**Table of Contents**

1. Project Background .......... 3
2. Sponsor Document .......... 9
3. Specifications and Requirements .......... 13
4. Project Goal, Objectives and Tasks .......... 17
5. Project Planning .......... 21
6. Project Execution .......... 27
7. Project Organization .......... 29
8. Project Outcomes .......... 31
9. Swanson Center for Product Innovation .......... 33
10. Preliminary Design Concepts .......... 35
11. Preliminary Design Review Comments .......... 45
12. Pugh Chart .......... 47
13. Adopted Design .......... 49
14. Updated Project Plan .......... 53
15. Updated Project Timeline .......... 55
16. Supporting Analysis .......... 57
17. Archive and Cleanup Plan .......... 65
18. Final Deliverables .......... 67
19. Design Validation .......... 69
20. Symposium Presentation .......... 71
21. Meeting Minutes .......... 81
22. Swanson School of Engineering Exposition Poster .......... 91

# 1. Project Background

Summary of Need

Westinghouse's eVinci™ microreactor design responds to a critical need for clean and reliable power generation in a multitude of operations. Traditional methods of power generation through combustion or larger nuclear reactors are not suited for these applications due to infrastructure limitations and environmental impact, among other reasons. The eVinci™ microreactor offers a solution by offering a contained, maintenance free nuclear energy source that can offer continuous operation for eight years or more without the need for refueling. [1] By harnessing the use of heat pipes to send energy from the reactor core to a Brayton gas turbine cycle replacement system as stated in the project description, the microreactor offers a very efficient solution to the generation of power in a noncentralized environment.

Traditional nuclear reactor designs are expensive, large and slow to construct. [2] Each plant must be designed from scratch to adjust to the local conditions, skyrocketing costs and dragging out the process. In a world of rapidly increasing energy demand and a looming climate crisis, this is not good enough. The solution is small modular reactors, or SMRs. These reactors simplify and minimize the design, enabling mass production, standardization and benefits of economies of scale. SMRs can be deployed to rural areas, and moved as needed, adding flexibility. The eVinci™ microreactor is one of many promising SMR designs.

One of the most challenging features of this system is the development of the Primary Heat Exchanger (PHX) to achieve structural integrity in conjunction with thermal performance. The design of the insulation contributes significantly towards balance because it regulates metal temperatures in addition to protecting the reactor components from extreme operating conditions [3].

This project meets the need for an expert insulation design for high temperature helium conditions [3]. Thermal conductivity simulation, insulation package design, and experimental performance investigation are all within the scope of this project. By the end, our team will generate data and methods that can be transferred directly to the micronuclear reactor development process when integrated at full scale. Success for this project aligns with Westinghouse's overall purpose to optimize and provide sustainable and resilient solutions for energy to address society's challenges, while remaining low carbon in emission. These challenges can include energy access in rural areas and dependable emergency power among others [1].

References:

[1] "EVinciTM Microreactor." *Westinghouse*, www.westinghousenuclear.com/energy-systems/evince-microreactor/ . Accessed 25 Sept. 2025.
[2] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *U.S. Nuclear Industry - U.S. Energy Information Administration (EIA)*, www.eia.gov/energyexplained/nuclear/us-nuclear-industry.php. Accessed 25 Sept. 2025.
[3] *NRC*, www.nrc.gov/docs/ML2509/ML25094A039.pdf. Accessed 26 Sept. 2025.

Industry Served

From 2024 to 2025 global energy demand increased by 4.3%. As temperatures continue to rise from the effects of global warming, the demand for electricity to be used for cooling will keep increasing [1]. Another source of increasing energy demand is the increasing investment in data centers and Artificial Intelligence. In 2024, data centers accounted for 1.5% of global electricity consumption. While this is only a small portion of the global demand, data centers can place a big strain on local power grids [2].

Small modular reactors (SMRs) offer a solution to this electricity problem. SMRs are small size, streamlined nuclear reactors. Compared to traditional full sized nuclear reactors, SMRs are easier to manufacture, transport, and operate. The lower power levels in SMRs also lead to more inherent safety [3]. These advantages also make SMRs a candidate for power generation in remote locations.

Westinghouse is currently developing a 5 MWe microreactor, the eVinci™ microreactor. The driving idea behind the development of the eVinci™ microreactor is simplicity. The eVinci™ does not have a reactor coolant pump or a primary coolant loop system. Instead, the heat generated in the core is carried by heat pipes to the primary heat exchanger as shown in Figure 1 [4].

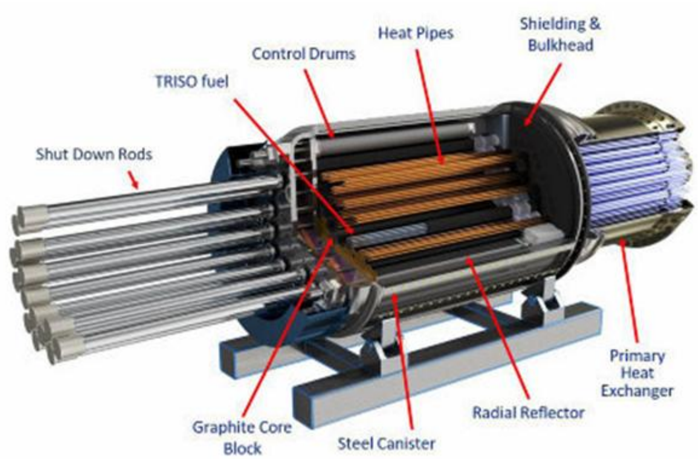


Figure 1: Cross sectional view of the eVinci microreactor

In order to have efficient operation of the primary heat exchanger, some sections of the heat pipe need to be insulated. As seen in Figure 2, heat is added to one end of the heat pipes and extracted from the other end. The center section of the heat pipe needs to very well insulated to minimize the heat loss.

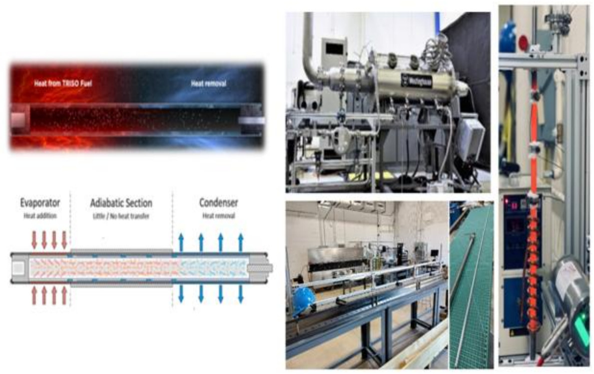



Figure 2: A diagram of the heat pipe in the eVinci microreactor

There are two major categories of materials used for insulation in nuclear reactors, metallic and nonmetallic insulation. Metallic insulation is made of thin layers of metal, usually austenitic steel as shown in Figure 3. Each of these layers has very low emissivity which limits heat transfer. Nonmetallic insulation usually consists of a material such as fiber glass that is wrapped in a metallic cladding to provide structure and protection [5].

Figure 3: The cross section of a reflective metal insulation cassette [6]

The thermal behavior of these insulation materials is understood in a traditional nuclear reactor, however, the eVinci reactor has a unique environment. The heat pipes and the surrounding insulation will be in a helium environment instead of air. Since these insulation types both have gaps between layers or fibers, this new environment will affect the heat transfer behavior of the system.

The goal of this project is to design and test an insulation package that can surround the heat pipe in the adiabatic section shown in Figure 2 of the eVinci. Meeting this goal will require simulating the heat transfer behavior in the heat pipe as well as designing and building a test rig to determine the thermal behavior of the selected insulation in a helium environment.

Successfully meeting these goals will help Westinghouse to build a safe and efficient microreactor. The eVinci microreactor can then be used to bring electricity to remote locations without contributing to carbon emissions.

References:


[1] IEA (2025), Global Energy Review 2025, IEA, Paris https://www.iea.org/reports/global-energy- review-2025, License: CC BY 4.0

[2] Spencer, T., & Singh, S. (2025). *World Energy Outlook Special Report Energy and AI*. IEA.

[3] Nuclear Energy Agency. (2021). *Small Modular Reactors: Challenges and Opportunities*.

[4] Arafat, Y., & Wyk, J. van. (n.d.). eVinci™ Micro Reactor. In *NuclearPlantJournal.com Nuclear Plant Journal*.

[5] International Standard (2020). *Design criteria for the thermal insulation of reactor coolant system main equipments and piping of PWR nuclear power plant*

[6] Hart, G. H. (2017, June 9). *Thermal insulation for nuclear power plants and nuclear safety issue GSI- 191*. Insulation Outlook Magazine. https://insulation.org/io/articles/thermal-insulation-for-nuclear- power-plants-and-nuclear-safety-issue-gsi-191/


End User

The primary end user for this project is Westinghouse which is the sponsor for the project and has a direct stake in developing safe, efficient, and cost-effective insulation for the eVinci™ microreactor. As a primary nuclear energy provider, Westinghouse requires insulation systems that can withstand helium environments and extreme operating temperatures while still maintaining a design life of 12 years. The success of this project is directly supporting Westinghouse's commercial viability and competitiveness in a rapidly growing market for nuclear energy.

Beyond Westinghouse, the impact of this project extends to a broader community of industrial consumers, regulatory committees, and society in general. Industries that use microreactors will benefit from reliable, continuous, and clean energy, even in locations where the traditional infrastructure is not available. Communities relying on disaster relief or remote operations stand to gain a suitable power source. Regulatory committees also have an important role as end users since validated insulation designs help satisfy nuclear safety and performance requirements which reduces the safety risk and improves reactor lifetime performance.

This project is distinct from traditional insulation studies which are typically performed in air atmospheres. By computationally and experimentally testing the insulation behavior in a helium atmosphere at 850°, we directly replicate the actual operating environment of the eVinci™. This combined approach fills the critical research gap, increasing the likelihood of success. If successful, a validated insulation package will extend the reactor lifetime, minimize energy loss, and lower long term maintenance costs. These results will improve the reliability and scalability of the eVinci™, increasing the potential use in diverse environments.

Motivation

The eVinci™ microreactor was designed to create sustainable energy, particularly in more remote locations. To create power, the heat needs to be transferred from the reactor core to the turbines. To ensure maximum efficiency and safety, the heat loss between reactor and the turbine needs to be minimized. This project is to select and test an insulation package that will fulfill this goal. A new insulation package needs to be developed and tested due to the unique environment of the reactor. A helium environment surrounds the heat pipe. Insulation suppliers do not typically test their insulation in this environment, so the thermal properties could be different than expected. This project is needed to determine how this environment will affect the heat transfer in the reactor based on the insulation material chosen.

Significance and Impact

Global electricity demand increased by 4.3% in 2024. Increased demand for cooling as global warming causes increased temperatures, as well as the electricity required for new Artificial Intelligence technologies will likely cause this demand to continue to rise [1]. To keep up with the demand for electricity and keep electricity prices affordable, there needs to be an increase in electricity generation. Nuclear energy provides electricity without the carbon emissions created by other sources like coal power plants [2]. The eVinci™ microreactor created by Westinghouse is aimed at creating electricity without carbon emissions. The eVinci™ microreactor is unique due to its size and simplicity. This makes it ideal for more remote applications that do not need a full-sized nuclear power plant [3].

References:

[1] IEA (2025), Global Energy Review 2025, IEA, Paris https://www.iea.org/reports/global-energy- review-2025, License: CC BY 4.0

[2] Sadiq, M., Wen, F., & Dagestani, A. A. (2022). Environmental footprint impacts of nuclear energy consumption: The role of environmental technology and globalization in ten largest ecological footprint countries. *Nuclear Engineering and Technology*. https://doi.org/10.1016/j.net.2022.05.016

[3] Arafat, Y., & Wyk, J. van. (n.d.). eVinci™ Micro Reactor. In *NuclearPlantJournal.com Nuclear Plant Journal*.

Project Continuation

This project is planned to continue after this semester. This semester was intended to be the computational phase of the project while the next semester was planned to be the experimental phase to validate the computations made. For this reason, the budget provided by the sponsor will not be physically given until next semester; however, an estimate of the budget will be given to our team. This will help our team create the insulation package while keeping in mind the relative budget for next semester. This will also help us be able to set the next team for success by providing well-written documentation, designing with the feasibility to test experimentally, and, if time permits, creating a low-resolution test rig that they can consider as a starting base for the experiment.

# 2. Sponsor Document

The following text was provided by the sponsor, Westinghouse, and serves as the impetus for this project.

Project Background:

Westinghouse is developing the eVinciTM microreactor as part of its commitment to providing innovative and competitive clean power solutions. The eVinci microreactor is designed to address environmental and economic challenges associated with distributed generation for remote communities, industrial consumers, and disaster relief. It is a game-changer in the nuclear energy sector due to its simple design with no moving parts within the reactor, ability to supply power 24/7/365 without refueling for eight years or more.

Westinghouse has established a dedicated eVinci microreactor accelerator technology hub in Pittsburgh, which will enable the team to operate more efficiently and co-locate next to innovative university campuses. This initiative is part of Westinghouse's broader strategy to lead communities and industries towards a cleaner, more sustainable future.

In this project, students will propose and test methods to explore how different environments will affect engineering properties used within component and system design. As explained below, the project will use non-proprietary information to support the development of micro-nuclear reactors like the eVinci.

The eVinci uses heat pipes to move heat from the reactor core. For power applications, the heat pipes transfer energy from the reactor (nuclear fuel) to the Primary Heat Exchanger (the PHX) which is used to replace a typical combustion chamber within a Brayton gas turbine cycle. The heat exchanger design is crucial for the efficient operation of the eVinci reactor. The PHX design is a balance between performance and structural strength, as increasing metal thickness will reduce thermal performance.

Through the project students will learn about new concepts to use nuclear “micro-reactors” to provide both power and heat to remote applications. Students will not test any nuclear components, but will use a controlled electric heater to mimic the heat output from the planned micro-reactor.

Primary Heat Exchanger:

To produce electrical power, multiple heat pipes are used to exchange heat from the reactor core to the compressed air in a gas turbine power cycle. Figure 1 shows a general arrangement of the reactor core and primary heat exchanger. In the reactor core, the heat pipes are arranged in a grid-pattern between the reactor fuel elements, forming six “sectors” (truncated triangles) as shown. The heat pipes extend from the reactor core into the primary heat exchanger shown notionally in the isometric view, lower right. Gas turbine air flows around the heat pipes, absorbing the reactor heat, and powering the turbine.

Design challenge:

With a high temperature reactor, insulation is a critical component to ensure materials can last the design life. The insulation's thermal conductivity is a parameter used to determine the effectiveness of the material's ability to conduct heat. A materials thermal conductivity is typically the same regardless of the environment in which it is placed, however this is not always true. The majority of insulation rely on free space, and most are only tested within an air environment leading to a gap in understanding of how the material will perform in other environments. The eVinci micro reactor relies on an inert helium environment within the canister during operation and the PHX requires insulation to reduce metal temperatures. Understanding the thermal conductivity of the insulation is necessary to model the performance and to size the thickness required.

Project Description:

Each team is expected to choose an insulation based on the design conditions, predict the performance of the insulation within a helium environment, and then use that information to design an insulation package to meet the performance requirements. Secondly the team will validate the predicted thermal conductivity used to size the insulation based on an experimental rig. After results of the test rig are determined satisfactory the teams will assess if there are any design changes needed to the insulation package to meet the design requirements.

Project Objectives:

- Choose an insulation based on the design conditions and the design life.
- Predict the thermal conductivity of the insulation within a high temperature helium environment.
- Design the insulation package based on the required performance requirements.
- Validate the thermal conductivity of the insulation within the design conditions
  - Build a rig to test thermal conductivity of materials within a non-air environment
  - Test the insulation to experimentally determine the thermal conductivity
- Determine if a design change is required based on the initial sized insulation package and the new testing data.

Design Requirements:

- Insulation Performance requirements (Not testing conditions)
  - Design Life: 12 years
  - Temperature: 850°C
  - Environment:
    - Insulation side: Helium at atm pressure, 850°C

        - Heat Sink side: Air at 7 Bar, 400°C
    - Maximize temperature drop given 2 inches of space
- Insulation must be rigid or fully contained (taken out of the 2 in space requirement)
    - Analytical model details (testing sample can be chosen by the team) Students are asked to analyze the geometry shown in the figure below. This is a simplified version of the larger eVinciTM design. The center rod represents the heat pipe (0.5 in OD). A concentric annulus is filled with air or helium as shown. Insulation surrounds the annulus (ID 1.5 in, OD 6 in). An alloy 625 ring represents the bulkhead between the air and helium chambers. A 0.125 in thick plate (alloy 625) keeps the gases separate as shown. The ring is centered along the horizontal axis from a to b. The seal plate extends 0.125 in to the right (i.e., slightly asymmetric). Axial dimensions between a and b are shown, for an overall length of 8 in.
    - For the heat transfer analysis, students should treat the center rod as a constant temperature heat source (850°C). Both ends of the model are adiabatic as shown. For the outside surface a-b, two different cases should be analyzed:
        - Case 1 – constant surface temperature, Tsurf = 400°C. Find the heat loss kW/m along the axis.
        - Case 2 – constant heat loss, q'surf = 5.0 kW/m. Find the temperature profile throughout entire assembly.Test rig design and sample design shall be chosen by the individual team(s)
    - Students are also encouraged (but not required) to conduct analysis on several cases of their choosing that demonstrate that insulation produces acceptable metal temperature in a surrounding pressure vessel (not prescribed here). Students should make assumptions about the surrounding environment and pressure vessel and discuss the viability of their insulation approach. Students should report their assumptions and explain their findings.
    - Testing conditions shall be chosen by individual team(s) and do not need to be tested at the listed performance requirements above.
- Project Deliverables:
    - Insulation Datasheet
    - Thermal calculations to predict thermal conductivity within a hot helium environment
    - Test rig design
    - Test plan
    - Safety Checklist / Hazard Analysis
    - Design Report including design description, results of analysis, and testing.

