be seen but are thought to be in constant, random motion. In a gas, students know that the particles are freely moving. Elementary students have studied some of the properties of air by making observations about wind and weather. Students have some familiarity with phase changes associated primarily with the water cycle, including condensation and evaporation. *A quick check for understanding Kinesthetic modeling of solids, liquids, gases Or a quick overview may be required. (video 2 min 44 sec) Modeling in Grade 6-8 builds on those elementary ideas and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. Students develop models to predict and/or describe phenomena. Engineers use science and technology to solve problems and design solutions. The performance expectation MS-PS3-3 lends itself to engineering challenges, as students design, construct, and test a device which either minimizes or maximizes thermal energy transfer. In order to cause a liquid to vaporize, students will need to design a device which maximizes thermal energy transfer <u>into</u> the system. For condensation, from gas to liquid, students will need to maximize thermal energy transfer <u>out of</u> the system.
Materials	**Each student will need:** ✓ device with internet access to utilize the digital resources ✓ electronic *PDF of the Argon Transfer Challenge Student Pages* **DO NOT PRINT the student PDF as it contains hyperlinked resources. ✓ Team Notebook (print copies would be great) **(Optional) for physical model** ▪ plastic bottles, cups, or bowls ▪ metal or glass bowls or buckets ▪ plastic or rubber tubing ▪ clear plastic wrap ▪ aluminum foil ▪ heat source ▪ cooling source (ice) ▪ black paper ▪ possibly other common household items (depending on system designs)

Design Challenge

Launch	
Engagement and Communication	**Argon Transfer Challenge Student Pages** Begin the unit by providing each student with an electronic copy of the Argon Transfer Challenge Student Pages. Students should access this PDF using a device with internet access. Pages 1-10 contain links to videos and articles so that the students can learn about the new international mega-science experiment--the Deep Underground Neutrino Experiment (DUNE). The DUNE experiment will detect neutrinos using enormous underground detectors which will contain 70,000 tons of liquid argon. Students will be introduced to the experiment, and then encouraged to ask questions and wonder about how the argon will be transported to the underground detectors. The neutrino detectors for this experiment will be housed in an underground laboratory deep in the heart of the Black Hills in Lead, South Dakota. In order to construct the neutrino detectors, engineers must overcome many unique design challenges. The fact that these enormous detectors will be located nearly one mile underground presents many one-of-a-kind problems.
Explore and Investigate	
Individual Investigation	Distribute a copy of the **Team Notebook** to the students. *Students should complete page 1 together, using what they learned during the launch (above). Team members should determine who will be Team Member #1, #2, and #3. The students will then work through the pages in the Argon Transfer Challenge—Student PDF that correspond to their assigned team role. Each team member will utilize different resources to investigate specific questions about solids, liquids, and gases. The students will also use online simulations to test the behavior of the particles in varying conditions of temperature and pressure, depending on which team role they are fulfilling. Each team member will need to work with the online simulations in order to make a CLAIM, provide EVIDENCE, and use REASONING to support the claim. *Students should only complete the Team Notebook page that matches their role as they work through their team member resources.
Student Questions	
	As students work, encourage them to ask questions about the DUNE experiment, and the challenge of moving so much argon underground. • How does a liquid become a gas? (MS-PS1-4) • How does a gas become a liquid? (MS-PS1-4) • When argon is heated, what happens to the argon atoms' position and movements? (MS-PS1-4)

	• When argon is cooled, what happens to the argon atoms' position and movement? (MS-PS1-4) • How can a pure substance, like water or argon, be transported from one place to another using phase changes? (MS-PS3-3) • What role does heat (energy transfer) have in the argon transfer system? (MS-PS3-3) • What state is the argon in during each part of the transport? (MS-PS3-3) (MS-PS1-4) • How could we design a model system so that the heat transfer is maximized or minimized? (MS-PS3-3) • How is transporting argon the same/different than moving water using phase changes? • How can I design a model for a system to move liquid argon to the underground detectors?
Devise a Plan	
Plan, Design, Communicate	**Design Solutions** After each team member has completed their own investigations, your students may find it to be very helpful to meet with other students who are in the same role. <u>If time allows</u>, arrange for students to meet by the three areas of expertise. Students could be asked to list "Five Major Points" that they wish to share with their own teams based on their learning from the packet resources. After the "role-alike" meetings, the original design team should come together and share what each learned during their individual investigation. Team members should briefly demonstrate the various online simulations for each other, so that every student understands them. Each design team should then develop a plan to move argon from the surface to the detectors underground.
Share!	
Final Product	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? Each team selects their own platform for sharing their design (with teacher's approval). The communication of the design may include video, pictures, animation, written, or graphic designs. **Explain** • How the argon will be *contained* at each stage, and how to minimize any loss of the argon atoms.

	• How cooling and heating (*energy transfer)* will be used to cause the argon to change phases during the transport to the underground detector. • What *state* the argon will be in (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. **Student's plans should include the following components:** • labels or directional arrows to indicate when thermal energy should be added or removed from the system • note to indicate the state of the argon in each part of the system • clearly modeled atoms of argon, showing position and motion of atoms in each stage of the system • tanker truck, transport vessel/container, and argon detectors in correct relative position • indication of the scale of the system including tons of argon, number of tanker trucks, length of pipe, size of detector tanks, etc. The students may select from a variety of different digital modalities to communicate their plan. The PDF gives instructions to check with their teacher before deciding on a platform. **Teacher look-fors** • Gas particles should be shown as freely moving and not in contact with other particles. Liquid particles should be shown as freely moving and in loose contact with other particles in the system. Particles in a solid should be shown as closely packed together and in fixed positions. • Student understanding of the connection between thermal energy flow and phase changes by describing the flow of thermal energy for all parts of the system.
Teacher Notes	
	The Facility Plan Students should have discovered that the argon arrives in liquid state in the tankers. It will also be in liquid state in the detector tanks. The facility master plan determined the argon will need to be vaporized to gas state for its transfer down the mile-deep shaft for two primary reasons:

	1. The refrigeration (cryogenics) required to maintain argon as a liquid down the shaft would be costly and complicated. 2. Liquid argon would build in pressure at the bottom of the shaft, creating a potential hazard. You may need to spend some extra time on this important point. Ask the students to think about what will be happening to the argon particles at the bottom of the mile-deep shaft (they will be very close together, due to pressure).
Terminology and Concepts to Solidify	**Solid**—particles tightly packed together, particle motion is vibrational **Liquid**—particles can move freely, some close contact **Gas**—particles can move freely, large distance between particles **Vaporization**—physical change from liquid to gas **Condensation**—physical change from gas to liquid **Heat**—energy transfer by convection, conduction, or radiation **Thermal energy**— the energy contained within a system that is responsible for its temperature **Thermal energy transfer**—The transfer of thermal energy as heat requires a difference in temperature between the two points of transfer. **Phase transitions—**refer to changes among the basic states of matter: solid, liquid, and gas 
Follow Up/ Practice	After students have completed their own investigations and designed their own systems, they read the full article from Symmetry Magazine entitled, "Researchers Face Engineering Puzzle." This article highlights some of the current discussions and decisions being made by the engineers working on the actual logistics of argon transfer for DUNE. Students can reflect on the similarities and differences between their own plan and that of the DUNE engineers. Students may wish to compare, revise, or improve their own plan. Classroom discussion with students should encourage thinking about additional engineering challenges that will be faced by the Deep Underground Neutrino Facility.