<u>Project Outcome and Requirements:</u>

- The final deliverable will be a detailed design of an insulation package, which includes all analysis and testing results.
- The project will culminate in a presentation and demonstration of the design at the Westinghouse Etna facility in April 2026, where it will be evaluated against designs from other schools.

# 3. Specifications and Requirements

<u>Design constraint categories</u>

- Technical and Performance Constraints
    - Insulation must be effective at reducing heat loss
        - Performance validated through hand calculations, analytical models, and simulation
    - Maximum radial thickness of 2.25 inches
    - Operates at 850 °C in helium and at 400°C in air environments
    - Airtight configuration for either the insulation package itself and the experimental rig.
    - Must satisfy both Case 1 (constant surface temperature) and Case 2 (constant heat loss) boundary conditions
    - Mechanically self supporting and rigid under testing conditions
    - Adequate yield strength and structural stability to minimize deformation
    - Radiation resistance
    - Although not directly tested, candidate materials must be evaluated for resistance to radiation damage in nuclear environments.
    - Corrosion resistance
    - Including compatibility with dissimilar metals at high temperatures.
    - Chemically stable over the reactor's 12 year lifetime

- Economic and Feasibility Constraints
    - Total cost must not exceed the allocated project budget
    - As explained in the section *Budget,* an estimate of the budget given to next team will be provided to us to keep in consideration when choosing materials
    - Candidate materials must be reasonably accessible for purchase or fabrication
        - With respect to time constraints and testing capabilities at the University
    - The insulation package or test rig design must be feasible for prototyping and eventual manufacture
        - Techniques available to Westinghouse or standard suppliers
        - Allow for application into real world
    - Design must be simple and feasible to allow continuation and testing by subsequent senior design teams
        - Geometrical complexity should be minimized to simplify fabrication and assembly.
        - Clear documentation and accessibility of materials and methods

- Health and Safety Constraints
    - All candidate materials must be safe to handle during fabrication and testing
        - No excessive toxicity, reactivity, or dust hazards aligning with Environmental, Health, and Safety (EHS) standards

  - Insulation or rig design must maintain helium containment to reduce leakage risks
  - High temperature stability must ensure that insulation does not degrade into unsafe byproducts when operating
  - Safety margins must be built into mechanical and thermal design factors to minimize failure risk

- Environmental and Sustainability Constraints
  - Insulation materials and processes must align with Westinghouse's mission of delivering clean energy solutions
  - Minimize environmental impact of material sourcing, fabrication, and disposal
  - Materials should be durable to extend lifetime and reduce waste

- Ethical, Social, and Political Constraints
  - Must comply with nuclear industry regulations and standards where applicable
  - Ethical responsibility to ensure that insulation performance does not compromise reactor safety
  - Social responsibility to design insulation that contributes to the broader goals of reliable clean power access
    - Use in remote or disaster relief areas
  - Consider international political factors if insulation materials are sourced globally
    - Relying on limited or politically affected supply chains

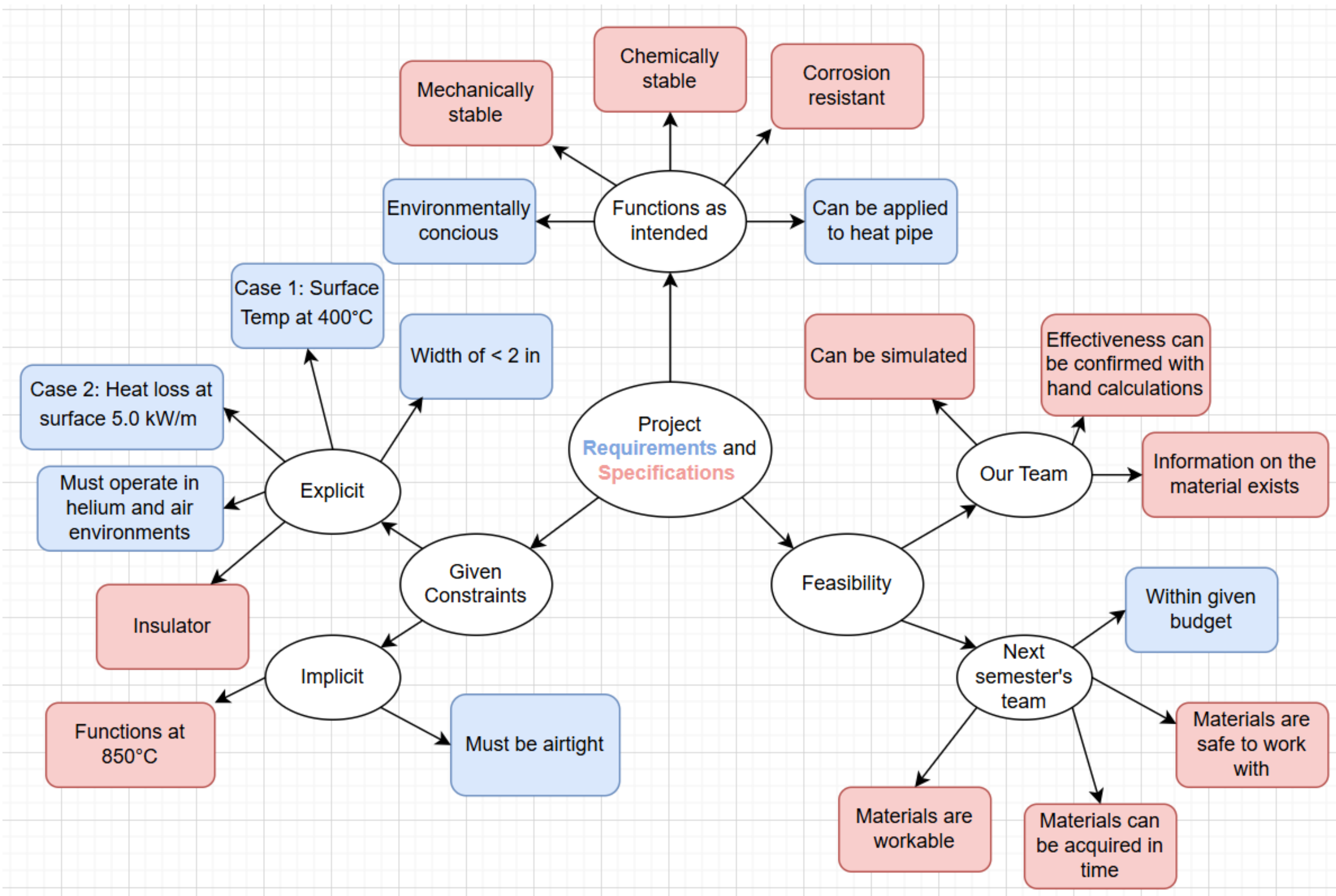
<u>Requirements & Specifications</u>

*Since nothing is being constructed physically, all requirements and specifications will be experimentally tested within the software that simulates the performance of the insulation and confirmed by hand calculations.*

| Req. or Spec. | Description | Metric | Experimental Test |
|---|---|---|---|
| Req. | Width | Largest distance between inside and outside of insulation < 2.25 in. | Measure within software. |
| Req. | Surface temperature in case 1 | Tsurf = 400°C | Measure within software, calculate by hand. |
| Req. | Operates in helium and air | All other metrics are met regardless of gas. | Measure within software, calculate by hand. |
| Req. | Heat Loss in case 2 | q'surf = 5.0 kW/m | Measure within software, calculate by hand. |
| Spec. | Insulation is a rigid body, able | The yield strength of | Measure within software, |

| | | | |
|---|---|---|---|
| | to support itself | insulation + heat pipe exceeds shear force on pipe. | calculate by hand. |
| Spec. | Insulator | T (inner) < T outer | Measure within software, calculate by hand. |
| Spec. | Functions at high temperatures | All other metrics are met when T > 850°C | Measure within software, calculate by hand. |
| Spec. | Chemically stable; corrosion resistant | All other metrics are not changed by chemical issues. | Research chemical stability in peer-reviewed journals. Confirm within software. |
| Spec. | Can be simulated | Chosen software can accurately simulate rig and insulator | Measure within software, confirm by hand |
| Spec. | Information exists | Can find accurate thermal conductivity data on material. | Research in journals |
| Req. | Within budget | Next semester's team can afford all materials. | To be determined next semester |
| Spec. | Materials can be acquired in time | Next semester's team can get all materials in one semester. | To be determined next semester |
| Spec. | Materials are workable | Next semester's team can make material into needed shape | Research workability in journals |

Summary Mind Map or Quad Chart



# 4. Project Goal, Objectives and Tasks

Project Goal

Design an insulation package for the Primary Heat Exchanger in the eVinci™ microreactor, meeting the specifications and requirements listed in *Section 2*.

Objectives

**Objective 1 – Literature Review and Concept Development:**
Conduct a thorough literature review to understand how microreactors function, focusing on the primary heat exchanger and the role of insulation. Compare and contrast common insulation types for heat pipes in nuclear applications. Look into how helium vs air environments affect insulation performance, specifically thermal conductivity $k_{eff}$. Create a set of potential insulation packages with estimated $k_{eff}$ that can be tested in the heat transfer analysis.

**Objective 2 – Analytical Analysis:**
Perform heat transfer analysis on the given heat exchanger model by Westinghouse, applying the estimated thermal conductivity of the candidate insulation materials. Analysis will consist of both Case 1) constant surface temperature, 400°Cand Case 2) constant heat loss, 5.0kW/m. Apply this analysis to a computational model to make ease of testing multiple materials. Use both to validate each other's calculations. Results will find the heat loss along the axis and the temperature profile across the entire assembly. This will show how $k_{eff}$ affects reactor performance.

**Objective 3 – Insulation Package Design:**
Use results from the analytical analysis to choose the optimum insulation material. Create a drawing and 3D model outlining the chosen insulation geometrical design. Prepare a datasheet consisting of geometrical parameters, $k_{eff}$ , heat loss per unit length, temperature distribution, mechanical properties, safety factors, and cost.

**Objective 4 (Time Permitting) - Test Rig Design:**
Begin conceptual design of a test rig to validate the thermal conductivity results from the analysis. Define rig constraints, candidate materials, and a CAD model/low resolution prototype. Create a safety checklist for constructing and utilizing the potential rig test rig. This will provide a framework for the following senior design team to build on for the continuation of the project.

Tasks

Objective 1:

- Collect and summarize references on microreactors

    - Focusing on common nuclear insulation materials (metallic and nonmetallic materials)
        - Mechanical properties, thermal properties, porosity, etc.
    - Understand typical environmental conditions the materials need to endure
        - How do different gas atmospheres affect performance?
- Compile a list of potential insulation materials
    - Estimate $k_{eff}$, mechanical properties, and geometrical design
    - State limitations

Objective 2:

- Review provided geometry and boundary conditions given by Westinghouse
- Set up heat transfer equations for both Case 1 and Case 2
    - Distinguish variables that are given and variables that need to be solved for
    - Use $k_{eff}$ from potential insulation materials
- Apply equations and calculations to a computational model
    - Compare each other's results to validate
- Compare how the results from Case 1 and Case 2 change with different $k_{eff}$ by testing different candidate materials
    - Specifically, observe the changes in performance in air vs. helium

Objective 3:

- Evaluate analysis results to choose the best performing insulation material
- Define the insulation design based on required geometry
    - Create a CAD model representing this design
- Create a datasheet outlining the properties of the insulation package
    - $k_{eff}$, mechanical properties, heat loss, temperature gradient, cost, safety, etc.

Objective 4: (Time Permitting):

- Research experimental methods for measuring $k_{eff}$ in helium
    - Existing test rig designs, structural materials, helium containment, etc.
- Define test rig constraints
    - Based off cost, environment, and safety
- Draft preliminary CAD model or low-resolution prototype of the test rig
    - Outline safety considerations with the design

<u>Endpoints – Deliverables and Metrics for Success</u>

Objective 1:

- Compiled literature review of insulation performance in microreactors
- Comparative table of 3- 5 potential insulation material packages
- Completed by: **End-September 2025**

Objective 2:

- Hand calculations for Case 1 and Case 2
- Thermal/computational model for Case 1 and Case 2
- Comparison of performance results for each potential insulation material
- Completed by: **Mid-October 2025**

Objective 3:
- Final insulation material and geometrical design
- CAD drawings and 3D model of package
- Datasheet including geometry, $k_{eff}$, heat loss, temperature gradient, mechanical properties, safety, and cost
- Completed by: **Mid-November 2025**

Objective 4 (Time Permitting):
- Preliminary literature review of test rig
    - Supporting information about design, gas containment, material selection, power input, safety, etc.
- Construction of a CAD model or low-resolution prototype
    - To be used by subsequent teams as groundwork to base their own ideas from
- Completed by: **December 2025**

# 5. Project Planning

Resources

As an option to validate the heat transfer calculations performed by hand, ANSYS can be used for thermal modeling and analyzing, with COMSOL Multiphysics, OpenFOAM, and MATLAB being viable substitute platforms. The potential test rig will be designed via SolidWorks CAD software, with Autodesk Fusion 360 as a substitute.

Though beyond the defined scope of this computational project, a future goal is the experimental validation of the experimental calculations using the test rig. This work will focus on the fabrication and testing of a physical apparatus. As such, the test rig will be constructed using only the optimal candidate materials and insulation geometries identified in the current phase. Depending on the insulation materials chosen, this could consist of metallic and nonmetallic materials, a heat source, gas containment, etc.

Anticipated Design Iterations

Below are the elements that are most likely to require iterations as the project moves forward. The main approach for these iterations is to build in flexibility into the project timeline to ensure that adjustments can be made.

**Material Selection:**
Selecting an insulation material is expected to take multiple iterations, especially as calculations are made. Materials must abide by a range of constraints outlined in *Section 2.*

Iteration approach:
- Start with a wide range of potential materials from the initial literature review
- Continuously evaluate the results from thermal calculations in both Case 1 and Case 2
    - Down select based on the comparison of the results
- In later project phases, calculated predictions will be validated by an experimental test rig
    - Allows for further iteration if results are not matching

**Insulation Design:**
The geometry of the insulation package (thickness, layering, etc.) will require iterations to optimize performance, manufacturability, and experimental limitations.

Iteration approach:
- Use heat transfer calculations to compare different thickness and layering effects
- Leave room for flexibility in meeting size constraints

- Use a flexible CAD framework to easily adjust changes

**Heat transfer calculations:**
Heat transfer equations may change as the sponsor outlines different constraints, new conditions need to be considered, or simplifications can be made.

Iteration approach:
- Establish a clear list of assumptions being made for the calculation
- Build equations and models in a modular way so that material properties and boundary conditions can be easily changed in
- Build in time for recalculations to try different conditions and parameters

Support from Project Sponsor

Main requirement from the project sponsor (Westinghouse) is to meet on a weekly basis to update the team on progress made, questions to be asked, items to be clarified, and to ensure the team is on track. Another requirement is for the sponsor to be in communication with their team at Westinghouse to ensure that our team's objectives are aligned with Westinghouse's. As the team makes progress throughout the semester, the sponsor is suggested to give feedback on the iterations and changes made.

Support from Swanson Center for Product Innovation

Consult Dr. Schmidt for heat transfer advice once thermodynamic system is fully defined. In addition, if time permits, working with SCPI to identify design and construction constraints when creating the preliminary test rig prototype.

Support from Subject Matter Experts

**Materials Science Experts**
Support from materials science faculty and researchers will be important in the material selection process. Their knowledge will guide the team in prioritizing parameters such as thermal conductivity, strength, porosity, and stability under helium-rich, high-temperature environments. These experts can also help in defining material indices that will be used in the down-selection process, ensuring that tradeoffs between competing properties are managed.

**Nuclear Energy Experts**
The project sponsor, Westinghouse, serves as a primary source of nuclear engineering expertise. Their understanding of the eVinci™ microreactor design, operating conditions, and safety requirements will help most overall in aligning the project to fulfill the objectives.

They will provide feedback on assumptions, highlight potential mistakes, and critique the design decisions to ensure that the insulation package completes the goal of the project.

**Heat Transfer Experts**
Getting advice from heat transfer experts will help with the calculations by refining the boundary conditions and assumptions used. They can verify the accuracy of thermal models, identify missing considerations, and assist in debugging when calculations are not aligning. Their feedback will help make sure that the team's thermal analysis is both accurate and representative of the actual reactor environment.

**Manufacturing and Prototyping Support**
If time permits for designing the test rig for the next term, support from machinists and manufacturing experts will be essential in evaluating the feasibility of the proposed designs. Their experience will help the team determine whether a prototype can be realistically fabricated, given constraints on geometry, cost, and safety. This feedback will ensure that the test rig concept is viable for the continuation of the project by future senior design teams.

## Potential Risks and Anticipated Failures

The following identifies any potential risks and failures to the project plan, with an associated workaround for each:

**Incomplete or Unreliable Material Property Data**
*Risk:* Thermal conductivity, emissivity, or mechanical data for candidate materials may be unapplicable in our high temperature, helium atmosphere; especially true as our design strays away from common geometries.
*Workaround:* Use multiple data sources and document any discrepancies; adjust values to the best of our knowledge based on test conditions.

**Boundary Condition Errors**
*Risk:* Misinterpretation of Case 1 and Case 2 conditions or missing details about thermodynamic boundary conditions.
*Workaround:* Request further clarification with the sponsor, clearly state and justify assumptions in reports to prevent hidden errors.

**Over-Simplification of Heat Transfer**
*Risk:* Neglecting radiation or contact resistance can underestimate how much heat is lost and overestimate insulation performance
*Workaround:* Start with conduction only and add radiation and interfacial resistance in later iterations as time permits; clearly state simplifications and assumptions made in final reports.

**Computational Model Convergence Issues**
*Risk:* Nonlinear thermal properties (e.g. temperature dependent properties) may fail to converge in finite element software.
*Workaround:* Maintain a validated analytical model as a backup for cross checking, and use sweeps with gradually increasing complexity

**Time Constraints**
*Risk:* Iterative plan may take longer than project timelines will end up allowing.
*Workaround:* Prioritize a minimum viable insulation package to ensure deliverables are met; build in extra time in the project timeline to provide a cushion as roadblocks occur.

**Uncertainty in Long-Term Performance Predictions**
*Risk:* Predicting insulation behavior for a 12-year design life may exceed current capabilities of computational data and simulation as the timeline is only a term.
*Workaround:* Focus computational analysis on initial conditions and maximum design temperatures, document risks for future team or subject matter expert to review and recommend that long term effects be validated in physical testing.

Milestones

**Milestone 1 – Completion of Literature Review and Concept Development**
*Deliverables:* Compiled literature review on insulation performance in microreactors; comparative table of 3–5 potential insulation material packages with estimated $k_{eff}$ and design considerations.
*Evaluation Criteria*: Completeness of references, understanding of primary heat exchanger system, in-depth comparison of insulation designs, 3-5 proposed candidate insulation materials.
*Target Date:* September 30$^{th}$, 2025 (non-negotiable)

**Milestone 2 – Analytical Heat Transfer Analysis**
*Deliverables:* Full (hand) calculations for Case 1 (constant surface temperature, 400°C) and Case 2 (constant heat loss, 5.0 kW/m)
*Evaluation Criteria:* Analytical efficiency comparison of proposed insulation packages, and iterative process to down select ideal insulation.
*Target Date:* Early-October 2025

**Milestone 3 – Insulation Package Design Finalization**
*Deliverables:* Heat transfer model to validate hand calculations; performance comparisons for each insulation candidate under both helium and air environments
*Evaluation Criteria:* Accurate calculations as compared to hand calculations, complete application onto a computational model, analytical comparison of proposed insulation packages, and further iterative processes from CAD results to down select ideal insulation.
*Target Date:* Mid-October 2025

**Milestone 4 – Insulation Package Design Finalization**
*Deliverables:* Selection of optimal insulation material and design; finalized CAD drawing and 3D model; datasheet including geometry, $k_{eff}$, heat loss per unit length, temperature distribution, mechanical properties, safety factors, and cost.
*Evaluation Criteria:* Completeness of package design and fulfills project requirements and specifications as described in Westinghouse project description.
*Target Date:* Late-October 2025

**Milestone 5 – Preliminary Test Rig Design (Time Permitting)**
*Deliverables:* Literature review of experimental methods for measuring $k_{eff}$ in helium; defined test rig constraints; CAD model or low-resolution prototype; safety checklist for rig operation.
*Evaluation Criteria:* Feasibility of proposed rig design, quality of supporting research, and clarity of safety considerations.
*Target Date: November 17$^{th}$ (non-negotiable)*

Budget

At present, no budget has been established as there is no external equipment to be purchased that the University of Pittsburgh does not already provide. Since the project will be continued in the following semester, Westinghouse is working to let us know the next team's budget so we can effectively set them up for success in the next phase. Please note that the project budget will be updated in parallel with any modifications if needed.

Timeline

Timeline completed within the specifications of what has been defined above in Teamwork.

# 6. Project Execution

Analysis & Design

**Heat Transfer Analysis (MEMS 1052: Heat and Mass Transfer)**
*Objective 2 – Analytical Analysis:* Using the provided Westinghouse heat exchanger model, the team will evaluate insulation performance under two cases: constant surface temperature (400 °C) and constant heat loss (5.0 kW/m). Analytical and numerical solutions will be compared to quantify how effective thermal conductivity ($k$eff) influences reactor performance in air versus helium environments.
*Metrics for success:* Calculated heat loss per unit length, predicted temperature profiles across the insulation, and validation of results against known values or experimental data.

**Materials Structures and Properties Analysis (MEMS 0023: Intro to Materials Science and Engineering; MEMS 1011: Structure and Properties Lab)**
*Objective 1 – Literature Review and Concept Development and Objective 3 – Insulation Package Design:* This analysis will evaluate how microstructural features of candidate materials (e.g., porosity, grain stability, phase composition) affect thermal and mechanical performance under helium exposure and high temperatures. The team will use experimental skills, such as linking structure to properties and designing experimental procedures, to help with down selection of insulation materials.
*Metrics for success:* Quantified thermal conductivity, design life, and mechanical strength before and after simulated helium exposure.

**Materials Selection (MEMS 1030: Materials Selection)**
*Objective 3 – Insulation Package Design*: A materials selection framework will be applied to identify the optimum insulation material and geometrical design. Constraints include the 2.25 in. radial space limit, rigidity, strength, thermal conductivity, and cost. Ashby performance indices will be used to compare candidate materials against project requirements, narrowing down choices to be tested in computational and experimental analysis.
*Metrics for success:* A ranked list of candidate materials with quantified indices, final selection of a material that meets all design constraints, and a complete datasheet summarizing thermal, mechanical, safety, and cost parameters.

Verification

The main verification process will be conducted in the following term by the next project team. The project was designed to have this term complete the computational calculations and the next term complete an experimental test to validate the results. The general plan for the following semester is for the next team to construct a test rig that can physically simulate our thermal modeling performed this semester. This will give experimental results to either validate or not validate the computational results.

As for this semester, the secondary verification steps we will perform are transitioning from hand calculations of the two heat transfer cases to modeling them computationally. By verifying that both processes give the same results, this gives us confidence that the insulation materials tested are giving accurate results. This enables us to compare each result with the requirements and specifications of the project and determine whether they were achieved and to what extent.

# 7. Project Organization

Team Meetings

Team meetings occur at least once a week, typically Friday mornings from 9:00am-10:00am via zoom. The team meets briefly after/before senior design class twice a week in Benedum Hall. The team also will schedule other meetings whenever they see fit. Presenters are designated note-takers, taking meeting minutes and recording topics covered in each meeting. The rest of the team facilitates each meeting, asking questions to the sponsor, and keeping the meeting on track.

Work Space

We will work mainly in Benedum Hall as that is a central and convenient location for the entire team. Since the project is mainly focused on computational analysis, there is no need to have a physical workspace to store the project. The project will be stored digitally through OneDrive on each of our personal accounts. Any work performed with external software will either be performed on personal laptops or University computers.

Sponsor Meetings

The team meets with our sponsor at least once a week, currently, Tuesday afternoons from 1:00pm-2:00pm via Zoom. This call is usually for about an hour to check in, bring up any questions, and get feedback from our sponsor. Other than meeting once a week, there is the ability to set up an alternate meeting at any point when deemed necessary, i.e. if there is an immediate question.

Sharing, Distribution and Archival of Project Data

The main plan is to have a OneDrive folder shared amongst team members with individual folders for class documents, meeting minutes, resources, program files, and image/ video archival materials. Every file will be available to the entire group whereas material to be looked over by the sponsor will be sent to them via email. The sponsor will receive a folder of finalized material at the end of the project term that will be able to be sent to the next team working on the project.

Return of Equipment

Since our project is computational, the plan to achieve/return equipment is not applicable. If the project goals and objectives changed, and equipment/materials were lent by the sponsor, then the team member responsible would be the Resource Manager.

# 8. Project Outcomes

Community

Westinghouse will use this information to be used on the future development of the eVinci™ microreactor. Insulation material package can aid in greater Brayton cycle efficiency which can help with extending microreactor life, decreasing cost, and increase system reliability. The successful implementation of the eVinci™ microreactor will impact the community at large by providing electricity in more remote areas where the infrastructures are lacking.

Educational

This project will teach our team the fundamentals of heat transfer and how it can be applied to a real-life scenario. This includes simplifying the problem, defining boundary conditions, defining what's being asked of in the problem, manipulating equations, and obtaining accurate results. It will then teach the team how to interpret the results after and be able to utilize them as a tool in material selection. This project will expose the team to many types of insulation designs and materials, helping us better understand the importance of material selection in projects. In addition, this project will help the team in experiencing different software. This can potentially include using ANSYS, SolidWorks, COMSOL Multiphysics, OpenFOAM, or MATLAB for aiding in heat transfer calculations, 3D modeling, and so on.

# 9. Swanson Center for Product Innovation

Since our half of the project is entirely computational, it is not necessary to utilize the Swanson Center for Product Innovation.

# 10. Preliminary Design Concepts

<u>Candidate Design Concepts</u>

Choosing the best insulation material for the heat pipe is defined by a variety of characteristics. These include the structure, composition, thermal properties, and cost. In the screening phase of the material selection process, a material database was used to filter out materials that did not meet the operating temperature of 850°C and the strength requirement of withstanding at least a pressure of 7 atm. From this initial elimination, insulation categories such as castable refractories, fibers, foams, and bricks were examined.

One option for insulation is castable refractories. This type of material is a combination of a high-temperature resistant aggregate and binder that can be poured as a liquid before it sets. The benefit is that the refractory can form into any shape before hardening creating a seamless lining. The refractory aggregates are normally composed of alumina, silica, or silica carbide. ASTM C401 classifies alumina and alumina-silica castable refractories by their operating temperature. The lowest class is class A, which is suitable for our operations as it includes materials rated for 1,260°C. There are different types of castable refractories, determined by its cement content. As cement content lowers, the castables show the bettert high temperature strength and corrosion resistance but come at a higher price.

Another option for insulation is refractory bricks. These are a collection of porous ceramics that are designed to withstand extremely high temperatures. A refractory brick that meets ASTM grade 23 from ASTM standard C155 will endure up to 1,260°C and is suitable for this design. Because of the air environment at 400°C, compositions containing large amounts of carbon, silica, and other oxidizing elements can cause cracking. For this reason, oxide-based refractories show the most strength and stability under both air and helium environments. They are cheap, have low thermal conductivities, and can be made into requisite shapes.

Our third alternative for the insulation is fibrous ceramics. They are made through the process of melting or spinning ceramics, then weaving them into the necessary shape. The diameter of the fibers in the ceramic is proportional to the thermal conductivity. This allows for much smaller thermal conductivities than possible with the other categories. They are also able to operate at high temperatures as approved by ASTM C892 to be used up to 1649°C but should still require checking with the technical specifications from the manufacturer. The fibers often come in the form of blankets which have an advantage of being bendable to be easily shaped around the pipe.

The final choice for the insulation category is ceramic foam. This is a lightweight, rigid, porous material that is fiber-free. Depending on the fabrication method, porosity can range up to 95%, which limits heat flow through conduction, reducing its thermal conductivity. The structural rigidity makes it stronger and more stable than fibers while still maintaining a low thermal conductivity.

For all four structural categories, the refractory composition mainly includes zirconia ($ZrO_2$), silica ($SiO_2$) and alumina ($Al_2O_3$), avoiding compositions with carbon to avoid oxidation. Of the three, zirconia generally has the lowest thermal conductivity, followed by silica, then alumina. Though it is beyond the scope of our design testing capabilities, zirconia is the least susceptible to ionizing radiation, followed by alumina, and then silica. As for cost, zirconia is the most expensive, followed by alumina, then silica. Even though zirconia seems to have the best thermal and irradiation properties, it comes at a higher cost. This emphasizes the need for a robust material selection process that can determine the material that balances

Requirements & Specifications

| Material Candidate | Operating Temperature | Design Life | Yield Strength (MPa) | Irradiation Environment | Cost |
|---|---|---|---|---|---|
| Castable Refractories | 1,260°C at class A, can be much higher. | Depends on maintenance. | 12 | Depends on Composition | Second most expensive |
| Ceramic Foam | Up to 1700°C, higher depending on composition | Depends on maintenance. | 0.6 in low-strength | Depends on Composition | Most Expensive |
| Insulating Fire Bricks | 1,260°C at grade 23, can be much higher | Depends on maintenance. | 4.2 | Depends on Composition | Second cheapest |
| Ceramic Fiber | Up to 1649°C, potentially higher | Depends on maintenance. | .6 | Depends on Composition | Cheapest |

| Material Candidate | Thermal Conductivity (W/mK) | Ionizing Radiation Resistance | Cost |
|---|---|---|---|
| Zirconia | 2.5-3.0 | Most resistant | Most expensive |
| Alumina | 20-40 | Middle | Middle |
| Silica | 8-12 | Least resistant | Least expensive |

Strengths and Weakness

**Castable refractories**

*Strengths:*

- Customizable
    - Easily and quickly poured into any shape needed
- Good strength

*Weaknesses:*

- Time intensive
    - Curing and sintering needed

- Highest density
  - Highest thermal conductivity out of the four

**Bricks:**

*Strengths:*

- Durable
- High mechanical strength
  - Compressive loading
-

*Weaknesses:*

- Complex to install due to its rigidity
- Dense
  - Higher thermal conductivity relative to fibers and foams
- Cracking at interfaces
  - Thermal expansion

**Fibers:**

*Strengths:*

- Highly porous and tortuous
  - Lowest thermal conductivity
- High degree of flexibility
  - Excellent thermal shock resistance

*Weaknesses:*

- Break off/fall apart
  - Damage/clog components and cause a shutdown
  - Fiber particles are hazardous to health
- Low structural stability

**Foams:**

*Strengths:*

- Gas filled pores
  - Low thermal conductivity
- Low density but still rigid

*Weaknesses:*

- Brittle
  - Thin walls can crack from thermal-mechanical loads

<u>References for Design Concepts</u>

AC2468 Alumina Foam Insulation. (2025). Samaterials.com; Stanford Advanced Materials. https://www.samaterials.com/alumina/2468-alumina-ceramic-foam-insulation.html

Bubble Alumina. (n.d.). In https://www.zircarceramics.com/. Zircar Ceramics. Retrieved October 24, 2025, from https://zircarceramics.com/wp-content/uploads/2017/01/Bubble-Alumina.pdf

Insulating Firebrick products. (n.d.). Morgan Advanced Materials. Retrieved October 24, 2025, from https://www.thermalmaxinc.com/wp-content/uploads/Firebrick_non-metric.pdf

"Your One-Stop-Shop for Thermal Processing Materials." (n.d.). CeraMaterials. https://www.ceramaterials.com/wp-content/uploads/2022/04/CERAMIC_FIBER_BOARDS_TDS_4_22.pdf

Current or Future Supporting Analysis or Validating Experiments

As our primary validation method, we employ a hybrid analytical-computational approach through thermal circuit analysis of the heat pipe system. We performed heat transfer calculations for two cases. For case 1, there was a specified surface temperature of the assembly, and we calculated heat loss along the length of the assembly. For case 2, there was a specified heat flux out the surface of the assembly, and we needed to calculate the temperature profile of the assembly. A schematic of the assembly is shown in Figure 1.

The validation strategy transforms the system into circuit equivalent with total resistance (R_tot) incorporating both conduction and radiation heat transfer modes. Convection heat transfer is ignored due to high operating temperatures of the heat pipe. This simplification is justified by standard heat transfer correlations and reduces computational complexity while maintaining physical accuracy. We also assumed that there is a linear temperature drop along the length of the heat pipe from 860°C to 840°C.

The thermal resistance network is analyzed in cylindrical coordinates with derived analytical expressions for each resistance component. The circuit equivalent is shown in Figure 2. The circuit equivalent model enables rapid parametric studies to provide physical insights into heat transfer analysis, serving as validation and design optimization tools.

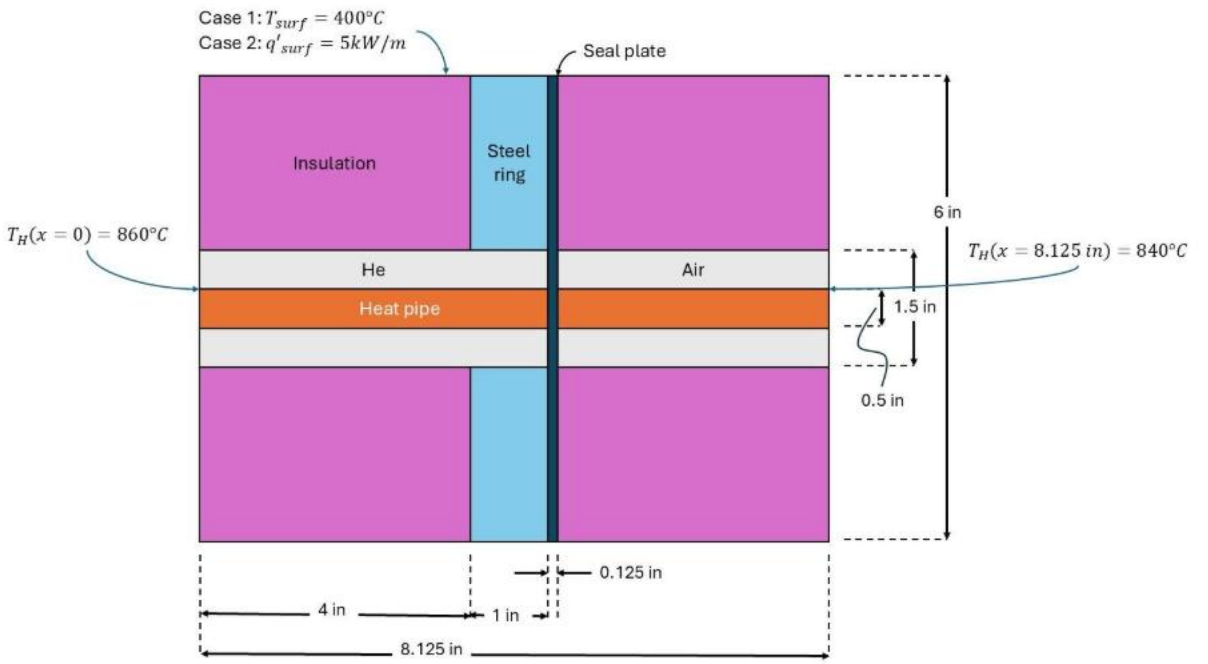



Figure 1: Schematic of the heat pipe assembly

Equations are derived as follows:

$$R_{cond,\ gas} = \frac{\ln\left(\frac{r_1}{r_2}\right)}{2\pi k_{gas}}$$

$$R_{cond,\ ins} = \frac{\ln\left(\frac{r_3}{r_2}\right)}{2\pi k_{ins}}$$

$$R_{rad,\ ins} = \frac{1}{2\pi \epsilon_{ins}(r_2 - r_1)\sigma(T_{ins}^2 + T_{gas}^2)(T_{ins} + T_{gas})}$$

$$R_{rad,\ pipe} = \frac{1}{2\pi \epsilon_{pipe} r_1 \sigma(T_H^2 + T_{ins}^2)(T_H + T_{ins})}$$

The radiation and the conduction through the gap are in parallel and the conduction through the insulation is in series, so we can derive equation for equivalent resistance at every location along the pipe as follows:

$$R(x) = \left[\left(\frac{1}{R_{rad,\ ins}} + \frac{1}{R_{rad,\ pipe}} + \frac{1}{R_{cond,\ He}}\right)^{-1} + R_{cond,\ ins}\right],\ 0 < x \leq 3.5 in$$

$R(x)=[(1R_{rad,\ ring}+1R_{rad,\ pipe}+1R_{cond,\ He})_{-1}+R_{cond,\ ring}]$, $3.5in<x\leq 4.5in$ *Rx=1Rrad, ring+1Rrad, pipe+1Rcond, He−1+Rcond, ring, 3.5in<x≤4.5in*

$R(x)=[R_{cond,\ seal}]$, $4.5in<x\leq 4.625in$ *Rx=Rcond, seal, 4.5in<x≤4.625in*

$R(x)=[(1R_{rad,\ ins}+1R_{rad,\ pipe}+1R_{cond,\ air})_{-1}+R_{cond,\ ins}]$, $4.625in<x\leq 8.125in$ *Rx=1Rrad, ins+1Rrad, pipe+1Rcond, air−1+Rcond, ins, 4.625in<x≤8.125in*

Two cases: Solving for Surface temperature and solving for heat flux can be derived as follows:

Case 1:

$Q(x)=T_H(x)-T_{surf}R(x)$ *Qx=THx−TsurfRx*

Case 2:

$T_{surf}(x)=QR(x)+T_H(x)$ *Tsurfx=QRx +THx*

Where,

$\epsilon$=emissivity *ϵ=emissivity*

$\sigma=5.76\times 10_{-8}$ $[Wm_2K_4]$ *σ=5.76×10−8 Wm2K4*

k=conduction coefficient [WmK] *k=conduction coefficient WmK*

x=distance along pipe [m] *x=distance along pipe m*

$T_H$=heat pipe temperature [K] *TH=heat pipe temperature K*

$T_{surf}$=surface temperature [K] *Tsurf=surface temperature K*

$T_{gas}$=gas temperature [K] *Tgas=gas temperature K*

$T_{ins}$=insulation temperature [K] *Tins=insulation temperature K*

$r_1$=radius of heat pipe [m]*r1=radius of heat pipe m*

$r_2$=radius of insulation gap [m]*r2=radius of insulation gap m*

$r_3$=radius of insulation [m]*r3=radius of insulation m*

$R_{cond, He}$=conduction resistance through He*Rcond, He=conduction resistance through He*

$R_{cond, air}$=conduction resistance through air*Rcond, air=conduction resistance through air*

$R_{rad, ins}$=radiation resistance from insulation*Rrad, ins=radiation resistance from insulation*

$R_{rad, pipe}$=radiation resistance from heat pipe*Rrad, pipe=radiation resistance from heat pipe*

$R_{cond, ins}$=conduction resistance through insulation*Rcond, ins=conduction resistance through insulation*

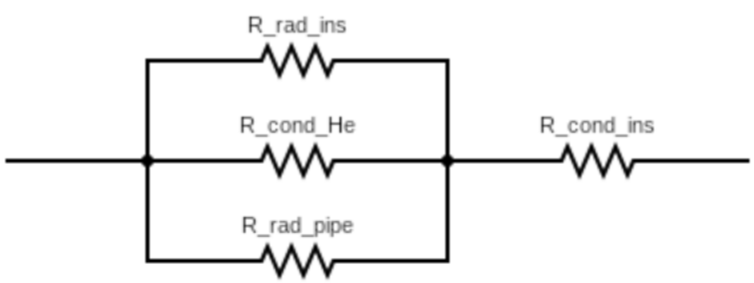



Figure 2: (circuit equivalent model)

Equation solving for case 1 focusing on finding Heat loss is equal to:

$Q(x)=\frac{T_H - T_{surf}}{R(x)}$ *Qx=TH−TsurfRx*

In this case, T_surf is known to be at 400C.

Equation solving for case 2 focusing on finding surface temperature on the surface is a rearranged version of equation above:

$T_{surf}(x) = QR(x) + T_H(x)$ $Tsurfx = QRx + THx$

In this case, Q is known to be 5kW/m^2

The axial temperature distribution within the heat pipe is validated by assuming boundary temperatures at ends A (860°C) and B (840°C), yielding an average operating temperature of 850°C. Thanks to this process, we are able to find changes in axial component of heat flux Q, and generation of temperature profiles along the heat pipe length.

The analytical thermal circuit model provides valuable physical insight and enables rapid parametric exploration, but the complexity of the actual heat pipe geometry, material property variation with temperature, and coupled radiation with conduction phenomena render hand calculations insufficiently accurate for final design validation. Our team will employ ANSYS Tool pack as our primary validation tool to perform thermal simulations of the complete system. The ANSYS finite element model incorporates the full cylindrical geometry with detailed meshing of critical regions and temperature-dependent material properties of insulation package. Simulation will significantly increase validation complexity compared to hand calculations but is justified by the improved accuracy and ability to capture localized thermal effects (hot spots, edge effects, etc.). The ANSYS results will be used as the benchmark for evaluating design performance of the insulation package.

Down Select Approach

To select our final design choice, we are using the materials selection process to select the best insulation material for the project. The first step is Translation, which is used to convert the design requirements outlined in Milestone 1 into constraints, objectives, and free variables. This is shown in the table below:

| | |
|---|---|
| **Constraints** | **Design life** – 12 years<br>**Environment** – Helium (1atm 850°C) and Air (7 atm 400°C)<br>**Structure** – Rigid, fully contained, thickness < 2 in. |
| **Objectives** | **Minimize** - Heat flux (case 1), outer surface temperature (case 2), and cost |

| **Free Variables** | **Material** – Thermal conductivity and emissivity |
|---|---|

The next step is Screening, which applies to the constraints to remove materials that do not meet the minimum requirements. This was performed using ANSYS Granta to initially filter out materials that could not operate at 850°C and withstand a pressure of 7 atm. This is shown in the figure below:

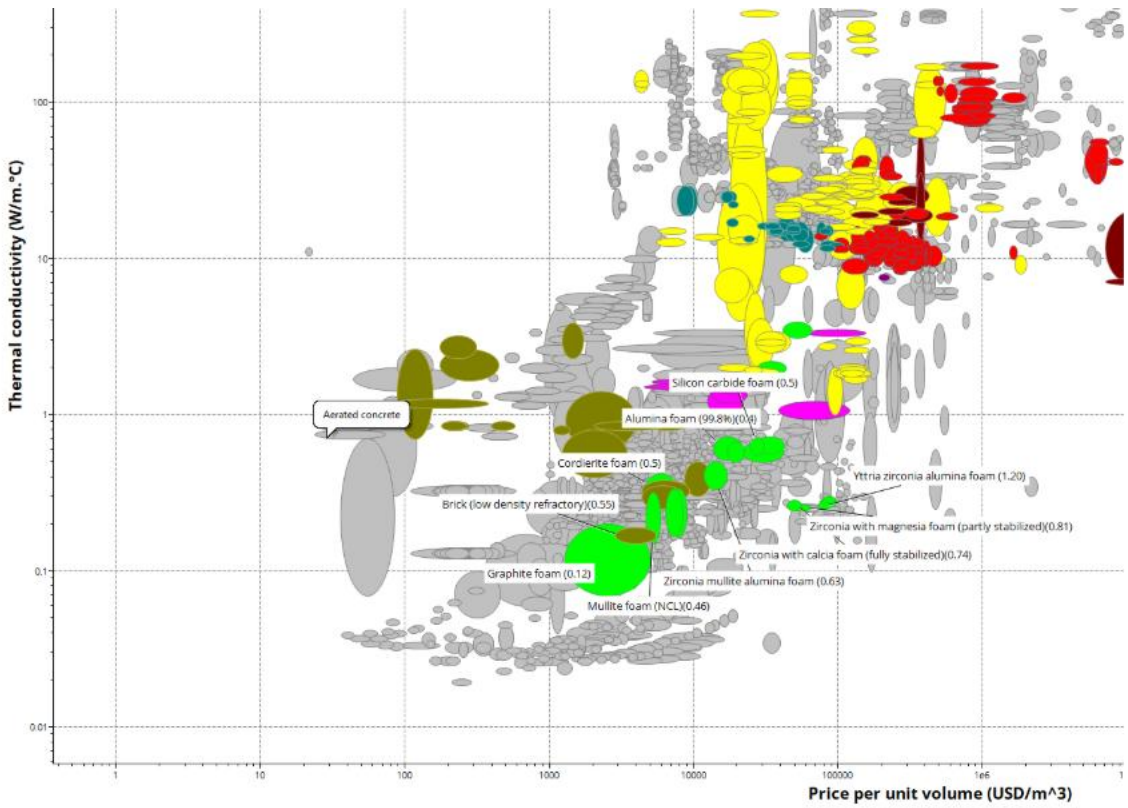



Figure 3: Granta graph – Thermal Conductivity vs. Price per Unit Volume

After Screening, the next step is Ranking which is to quantitatively identify which materials are best for the job. This is going to be done using a materials indice based on the heat transfer equations for Case 1 and Case 2 explained above. From the equations, the materials index is based on the thermal conductivity (k) and the emissivity ($\varepsilon$). This will be used to determine the material with the best combination of these properties.

The last step is Documentation which is to consider high order properties of the material. This includes considering other factors such as manufacturing feasibility, environmental compatibility, safety, etc. This is done by looking into case studies, instances of failure, manufacturing supply, etc. We put these factors into a Pugh chart to make our final selection.

# 11. Preliminary Design Review Comments

Reviewing Peer Team

Team 11
Title: Full Body Recovery Roller System
*Industry Sponsor: Cobra Systems (Mr. Taylor)*
James Hill, David DeFrancisis, Nicholas Chiaro

Peer Team Preliminary Design Review Comments

When discussing with team 8 what additional considerations should be brought to our attention, they suggested that we start broad and then narrow down our selection process. Since there are plenty of materials to choose from that have varying pros and cons, it is important to cast a wide net first but then narrow down the choices effectively. It was suggested that we begin with a large variety of materials from each category and narrow down to subcategories. This ensures that our process considers all materials, and each evaluation result is accounted for. This ultimately allows us to rank results against the ranked characteristics outlined in the Pugh chart.

Additionally, they suggested that we consult a subject matter expert to help us understand the design problem. Additionally, team 8 facilitated conversation regarding mechanical constraints that weren't considered thoroughly in our first milestone. They talked to us through the role of the steel plate, what support might need to be added to the insulation, inner vs outer material, and the potential use of fasteners. Lastly, our peers in class asked us leading questions regarding how we are ranking characteristics of material properties. The class recommended treating the process for each case that we were given in the problem statement to better capture each individual outcome and then move to compare our findings.

Actions

Given the feedback we received, we took action by ensuring that our Granta chart encapsulated broad categories of materials. We looked at the material database and down selected after reviewing the full picture of materials and ultimately each type of material. This was done quantitatively to rank the material packages we were looking at and allowed us to separately down select by material category.

Additionally, we consulted with an SME, Dr. Schmidt, who helped us better understand the flow analysis of our project. This ensured that we were on the right track and able to effectively communicate with our sponsor for additional information. Another SME that the team consulted with was Dr. Harris, who provided additional support on the material selection process, specifically the set up for material indices. This gave us a starting point for our material selection process where we used Granta to compare material performance metrics.

Lastly, mechanical constraints were brought to Westinghouse during a sponsor meeting where we were provided with more insight into what codes and standards to investigate in terms of cycle life and factors of safety. Our sponsor was also able to provide more context to the materials already found in the microreactor design, the validation process they internally conduct, and the preferred materials with more key concerns being outlined. This includes Westinghouse's recommendation to stray away from materials that would damage the reactor system by breaking apart within the environment.

Overall, the peer review allowed us to identify pain points and talk it through with a team with a different perspective. A different lens and the open-minded environment allowed us to take a step back and look for alternate approaches. Taking action and adopting suggested changes helped our team move forward with the project and come up with the right questions to ask moving forward.

# 12. Pugh Chart

| | |
|---|---|
| 1 | Better |
| 0 | Same |
| -1 | Worse |

| Critical to Quality (CTQ) Items | WEIGHT Score of 1 to 10 | General Structural form Concept A: Castable | General Structural form Concept B: Fire Brick | General Structural form Concept C: Foam | General Structural form Concept D: Fiber | Composition Proposal 1: Zirconia | Composition Proposal 2: Silica | Composition Proposal 3: Alumina |
|---|---|---|---|---|---|---|---|---|
| Reliability | 6 | 1 | 0 | 1 | -1 | 0 | 0 | 0 |
| Efficiency | 8 | 0 | 0 | 0 | 1 | 1 | 0 | -1 |
| Cost | 7 | -1 | 1 | 1 | 0 | -1 | 1 | 0 |
| Ease of Implimentation | 5 | 1 | 0 | 0 | -1 | 0 | 0 | 0 |
| Regulatory Compliance | 6 | 0 | -1 | 1 | -1 | 1 | -1 | 0 |
| Meets Design Requirements | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Number of 1 | | 2 | 1 | 3 | 1 | 2 | 1 | 0 |
| Number of 0 | | 3 | 4 | 3 | 2 | 3 | 4 | 5 |
| Number of -1 | | 1 | 1 | 0 | 3 | 1 | 1 | 1 |
| Non-Weighted Solution Scores | | 1 | 0 | 3 | -2 | 1 | 0 | -1 |
| Weighted Solution Scores | | 4 | 1 | 19 | -9 | 7 | 1 | -8 |

Design Options

Figure 4: Pugh Chart

# 13. Adopted Design

Adopted Design

Based on the Pugh chart we selected a zirconia foam insulation design.

Castable insulations are easy to implement since they can be cast to the correct shape which minimizes the need for machining. It is also resistant to breaking when at high temperatures for a long period of time. However, it is significantly more expensive than the other forms of insulation. This additional cost would make it very hard for the students continuing this project to obtain and test the insulation.

Firebrick refractories are ceramic materials usually used to line furnaces, kilns, or other high temperature environments. They have a low thermal conductivity, and depending on the composition, they typically have a low cost. However, firebrick contains elements that are prone to cracking when in an oxygen environment like that in the reactor. Cracked brick may require the reactor to be shut down for repairs which would decrease the design life.

Fiber insulations had some of the lowest costs and thermal conductivities. However, case studies have revealed that fibers from the insulation have been shown to break off and interfere with other reactor components. For this reason, nuclear regulations advise against the use of fiber insulations near critical components. If the insulation were to interfere with the other operations of the reactor, it may need to be shut down for repairs, which would hinder the reactor's ability to reach the design life of 12 years.

Foam insulations have a low thermal conductivity in part due to their low density. This means that they are not difficult to shape. They are also very low cost. Foam insulations are often used in nuclear reactors and are approved by nuclear regulations. For these reasons, we selected foam as the structure of the insulation.

Foam insulations can be made of many different compositions. Graphite foam was immediately eliminated because it cannot withstand the high temperatures of the reactor in combination with the oxygen containing environment in the reactor. This left alumina, silica, and zirconia as potential insulation materials.

Silica is the cheapest of the materials, however it has problems when used in nuclear reactors. The gamma radiation from the reactor core can cause damage to the microstructure of the silica and cause it to break down. This eliminates silica from being a candidate for our design.

Alumina has a significantly higher thermal conductivity than silica and zirconia. While it is affordable and easy to source, the main goal of this project is to minimize heat loss. A material with better insulation properties would better meet the primary function of our design.

Zirconia is the most expensive of the foam materials. However, it also has the lowest thermal conductivity and is the most resistant to radiation. Despite the higher initial cost, zirconia will be more effective in the long run because it will allow less heat loss and will not degrade from the radiation. For this reason we selected a zirconia foam for our design.

Detailed Design Description

The overall project design was in large part outlined by Westinghouse. Their description involved a .5-inch diameter and 8-inch-long heat pipe containing flowing liquid sodium, surrounded by a gap filled with helium at atmospheric pressure on one side of a seal plate, and air at 7 atm on the opposite side. The gap would extend another half inch outward from the pipe, and the seal plate would be made of INCONEL alloy 625 and be .125 inches thick. A diagram of the design is pictured below:

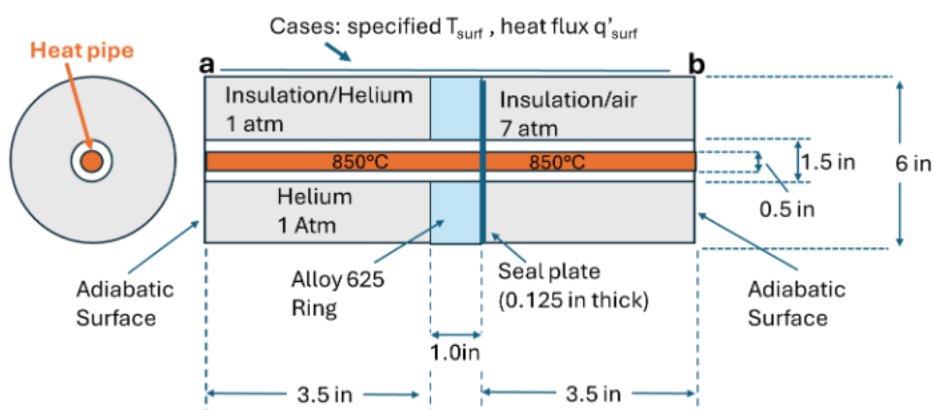



Figure 5: Heat pipe cross-section

Surrounding the entire system is the adopted insulation design we have finalized. The insulation, as decided with the assistance from the Pugh chart is a zirconia foam with a reflective coating on the inner surface.

Bill of Materials

A bill of materials is not applicable for our project.

Anticipated Supporting Analysis

It is anticipated that physical experimental analysis will be performed in the following semesters to validate the calculations and therefore insulation design choice. The physical analysis should include building a test rig that will directly measure the thermal conductivity of the insulation in a non-air environment. The testing conditions should be similar to those of the actual performance requirements listed previously, but do not have to be the same due to feasibility. Once the physical testing has finished, they can determine if a design change is required based on the initial insulation package and the new testing data.

Sponsor Approval

Our sponsor has approved our down selected insulation package. Throughout the term, we have met weekly to update him on our progress. This involved sharing our initial literature review of potential insulation designs and our remaining candidates after screening. Each of which had been approved by the sponsor. We will continue to update our sponsor as we provide more "material selection" based validation metrics to support our finalized design.

# 14. Updated Project Plan

The scope of the project was revised following Milestone 1. This revision is a result of a critical clarification of the boundary conditions realized between the previous second and third milestones. The first project requirement was that both ends of the heat rods of the nuclear microreactor would be adiabatic with a constant temperature of 850°C. However, through our discussions with our faculty advisor and Westinghouse sponsor, Mr. Cerilli, it was determined that this boundary condition was physically inconsistent with the behavior of the system under operation. Since the rods are supposed to be a heat transfer device, they must undergo an energy difference from the inlet to the outlet to effectively simulate thermal performance.

Thus, the new specification for the project, as recommended by our professor Dr. David Schmidt, is to have a linear temperature gradient of 860°C to 840°C along the length of the heat rods. This adjustment accommodates a more realistic thermal condition and enables accurate measurement of how effective the insulation design is. This clarification necessitated revisions in the analytical approach and computational model framework, causing an estimated two-week schedule to shift from the second to the third previous milestones. Please note that the previous final and fifth milestone involving the building of a prototype insulation package has been removed from the project timeline. This change has been made due to previously defined time constraints, and because prototype development was not included within given required project deliverables.

As such, all subsequent effected dates for these milestones have been updated accordingly to reflect this new schedule:

**Milestone 1 (COMPLETE) – Completion of Literature Review and Concept Development**
*Deliverables:* Compiled literature review on insulation performance in microreactors; comparative table of 3–5 potential insulation material packages with estimated $k_{eff}$ and design considerations.
*Evaluation Criteria*: Completeness of references, understanding of primary heat exchanger system, in-depth comparison of insulation designs, 3-5 proposed candidate insulation materials.
*Target Date:* September 30$^{th}$, 2025 (non-negotiable)

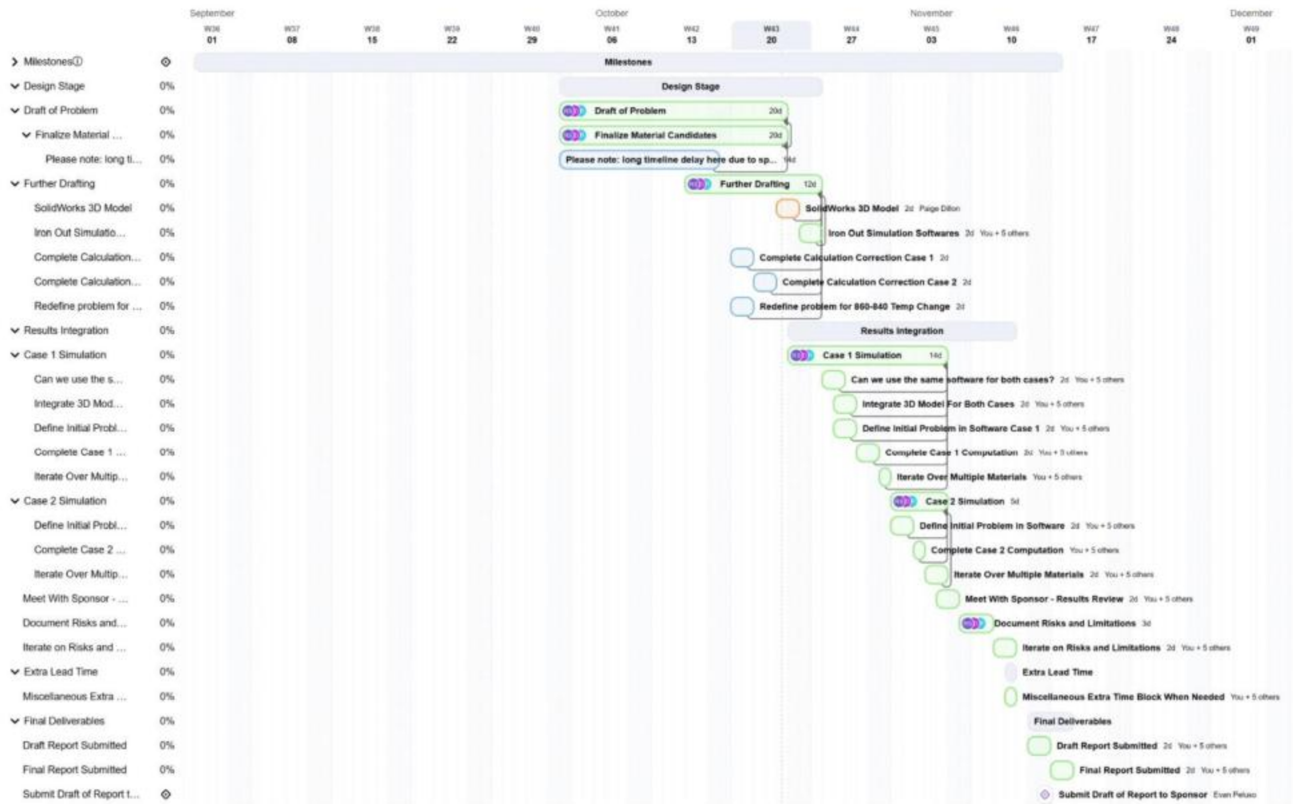
**Milestone 2 (WIP – ALMOST COMPLETE) – Analytical Heat Transfer Analysis**
*Deliverables:* Full (hand) calculations for Case 1 (constant surface temperature, 400°C) and Case 2 (constant heat loss, 5.0 kW/m)
*Evaluation Criteria:* Analytical efficiency comparison of proposed insulation packages, and iterative process to down-select ideal insulation.
*Target Date:* Mid to Late-October 2025

**Milestone 3 – Heat Transfer Analysis (Modeling/Simulation)**
*Deliverables:* Heat transfer model to validate hand calculations; performance comparisons for each insulation candidate under both helium and air environments
*Evaluation Criteria:* Accurate calculations as compared to hand calculations, complete application onto a computational model, analytical comparison of proposed insulation packages, and further iterative processes from CAD results to down select ideal insulation.
*Target Date:* Late-October 2025

**Milestone 4 – Insulation Package Design Finalization**
*Deliverables:* Selection of optimal insulation material and design; finalized CAD drawing and 3D model; datasheets including geometry, $k_{eff}$, heat loss per unit length, temperature distribution, mechanical properties, safety factors, and cost.
*Evaluation Criteria:* Completeness of package design and fulfills project requirements and specifications as described in Westinghouse project description.
*Target Date:* November 17th 2025 (non-negotiable)

# 15. Updated Project Timeline

Our project timeline has been updated bi-weekly to reflect task work, and our project plan is expressed entirely in 1–2-day increments assigned to specific team members.



# 16. Supporting Analysis

## Analysis Approach

The final design includes a complete insulation package that meets the project's requirements and specifications outlined in Milestone 1. To validate this finalized design, the approach focuses on applying each step of the material selection process, supported by heat transfer calculations. The material selection process is a technique from the MEMS course Material Selection (MEMS 1030). The procedure involves 4 key steps – translation, screening, ranking, and documentation. Translation explicitly converts the design requirements into constraints, objectives, and free variables. The screening step then filters out the materials that do not meet these constraints. Completing both steps early in the validation process ensures that the potential design meets the minimum performance criteria.

The next step in the material selection process is ranking. This step quantitatively validates that the chosen design is the best option. Hand calculations were performed on the final design for Case 1 (constant surface temperature) and Case 2 (constant surface heat flux) defined by the sponsor. The hand calculations were performed by utilizing principles from the Heat and Mass Transfer (MEMS 1052). Previous knowledge of using a thermal resistance network provided the ability to combine multiple modes of heat transfer including conduction, convection, and radiation through different sections of the system. This ultimately helped with calculating heat loss, one of the goals of the project, as well as applying the correct cross-sectional area. After setting up the network and defining the boundary conditions, ANSYS CFX was used to have an extra validation step through simulation. In addition, the course Intro to Engineering Computing (ENGR 0012) was also applied to use Excel to calculate and organize the results for each heat transfer case. Excel allowed more efficient computation of results and the ability to plot thermal gradients of the system which supported validation of the simulation results.

The final step is documentation which considers higher order properties to determine the feasibility of implementation. This includes evaluating factors such as manufacturability, supplier availability, cost, and safety. Each factor influences the feasibility of future experimental validation. This process involves looking into supplier databases to compare trade-offs between cost and quality of the insulation, as well as assessing the ability to manufacture components at smaller-scale dimensions for future testing.

## Analysis

The first analysis step we performed was hand calculations of the surface temperature and the heat flux through the system. We first idealized the system as a thermal resistance network, as shown in Figure 1.

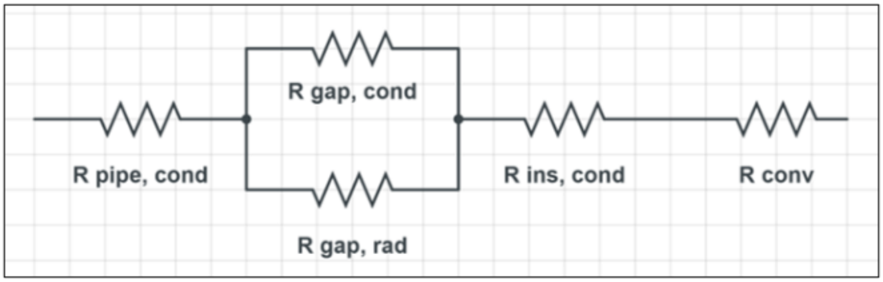


Figure 1: Thermal Resistance Network of heat transfer mechanisms

The thermal resistance from each transfer mechanism can be calculated as follows:

$$R_{cond} = \frac{\ln(\frac{r_2}{r_1})}{2\pi k}$$

$$R_{rad} = \frac{(T_2 - T_1)(\frac{1}{\epsilon_1} + \frac{1-\epsilon_2}{\epsilon_2}\left(\frac{r_1}{r_2}\right))}{2\pi r_1 \sigma (T_2^4 - T_1^4)}$$

$$R_{conv} = \frac{1}{2\pi r h}$$

$$q' = \frac{\Delta T}{R}$$

T= $T=$
Temperature [K]
ϵ= $\epsilon=$
Emissivity
k= $k=$
Thermal conductivity [W/m*K]
h= $h=$
Convection coefficient [W/m$^2$*K]
q′= $q'=$
Heat flux [W/m]
σ= $\sigma=$
Boltzmann constant [W/m$^2$*K$^4$]
r= $r=$
Radius [m]

The heat flux will be the same at each node of the system, so four equations for heat flux can be derived as follows:

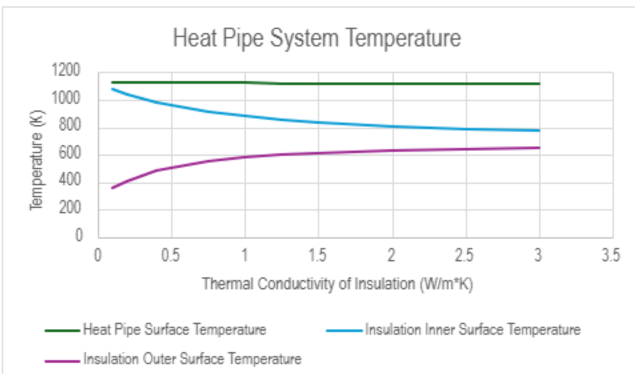
$$1.\; q' = \frac{T_{pipe,outer} - T_{pipe,inner}}{R_{pipe,cond}}$$

$$2.\; q' = \frac{T_{ins,\,inner} - T_{pipe,outer}}{\left(\frac{1}{R_{gap,cond}} + \frac{1}{R_{gap,rad}}\right)^{-1}}$$

$$3.\; q' = \frac{T_{ins,outer} - T_{ins,inner}}{R_{ins,cond}}$$

$$4.\; q' = \frac{T_{\infty} - T_{ins,outer}}{R_{conv}}$$

There are four unknown variables:
$T_{pipe,\,outer}$, $T_{ins,\,inner}$, $T_{ins,\,outer}$, $q'$
. Since there are four equations and four unknown variables, we can solve for the temperatures and the heat flux for different values of thermal conductivity of the insulation as shown in Figure 2.



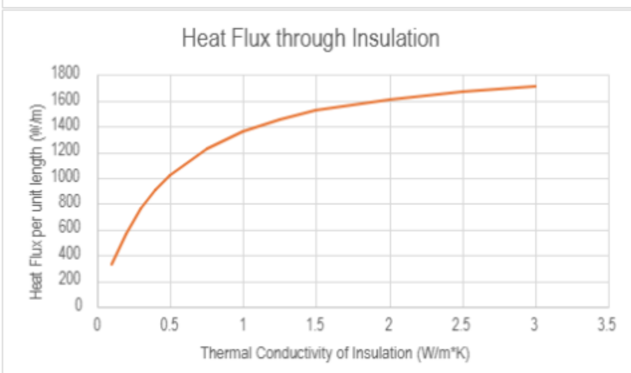




Figure 2: Graph of how temperature and heat flux vary with thermal conductivity of the insulation

Simulation in ANSYS CFX was performed using a model of heat pipe and insulation assembly created in SolidWorks (Figure 6). Our team considered only a quarter of the full assembly (Figure 7) and decided to apply symmetric boundaries later on to make the simulation faster and save computational data. At the central location of the model, where the heat pipe is located, a fine mesh was created that scales down to coarser mesh as the radius gets higher; that ensures the simulation was run precisely. Several assumptions were applied in the simulation: both ends of the model were treated as adiabatic surfaces, the system was considered to be in a steady state, and the heat-pipe surface temperature was held constant, radiation being dominant heat transfer mode in the gas gap region, conduction through heat pipe wall as well as insulation package. The boundary conditions included convection heat transfer at the outer surface of the insulation to replicate the conditions of the experimental test rig.

The simulation results shown in Figure 3, Figure 4, and Figure 5 show the contour of the temperature profile. We can clearly see the different temperature contours at different stages of the assembly. Figure 3 shows a temperature profile plotted as unit length vs temperature that allowed us to extract a more precise temperature. Simulation data matched very closely with the hand calculations made prior to the simulation.

From the simulation images in Figures 3 and 4, we can see that the selected insulation material performs well for this application, effectively retaining most of the heat as intended. In Figure 5, the different slopes represent transitions between various sections of the model, aligning with our expectations: the steepest and most rapid temperature change occurs closest to the pipe, while the lowest temperature gradient appears across the insulation layer. This confirms that the insulation package is functioning as designed.

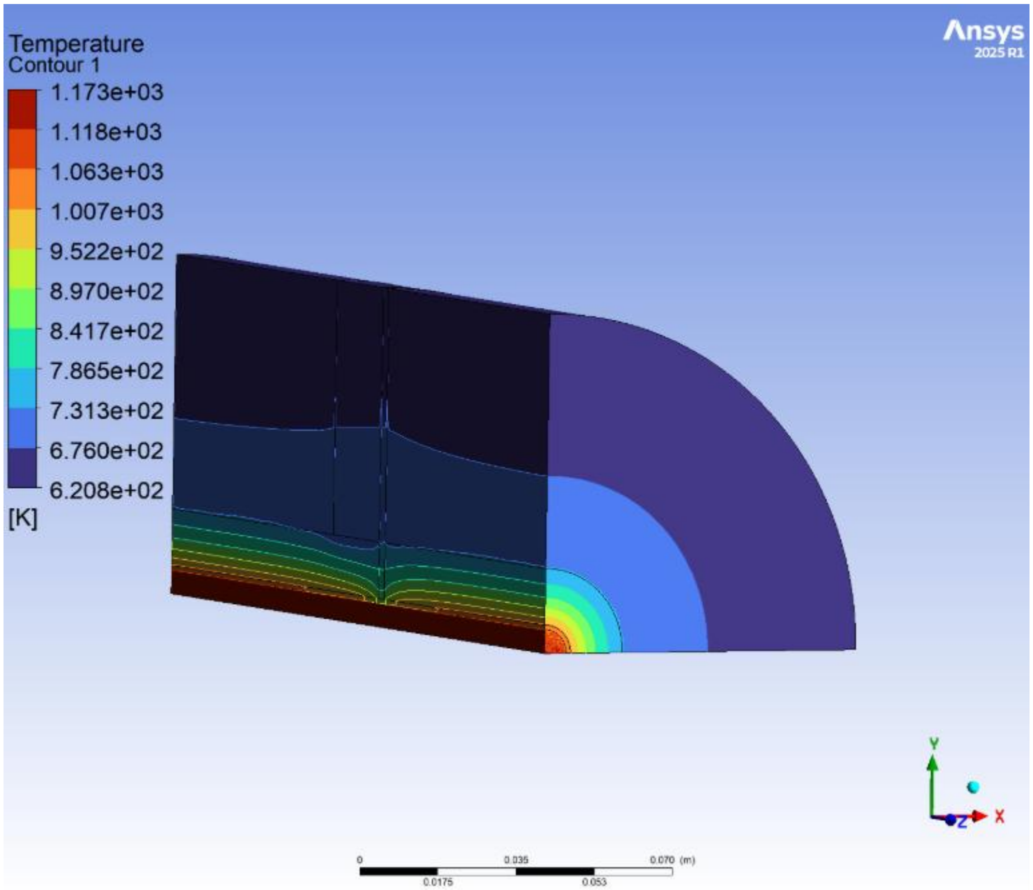


Figure 3 (isometric view of temperature contour of simulation in ANSYS CFX)

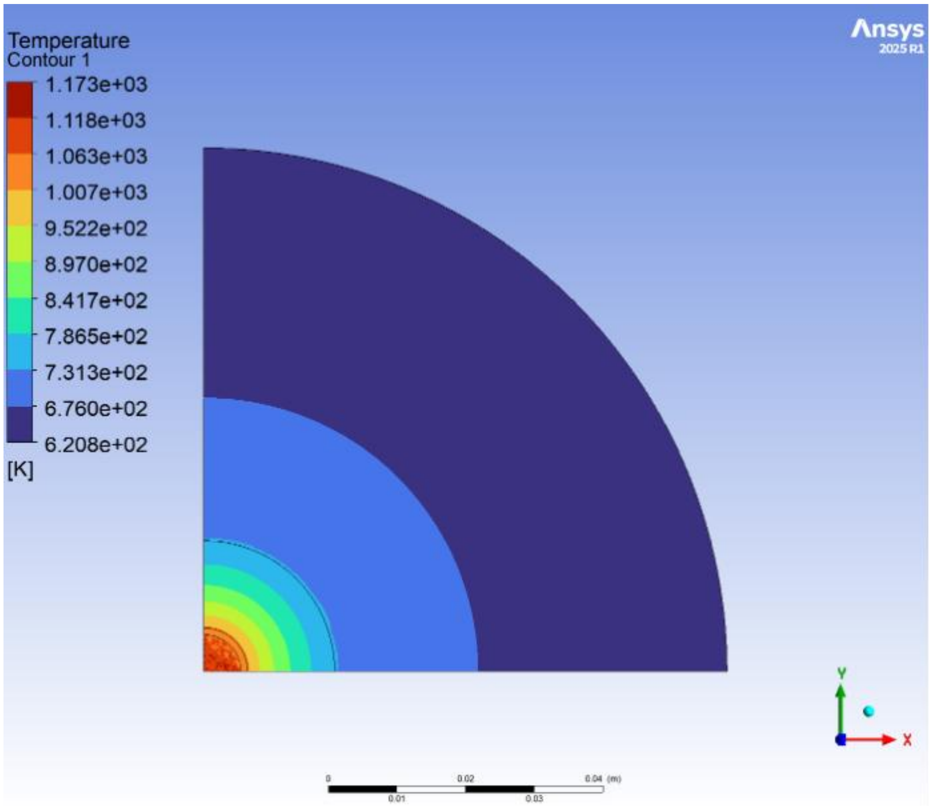



Figure 4 (temperature profile in simulation ANSYS CFX)

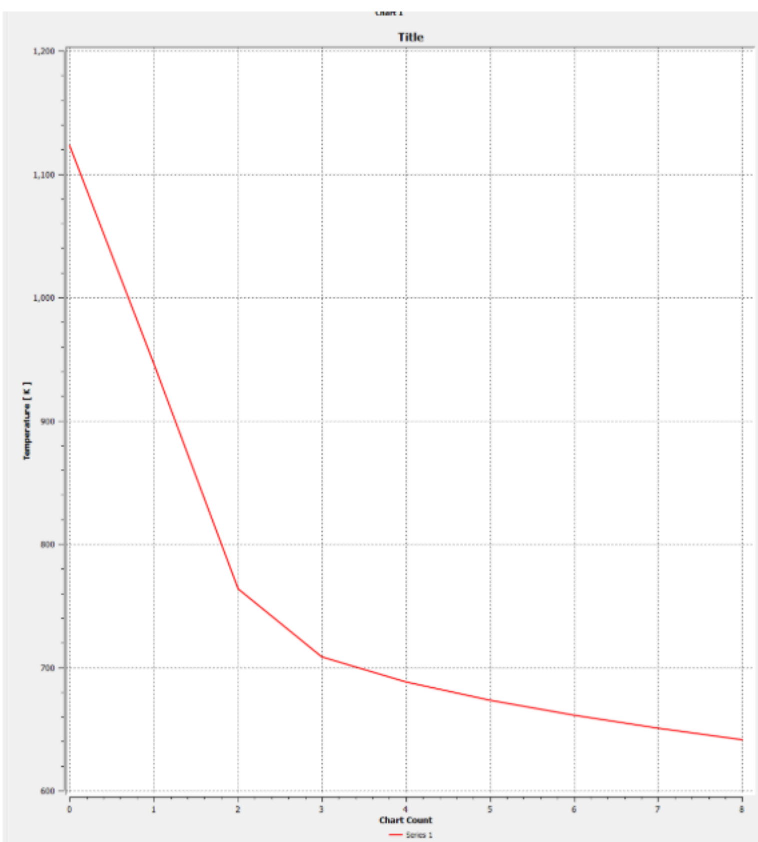


Figure 5 (Unit length vs Temperature plotted using data from simulation)

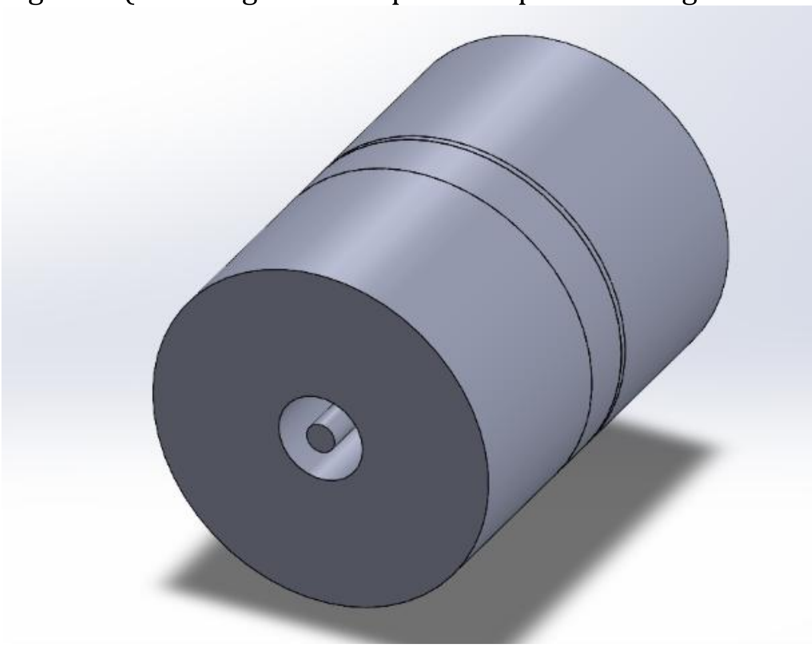


Figure 6 (original SolidWorks model of entire assembly)

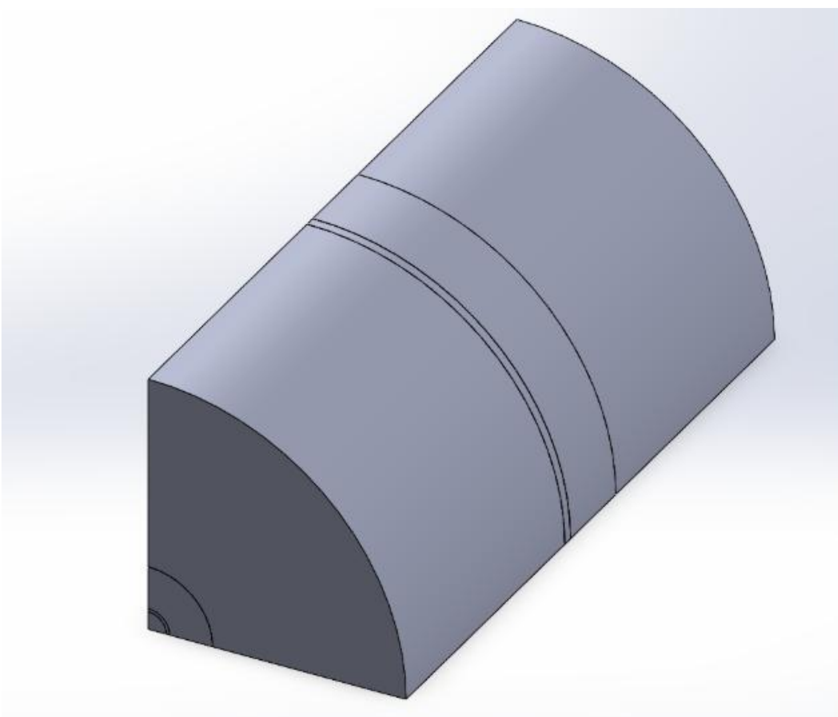


Figure 7 (Quarter of the assembly model in SolidWorks)

Requirements and Specifications

The following table indicates which method was used to address the corresponding requirements and specifications.

| | Helium Environment | High temperatures | Workability | Feasibility | Insulator | Cost effective |
|---|---|---|---|---|---|---|
| Hand Calculation | ✓ | ✓ | | | ✓ | |
| ANSYS CFX | ✓ | ✓ | | | ✓ | |
| ANSYS Granta | | | | | ✓ | ✓ |
| Supplier information | | ✓ | ✓ | ✓ | ✓ | ✓ |

# 17. Archive & Cleanup Plan

Archive Plan

The final digital deliverables for the entire project will be transmitted to the sponsor in an organized package by email. The submission package will include the final heat transfer equations, ANSYS CFX project files, ANSYS meshing files, supporting hand calculations, and simulation outputs that were compiled in Excel. The finalized material data sheet and supplemental documents will be packaged into a .ZIP archive and sent via email for convenience of transfer. All written documentation included in the project binder will be combined into one PDF. This document will be included in the final deliverable folder for the sponsor alongside the digital files.

The complete set of semester resources will be saved on the team's OneDrive to ensure continuity and straightforward future developments. Access to this repository will be maintained by future project teams. The OneDrive directory will be fully accessible for the follow-on team next semester, for them to use as a starting point in their developments. In doing so, the future team will be in a good position to supplement the current computational work by designing and constructing a physical test rig to experimentally validate the results coming from the simulation.

Clean Up Plan

Since this project does not involve physical deliverables, there is no need to include a cleanup plan.

# 18. Final Deliverables

The final deliverables package includes complete documentation and analysis of the insulation material selection process, supporting calculations, computational modeling, and final material recommendations. All deliverables are summarized below, along with the differences from the original project deliverable plan and sponsor approval status.

<u>Material Selection Documentation</u>

- A clearly documented material selection approach supported by literature review of potential insulation types
  - e.g. fibers, aerogels, bricks, castables, and metallic materials.
- Justification is provided for materials excluded from consideration and for the final selection of refractory bricks as the preferred insulation type
- The screening process used Granta EduPack plots to filter out materials that did not meet the minimum constraints defined by our project sponsor
- A ranking process evaluated a range of thermal conductivity values and corresponding system performance in the two defined analysis cases.

<u>Hand Calculations</u>

- The expressions for heat transfer across the system were defined by hand utilizing a thermal resistance network
- Two distinct cases were analyzed:
  - Case 1: Natural convection in air at room temperature ($h = 10$ W/m²·K, $T_\infty = 25$ °C). The surface heat flux was solved, and the corresponding thermal gradient was visualized.
  - Case 2: Constant surface heat flux (5 kW/m²). The surface temperature and complete radial temperature profile were computed and plotted.
- Calculations were performed over a range of insulation thermal conductivities
- Results for both cases were generated in Excel with visual representations of the temperature distributions and gradients

<u>Computational Simulations</u>

- ANSYS CFX simulations were performed in correspondence with the hand calculations to visualize the thermal performance of the system under both boundary conditions
- Deliverables include:
  - .cfx5 and .cfx files (CFX-Pre setup with full geometry, boundary conditions, and material properties)
  - .res files (solver output), compatible with CFX-Post for post-processing
    - Ability to extract results depending on which case

- Temperature contour plots and profiles for each thermal conductivity case tested

Final Material Datasheet and Recommendations

- A compiled datasheet summarizing recommended insulation materials and suppliers, including composition, thermal conductivity, compressive strength, and cost.
  - Each recommendation is directly supported by analytical and computational results for Case 1 and Case 2
  - Defines the maximum thermal conductivity needed to meet the maximum allowable values of surface temperature (400°C) and surface heat flux (5 kW/m)
- Any insulation with a k value meeting these constraints was considered acceptable
  - The final recommendation balances thermal performance and cost to guide future team on choosing viable materials to physically test

Differences from Original Project Plan

- Case 1 boundary condition was modified from a constant surface temperature of 400 °C to a more realistic natural convection condition
- System design was updated to include heat conduction through the heat pipe wall to provide a more complete thermal model
- The material testing plan was refined
  - Instead of selecting 3–5 specific materials for direct comparison, we used a continuous parameter sweep across realistic k-values to find the maximum k that meets the system requirements
  - Due to the large variability in available compositions, suppliers, and costs

Sponsor Approval

Mr. Cerilli has reviewed and approved the final deliverable package. Our team met consistently to present progress, clarify objectives, and confirm alignment with project goals. A weekly in-person meeting with the Westinghouse team helped refine our system definition and constraints, allowing us to make improvements to the original project plan. Throughout every iteration, our sponsor approved all modifications to the project deliverables.

# 19. Design Validation

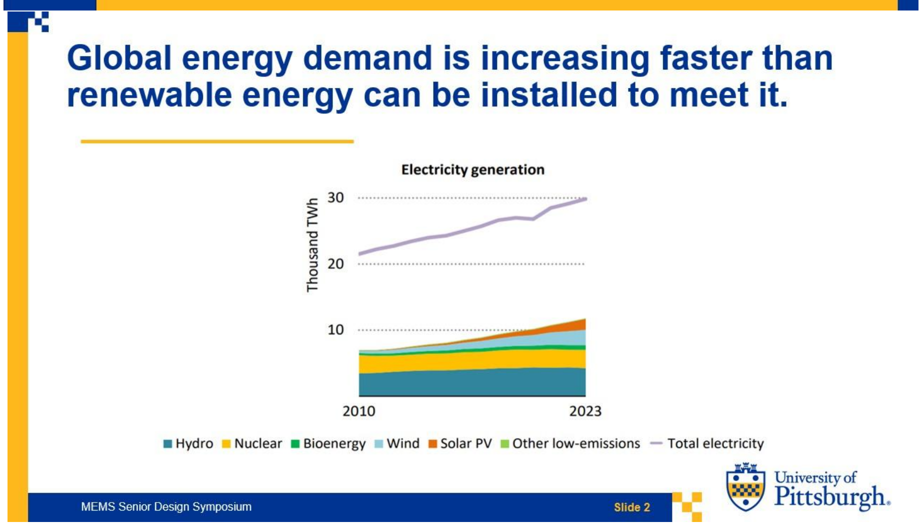
The final insulation design was validated by systematically applying the full material selection methodology (translation, screening, ranking, and documentation) supported by analytical heat transfer calculations and ANSYS CFX simulations. Translation and screening established the required constraints and removed materials that failed to meet minimum thermal performance criteria while ranking quantitatively confirmed that the selected insulation meets system requirements under both sponsor-defined boundary conditions. Validation incorporated thermal resistance network hand calculations, simulation of the full geometry in ANSYS CFX, and Excel-based computation and plotting to compare analytical and numerical results.

The documentation step evaluated higher order feasibility factors, including manufacturability, supplier availability, cost, and safety. This ensures that the design could be realistically implemented in future testing. All performance requirements were achieved using a continuous sweep of thermal conductivity values rather than a discrete set of candidate materials. This represented an improvement to the original plan, justified by variability in commercial compositions. The only modified requirement was the boundary condition for Case 1, which changed from a fixed 400 °C surface temperature to a more realistic natural convection condition.

Throughout the project, the validation approach, system assumptions, and all modifications to the original deliverable plan were reviewed and approved by the sponsor, confirming that the final design meets the primary project objectives.

# 20. Symposium Presentation

The following slideshow was presented at the symposium on November 19, 2025.

## Nuclear energy can provide electricity without emissions, but it requires investment of time, money, and space.

MEMS Senior Design Symposium Slide 3

University of Pittsburgh

## Westinghouse is designing the eVinci microreactor to meet the energy demands of remote, critical energy areas.

Military bases

Industrial Sites

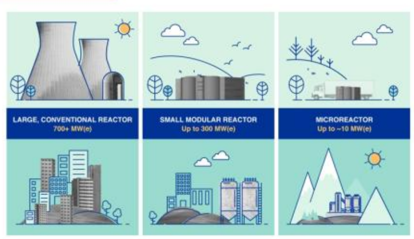
Remote Communities

Data Centers


MEMS Senior Design Symposium Slide 4

University of Pittsburgh

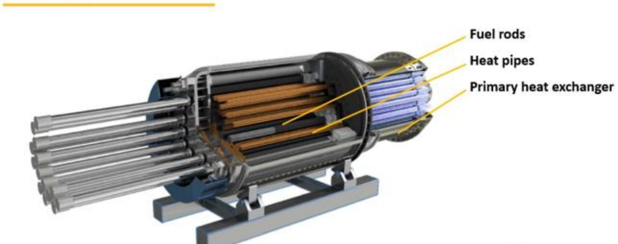
## The eVinci microreactor is easier to manufacture, transport, and operate than a traditional nuclear reactor.




MEMS Senior Design Symposium Slide 5

University of Pittsburgh

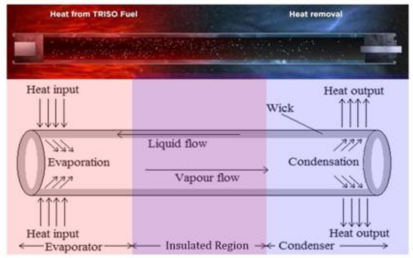
## Heat generated in the core of the eVinci is transferred to the primary heat exchanger using heat pipes.




MEMS Senior Design Symposium Slide 6

University of Pittsburgh

## Efficient operation of the eVinci reactor requires effective insulation of the heat pipes.



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## Project Goal and Deliverables

**Design an insulation package that meets given requirements in the helium environment**

**Thermal Simulation of Heat Pipe System**

- Temperature profile of the system
- Heat flux through surface of the insulation

**Material Datasheet**

- Material properties (Composition, grade, operating temperature, conductivity, strength, cost, etc).



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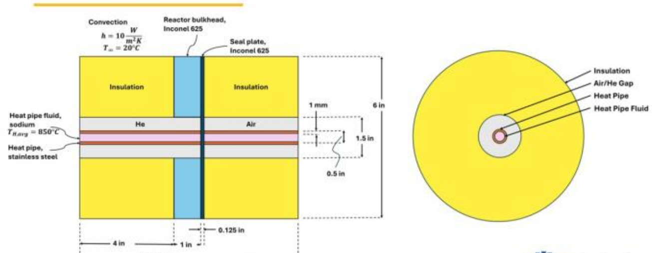
## We designed a schematic to model the heat transfer conditions reflecting the future testing environment.

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## Different insulation materials show variation in thermal and mechanical properties, requiring a structured material selection approach.


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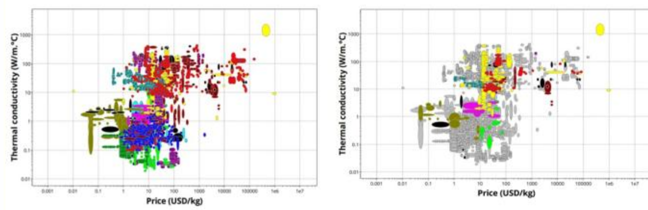
## Translation - converting design requirements into constraints, objectives, and free variables.

| | |
|---|---|
| **CONSTRAINTS** | **Design life** – 12 years<br>**Environment** - Helium (1 atm) and air (7 atm)<br>**Structure** – Rigid, fully contained, thickness ≤ 2.25 in.<br>**Thermal Performance** – Max surface heat flux (5 kW/m) and max surface temperature (400°C) |
| **OBJECTIVES** | **Minimize** – surface heat flux and surface temperature, balance with cost |
| **FREE VARIABLES** | **Material** – thermal conductivity and emissivity |

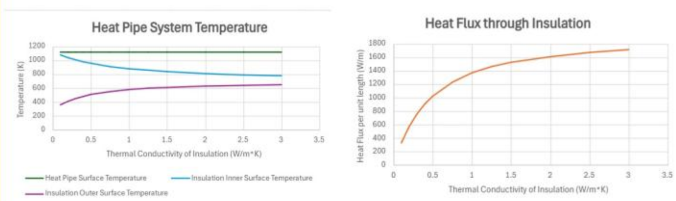
MEMS Senior Design Symposium Slide 11 University of Pittsburgh

## Screening – Apply constraints to remove materials that don't meet minimum requirements.



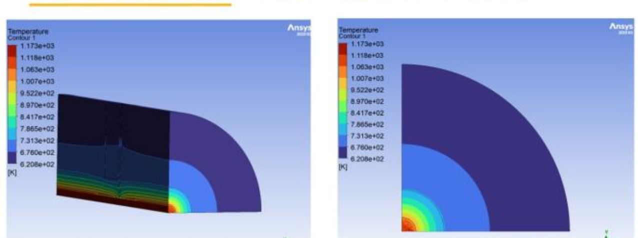

MEMS Senior Design Symposium Slide 12 University of Pittsburgh

## Ranking – Quantitatively identify which materials are the best for the job.




MEMS Senior Design Symposium Slide 13 University of Pittsburgh

## A simulation was performed to validate the hand calculation and material choice.




MEMS Senior Design Symposium Slide 14 University of Pittsburgh

## Documentation – Consider higher order properties to determine feasibility of implementation.

| | |
|---|---|
| Hot Face Environment | Exposed to helium; inert gas |
| Structural Loading | Minimal loading with pressure up to 7 atm (~0.7MPa) |
| Thermal Cycling | Insulation section is ideally isothermal |
| Cost vs Performance | Balance between optimizing performance vs. cost |
| Manufacturing | Machinability, testable sizes, and multiple supplier options |
| Safety | Minimize risk to reactor components |

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MEMS Senior Design Symposium Slide 15

## Documentation – Consider higher order properties to determine feasibility of implementation.

| | |
|---|---|
| Hot Face Environment | Exposed to helium; inert gas |
| Structural Loading | Minimal loading with pressure up to 7 atm (~0.7MPa) |
| Thermal Cycling | Insulation section is ideally isothermal |
| Cost vs Performance | Balance between optimizing performance vs. cost |
| Manufacturing | Machinability, testable sizes, and multiple supplier options |
| Safety | Minimize risk to reactor components |

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MEMS Senior Design Symposium Slide 16

## Documentation – Consider higher order propertiesto determine feasibility of implementation.


Refractory Ceramic Fibers (RFCs)


Aerogels


Dense Refractory Brick

University of Pittsburgh

Slide 17

## Documentation – Consider higher order propertiesto determine feasibility of implementation.


Refractory Ceramic Fibers (RFCs)

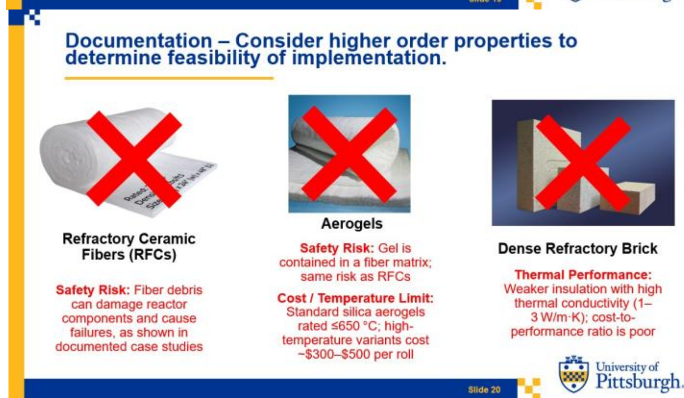
**Safety Risk:** Fiber debris can damage reactor components and cause failures, as shown in documented case studies

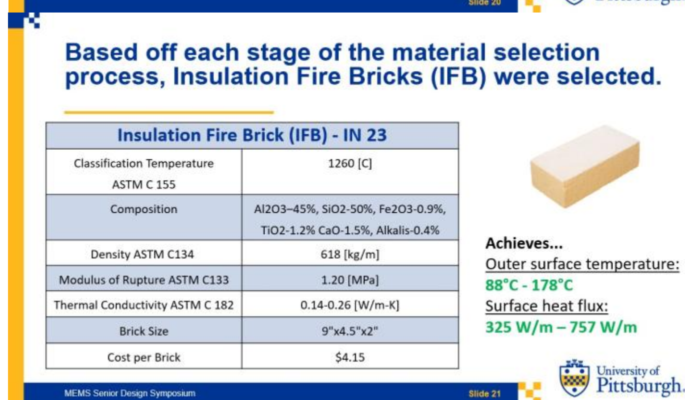

Aerogels


Dense Refractory Brick

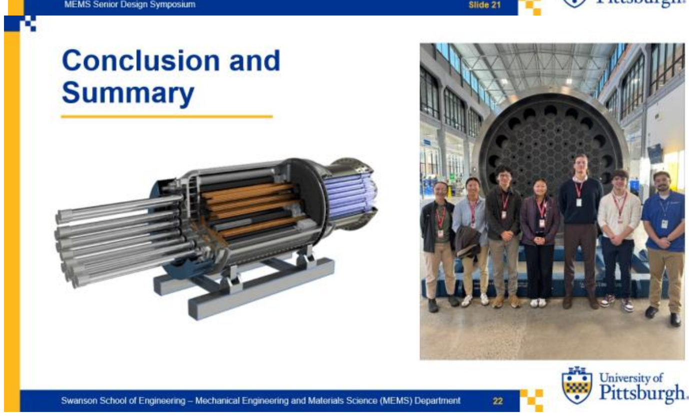
University of Pittsburgh

Slide 18


| Insulation Fire Brick (IFB) - IN 23 | |
|---|---|
| Classification Temperature ASTM C 155 | 1260 [C] |
| Composition | Al2O3–45%, SiO2-50%, Fe2O3-0.9%, TiO2-1.2% CaO-1.5%, Alkalis-0.4% |
| Density ASTM C134 | 618 [kg/m] |
| Modulus of Rupture ASTM C133 | 1.20 [MPa] |
| Thermal Conductivity ASTM C 182 | 0.14-0.26 [W/m-K] |
| Brick Size | 9"x4.5"x2" |
| Cost per Brick | $4.15 |



## Westinghouse site tour to discuss heat loss roadblocks

- Viewed full-scale Modular Design Unit (MDU) of reactor core
- Met with the Westinghouse eVinci design team
- Gathered counsel on how to proceed
- Left with an alternative project description of the insulation package



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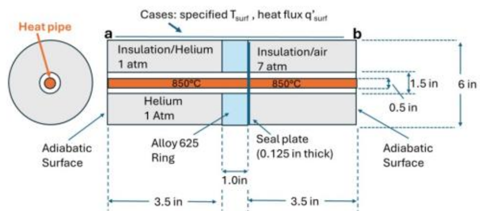
## Heat loss analysis could not be conducted based on provided requirements.



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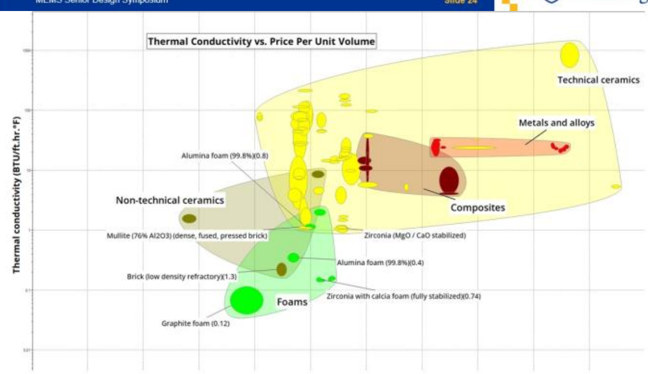


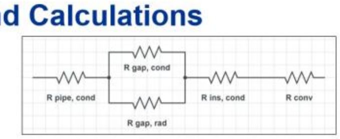

## Heat Transfer Hand Calculations

$$R_{cond} = \frac{\ln(\frac{r_2}{r_1})}{2\pi k}$$

$$R_{rad} = \frac{(T_2 - T_1)(\frac{1}{\epsilon_1} + \frac{1-\epsilon_2}{\epsilon_2}\left(\frac{r_1}{r_2}\right))}{2\pi r_1 \sigma (T_2^4 - T_1^4)}$$

$$R_{conv} = \frac{1}{2\pi r h}$$

$$q' = \frac{\Delta T}{R}$$




**4 Equations**

1. $q' = \frac{T_{pipe,outer} - T_{pipe,inner}}{R_{pipe,cond}}$
2. $q' = \frac{T_{ins,inner} - T_{pipe,outer}}{(\frac{1}{R_{gap,cond}} + \frac{1}{R_{gap,rad}})^{-1}}$
3. $q' = \frac{T_{ins,outer} - T_{ins,inner}}{R_{ins,cond}}$
4. $q' = \frac{T_{\infty} - T_{ins,outer}}{R_{conv}}$

**4 Free Variables**

1. $q'$
2. $T_{pipe,outer}$
3. $T_{ins,inner}$
4. $T_{ins,outer}$



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## Heat Transfer Hand Calculation

- $K_{SS316}$ = 25.4 W/m-K
- $K_{He}$ = 0.067 W/m-K
- $\varepsilon_{ins}$ = 0.7
- $\varepsilon_{SS316}$ = 0.8

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Slide 27

| k [W/m*K] | Rcond,ins | q' | Heat Pipe Surface Temp [K] | Insulation Inner Surface Temp [K] | Insulation Outer Surface Temp [K] | in c |
|---|---|---|---|---|---|---|
| 0.1 | 2.206356002 | 325.1 | 1122 | 1078 | 361 | 88 |
| 0.2 | 1.103178001 | 569.6 | 1122 | 1040 | 412 | 139 |
| 0.3 | 0.735452001 | 757.5 | 1122 | 1008 | 451 | 178 |
| 0.4 | 0.551589 | 904.9 | 1122 | 981 | 482 | 209 |
| 0.5 | 0.4412712 | 1022.6 | 1122 | 958 | 507 | 234 |
| 0.75 | 0.2941808 | 1231.1 | 1122 | 912 | 550 | 277 |
| 1 | 0.2206356 | 1365.2 | 1122 | 879 | 578 | 305 |
| 1.25 | 0.17650848 | 1457.3 | 1121 | 855 | 597 | 324 |
| 1.5 | 0.1470904 | 1523.8 | 1121 | 835 | 611 | 338 |
| 2 | 0.1103178 | 1612.9 | 1121 | 808 | 630 | 357 |
| 2.5 | 0.08825424 | 1669.2 | 1121 | 789 | 642 | 369 |
| 3 | 0.0735452 | 1707.9 | 1121 | 775 | 650 | 377 |

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Slide 28

## Insulation Fire Bricks (IFBs)

**What They Are**

- Lightweight refractory bricks engineered for thermal insulation at high temperatures
- Common commercial compositions:
  - Alumina–silicate (most widely used)
  - Silicate-based IFBs (lower temperature grades)
  - Lightweight corundum (high-alumina, higher strength, higher service temperature)
- Microstructure: high porosity, fine cellular pores, and lightweight crystalline phases
- Higher alumina content + higher firing temperature → higher classification temperature
  - Max operating temperature typically ~100 °C lower than classification temperature
- Classified under ASTM C155 into 4 groups based on density, composition, and service temperature
- Cast IFBs generally show better uniformity and thermal performance than cement-bonded IFBs

**ASTM C-155 Guidelines**

| IFB Classification | Shrinkage < 2% after 24hrs at | | Maximum Density | |
|---|---|---|---|---|
| Groups | °F | °C | lb/ft³ | kg/m³ |
| Group 16 | 1550 | 845 | 34 | 545 |
| Group 20 | 1950 | 1065 | 40 | 641 |
| Group 23 | 2250 | 1230 | 48 | 769 |
| Group 26 | 2550 | 1400 | 54 | 865 |
| Group 28 | 2750 | 1510 | 60 | 961 |
| Group 30 | 2950 | 1620 | 68 | 1089 |
| Group 32 | 3150 | 1730 | 95 | 1522 |
| Group 33 | 3250 | 1790 | 95 | 1522 |

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Slide 29

## Insulation Fire Bricks (IFBs)

**Advantages**

- High operating temperature capability, suitable for >1000 °C applications
  - Higher alumina IFBs can support up to 1400–1600 °C depending on grade
- Cost-effective
  - Typical price range \$4–\$22 per brick; Lower-temp grades (adequate for our design) are inexpensive
- Low thermal conductivity
  - Typical k = 0.14–0.48 W/m·K (varies with density and grade)
  - Fine pore structure disrupts solid conduction and reduces gas conduction
  - Closed-cell porosity lowers radiative heat transfer at high temperature
- Lightweight
  - Densities commonly 0.6–1.2 g/cm³, much lower than hard refractory bricks
- Chemically stable in oxidizing environments
  - Stable in air and helium (helps for sealed R&D setups)
- Easy to work with
  - Can be cut, shaped, and drilled using simple tools (hacksaw, bandsaw, drill press)
  - Allows custom fits for cylindrical assemblies or test articles

**Disadvantages**

- Higher thermal conductivity compared to ceramic fiber blankets or aerogel materials
- Lower mechanical strength
  - High apparent porosity → reduced compressive strength
  - Acceptable for our design due to low mechanical stresses
- Poor wear resistance
- Not suited for environments with erosion, abrasion, or high gas velocities

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Slide 30

## IFB Properties

| Properties | Unit | IN-23 | IN-26 | IN-28 | IN-30 |
|---|---|---|---|---|---|
| Classification Temperature ASTM C 155 | °F | 2300 | 2600 | 2800 | 3000 |
| | °C | 1260 | 1427 | 1538 | 1649 |
| Density ASTM C 134 | $lb/ft^3$ | 39 | 50 | 55 | 65 |
| | $kg/m^3$ | 618 | 801 | 881 | 1036 |
| Modulus of Rupture ASTM C 133 | $lb/in^2$ | 124 | 247 | 290 | 450 |
| | MPa | 0.85 | 1.70 | 2.0 | 3.10 |
| Cold Crushing Strength ASTM C 210 | $lb/in^2$ | 174 | 377 | 435 | 609 |
| | MPa | 1.20 | 2.60 | 3.00 | 4.20 |
| Percent Linear Change 24hrs @ Soaking Temp. ASTM C 210 | °F \| °C | | | | |
| | 2250 \| 1232 | 0.0 % | - | - | - |
| | 2550 \| 1399 | - | -0.4 % | - | - |
| | 2750 \| 1510 | - | - | -0.7 % | - |
| | 2950 \| 1621 | - | - | - | -0.7 % |
| | 3150 \| 1732 | - | - | - | - |
| Thermal Conductivity ASTM C 182 | Btu-in/ft²,hr,°F (W/mk) °F \| °C | | | | |
| | 500 \| 260 | 1.0 (0.14) | 1.6 (0.23) | 2.3 (0.33) | 2.8 (0.40) |
| | 1000 \| 538 | 1.3 (0.19) | 1.9 (0.27) | 2.4 (0.35) | 2.9 (0.42) |
| | 1500 \| 816 | 1.6 (0.23) | 2.2 (0.32) | 2.6 (0.37) | 3.1 (0.45) |
| | 2000 \| 1093 | 1.8 (0.26) | 2.6 (0.37) | 2.7 (0.39) | 3.3 (0.48) |
| Chemical Composition *% | $Al_2O_3$ | 45 | 51 | 64 | 72 |
| | $SiO_2$ | 50 | 43 | 33 | 26 |
| | $Fe_2O_3$ | 0.9 | 0.8 | 0.7 | 0.5 |
| | $TiO_2$ | 1.2 | 1.3 | 0.9 | 0.5 |
| | CaO & MgO | 1.5 | 1.5 | 1.0 | 0.3 |
| | Alkalies, as $Na_2O$ & $K_2O$ | 0.4 | 0.4 | 0.4 | 0.2 |

# Refractory Ceramic Fibers (RCFs)

**What It Is**

- Man-made aluminosilicate fibers (ASW: aluminum silicate wool)
  - Produced by melting + blowing/spinning calcined kaolin or $Al_2O_3$–$SiO_2$ mixes (≈50/50 wt%)
- AES wool (alkaline-earth silicate) = biosoluble, made from CaO–MgO–$SiO_2$ formulations
  - Safer for lungs; dissolves more easily in the body
  - Lower chemical resistance; prone to recrystallization
  - ~1150 °C continuous-use rating

**Forms**

- Blankets (most common): high porosity, binder-free, flexible
- Also available as modules, papers, boards, textiles, foams, adhesives, and coatings


Slide 32

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**HIGH TEMPERATURE INSULATION WOOL (HTIW)**

| HTIW Grades | | Chemical Composition | Acid / Alkaline | Max Temp. | Continuous Use Temp. | Typical Service Temp. | Melting Point | Mean Fiber Length | Thermal Shock Sensitivity | Bulk Density |
|---|---|---|---|---|---|---|---|---|---|---|
| RCF | AES Wool | CaO 27 - 32 %, MgO 2 - 6 %, $SIO_2$ 61 - 68 % | - / + | 1260°C 2300°F | 1150°C 2102°F | < 1000°C < 1832°F | ≈ 1300°C ≈ 2372°F | 1 - 4.5 µm | + | 64-128 $kg/m^3$ 4 - 8 $lb/ft^3$ |
| RCF | Aluminum Silicate Wool | $Al_2O_3$ 47 - 49%, $SIO_2$ 50 - 52% | + / - | 1260°C 2300°F | 1180°C 2156°F | < 1150°C < 2102°F | ≈ 1760°C ≈ 3200°F | 1 - 4.5 µm | ++ | 64-160 $kg/m^3$ 4 - 10 $lb/ft^3$ |
| RCF | Aluminum Silicate Wool | $Al_2O_3$ 35 - 40%, $SIO_2$ 38 - 50%, $ZrO_2$ 15 - 17% | + / - | 1427°C 2600°F | 1343°C 2450°F | < 1300°C < 2372°F | ≈ 1760°C ≈ 3200°F | 1 - 4.5 µm | ++ | 96-160 $kg/m^3$ 6 - 10 $lb/ft^3$ |
| PCW | Polycrystalline Wool | $Al_2O_3$ 72 - 80%, $SIO_2$ 20 - 28% | +/+ | 1649°C 3000°F | 1600°C 2912°F | < 1600°C < 2912°F | ≈ 1871°C ≈ 3400°F | 1 - 4.5 µm | ++ | 96-160 $kg/m^3$ 6 - 10 $lb/ft^3$ |
| PCW | Polycrystalline Wool | $Al_2O_3$ 95 - 97%, $SIO_2$ 3 - 5% | +/+ | 1800°C 3272°F | 1650°C 3002°F | < 1650°C < 3002°F | ≈ 2000°C ≈ 3600°F | 1 - 4.5 µm | ++ | 96-160 $kg/m^3$ 6 - 10 $lb/ft^3$ |

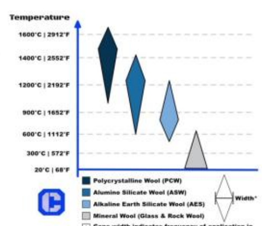
# Refractory Ceramic Fibers (RCFs)

**Advantages**

- Lightweight
- Excellent thermal shock + good chemical resistance
- Very low thermal conductivity at high temp (k ≈ 0.10–0.275 W/m·K at ~850 °C)
  - High porosity → disrupts solid conduction paths
  - Fibrous structure → strong phonon scattering (reduces solid conduction)
  - Large fiber surface area → reduces radiative heat transfer
- Easy to shape around cylinders
- High service temperature (≈1100–1600 °C)
  - Most common "high-purity" grade: ~1180 °C continuous use

**Disadvantages**

- Fibers shed → can damage reactor components, clog systems
- Health/safety hazard if fibers burn or become airborne
- Requires additional mechanical support/containment




Slide 34

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## Aerogels

**What They Are**

- Ultra-lightweight, highly porous solids made from sol-gel derived networks (most commonly silica aerogels).
- Typical structure: 90–99% air, nanoscale pores (10–100 nm), and a continuous silica or oxide network.
- Extremely low density (0.03–0.2 g/cm³) and extremely low solid conduction due to thin silica "struts."
- Variants include:
  - Silica aerogels (most common for insulation)
  - Composite aerogel blankets (silica aerogel embedded in fiberglass mats → flexible + durable)
  - High-temperature aerogels (alumina, mullite, SiC-modified, or doped silica for >1000 °C stability)

**How They're Made**

- Sol–gel process: precursor (e.g., TEOS, sodium silicate) → hydrolysis → gel formation
  - Gel is "aged" to strengthen the network
- Drying step is critical:
  - Supercritical $CO_2$ drying → classic monolithic aerogels
  - Ambient pressure drying + surface modification → cheaper composites used in commercial blankets
- Commercial insulation products are typically aerogel particles impregnated into fiber blankets, giving flexibility and toughness.



## Aerogels

**Advantages**

- Extremely low thermal conductivity
  - Typical k (room temperature): 0.012–0.020 W/m·K and even at high temperature: 0.03–0.05 W/m·K
  - Outperforms IFB and ceramic fiber at equal thickness
- Suppress all heat-transfer modes
  - Nanoscale pores limit gas conduction
    - Very low solid volume → minimal solid conduction
  - High scattering of IR radiation (especially opacified and composite aerogels)
- Very lightweight
  - Much lighter than IFBs; similar or lighter than ceramic fiber
- Flexible (as blankets)
  - Conforms easily around cylindrical pipes
  - Thin layers (2.5–10 mm) achieve performance equivalent to much thicker fiber or brick insulations

**Disadvantages**

- Cost
  - Blanket prices typically $10–$40 per ft², depending on thickness
  - High-temperature grades (Pyrogel XTE, Pyrogel HPS) can be $500+ per roll
- Temperature limitations (for silica aerogels)
  - Pure silica aerogels start to shrink or sinter above ~600–800 °C
  - Stabilized/modified high-temp aerogels can handle 1000–1200 °C, but at even higher cost
- Fragility (in monolithic form)
  - Pure aerogels are brittle; crumble under mechanical load
  - solve this by embedding aerogel into fibrous matrices
- Dust generation during cutting
  - Similar to ceramic fibers: particles can irritate skin and lungs
  - PPE recommended
- Hydrophilicity (unless treated)
  - Moisture absorption can reduce insulation performance
  - Commercial products usually include hydrophobic surface modification



## Dense Refractory Brick

| Properties | Unit | High Duty | Super Duty | High Alumina |
|---|---|---|---|---|
| Classification Temperature | °F<br>°C | 2900<br>1593 | 3000<br>1650 | 3254<br>1790 |
| Density<br>ASTM C 134 | lb/ft³ \| g/cm³ | 130-139 \| N/A | 141 \| 2.26 | 161 \| 2.58 |
| Modulus of Rupture<br>ASTM C 133 | lb/in²<br>MPa | 900 -1500 | 900 - 1500<br>6.2 - 10.3 | 1970<br>13.6 |
| Cold Crushing Strength<br>ASTM C 210 | lb/in²<br>MPa | 2500-4000 | 3000 - 5000<br>20.7 - 34.5 | 9000<br>62.1 |
| Apparent Porosity<br>ASTM C 830 | % | 13-18 | 14-19 | 15.5 |
| Chemical Composition<br>% | $Al_2O_3$<br>$SiO_2$<br>$TiO_2$<br>$Fe_2O_3$<br>CaO<br>MgO<br>$P_2O_5$<br>Alkalies, as $Na_2O$ & $K_2O$<br>SiO | 38.40<br>-<br>2.80<br>-<br>.21<br>.61<br>-<br>.98<br>55.20 | 41.5<br>52.8<br>2.86<br>1.89<br>0.03<br>0.20<br>0.00<br>0.93<br>- | 67.3<br>26.2<br>2.50<br>1.40<br>0.20<br>0.30<br>1.60<br>0.50<br>- |



## References


Insulating Firebricks & Hard Firebricks | Straights & Custom Shapes

An overview of insulating firebricks | Thermal Processing Magazine

A Review of High-Temperature Aerogels: Composition, Mechanisms, and Properties

An overview of refractory ceramic fibers | Thermal Processing Magazine

Hard_FireBrick_TDS_09_21

K-Aerogel-Ht-i-Flyer.pdf

Emissivity of Common Materials

# 21. Meeting Minutes

The following are the minutes from each of the meetings that took place throughout the semester. Some of which were with the sponsor, Mr. Nicolas Cerilli.

**Meeting 13:07 - 14:15**
**09/02/25**

Main Task: Compiling List of questions prior to meeting
13:00 – creating and using OneDrive
13:10 – Organization of docs and platforms
13:25 – Going through provided document from Westinghouse
13:35 – Organization of zoom meeting with sponsor for Friday 09/05 at 09:00
 -Going to ask about Westinghouse's own design expo
13:45 – Insulation material options
14:15 – Meeting organizational housekeeping

**Meeting minutes: 09-05**
9am – introductions
9:05 – scope of project
- Heat pipes: sodium solution, passively transfer heat
- Convective process, air flow passing through
- Used for places where hard to transfer fuel

9:10 – Insulation
- More analytical approach, estimate, process, numbers
- Later semester responsible for more test rig related
- Ambient air, what material what environment will be around the insulation
- What best atmosphere / material would be best for that

9:15 – Deliverables clarification
- Helium insulation

Test Bed Questions
9:17 – Expo in spring, still able to attend
9:20 – Budget
- Dr. Schimdt will
- Materials
- Test rig Etna?
- Heat source for test rig availability

9:24 – radiation management
- Does this need to be something to consider when choosing materials

9:25- prediction of insulation efficiency
9:30 – Fuel line clarification
- Need to wait on follow-up

9:35 – Proprietary info

- Model at facility
- Still in development
- Design changes
- Still being put together
- 10+ years till operation
- Still need to work through codes and standards in nuclear world
- Nuclear test center in Idaho to set up a smaller version of the microreactor
    - o Done within the next year or two
- Diagram question: airgap, what material that should be
- Material of the heat pipe, assembly (will get back to us)

9:40 – diagram clarification
- 2” of space requirement question (will follow-up)
- Free floating or supported and if so by what
- Talk of thermal expansion issues

9:45 – test plan
- Think about maximizing data
- Think about optimal test conditions?
- Good direction to go in: different perspective, thinking outside the box, using engineering intuition to come up with creative solutions and ideas, opportunity to step into the Westinghouse environment, take advantage of connections and working for westinghouse, you get out what you put in, maximize opportunity, reach out, use resources,

9:51 – overcoming obstacles from sponsor perspective
- Lay the groundwork, working 10 steps ahead from step 1, working with a team and communication are important

Post meeting notes: for email
List of topics covered, list of questions that require follow-up, remaining questions

**Meeting 13:02 – 14:00**
09/09/25

Main Task: Literature Review
13:02 – Review general notes
13:15 – Reading through other articles
13:30 – Note taking on articles

- Metallic insulation looking promising (Austenitic steel, polished interior with exterior steel cladding)
- How will cladding be attached to primary insulator (austenitic steel)?

14:00 – Adjourned

Main takeaways:

Metallic insulation sounds most promising, Heilmeier questions answered, further research on non-metallic insulation needed, method of fastening cladding to insulator needs research, talking to Dr. Schmidt about thermal simulation seminar, follow up with sponsor for Friday

**Meeting Minutes 9-12**

Scope of the Project

- We are tasked with creating a test rig
- 100-200 C temperatures or whatever is feasible
- Chamber that can hold the He and the air
- Westinghouse will be providing money, but not until the spring

- Analysis
    - Only looking at one heat pipe, don't worry about radiation or effects from the environment
    - Net thermal input and output on each wall
    - Idealize as perfectly insulated on the outside
    - It says insulation/air because metal is porous and porosity is good for insulation
        - Might be good to model the contribution of He to the insulation depending on porosity of the insulation
    - Seal plate is a pressure boundary to separate different pressures
    - Spacing is a mistake—diagram is correct and we have 2.25in to work with for insulation
- Westinghouse won’t give funds to build test rig until spring
    - Try to model the test rig to set up the spring semester for success
    - $2500 budget
    - Spec out components and costs
    - Determine a source for He based on costs for the next group
- Safety Checklist and Hazard Analysis
    - Really important
    - Human behavior tools—engineer test plan to account for statistical likelihood of humans to make mistakes
- Status Update from us
    - Literature review about types of insulations
        - Metallic or nonmetallic
        - Reflective Metal Insulations
- Materials Selection
    - We dont have to do detailed analysis about radiation but still consider it in materials selection.

**Meeting Minutes 09-15**

11:00 – Sharing resources

- Microfibers
- Other insulators
- Thermal conductivity of materials
- Chemically stable
- High temperature
- Different structures

11:10 – Ceramics?

- Multi-layer thermal insulation
- Ansys
- What modeling package do we want to use
- Helium has higher conductivity
- Use two different materials?

11:20 – compiling docs

- Preparing for meeting tomorrow

11:25 – more material structure

- Explore more on structures
    - Honeycomb

11:30 – Timeline

11:40 – independent work

11:50 – adjourned

**Meeting Minutes 9-16**

13:05 – Discussion of Dr. Schmidt's class

- Heat transfer
- Drawing to set up the problem

13:15 – Questions

- Milestone one
- Outline of timeline

13:20 – Questions doc organization

- Helium
    - Can optimize materials across air changes
- Steady state to start, might want to look at something else?
    - Might let us know
    - Ideally the eVinci operates at steady state
- Heat gen through heat pipes (looking at diagram)
    - Left to right wall is adiabatic
    - Radial heat transfer from heat pipe to wall
- Don't need to worry about the interaction between left and right side of seal

13:30 – Temperature Drop ("Maximize")

- Look for rephrasing
- Where max temperature drop will occur
- Standards for reference NUREG
- Test rig design planning
    - Heat source?

- Spec out everything
    - Safe workspace
    - Responsible for heat source
    - Equipment for test to get access to at pitt?
    - (I think for conceptualizing purposes

13:35 – More on test rig requirements

- Do we choose temperature/environment
    - Decide ourselves
    - Ex. Heat source might not meet requirements
        - Need to scale from model
    - Modeling based on temperatures feasible given test rig specs
- Literature review
- Test rig seals
    - Expectation for use of helium
    - McMaster-Carr
    - What resources we need
    - B31.1 B31.3 Pressure vessel regulations and standards
- Testing of insulations and standards is a good direction to go in

Meeting Minutes 9-23

13:00 – Baseline of timeline

- Milestones
- Pulling up resources
    - Note for ourselves: get that ready before meeting starts
    - Have a better meeting plan going into meeting with sponsor
- Teamwork site and plan

13:05 – low resolution drafting

- Tentative schedule
    - Materials
    - Case compliance
    - Optimize
    - Results
- Well organized timeline

13:10 – going over preliminary hand calculations

- Case 1
    - Heat flux calculations
    - Radially vs linearly
    - Surface temperature calculations
    - Thermal conductivity K
    - “Perform calculations to get the K value”
    - How to determine the heat drop from one end of the pipe to another
- Heat pipe constant temperature
- High rate of heat transfer that it close to uniform heat temperature
- Internal to outer surface one single temperature
- No need to worry about the flow within the pipe

- Heat pipe design still being worked on
- Solving for K?
    - Will follow up
    - Case 1, Tsurf is the outer temperature
    - Radial and then linearly from a to b
    - 800 --> 400
    - Specing out insulation

13:15 – Case 2 clarification
- 3D aspect
- How heat is transferred in all directions
- Additional considerations from literature notes
    - On the right track

13:20 – Milestone due Friday
- Achievements struggles within other schools

13:25 – group meeting without sponsor
- Getting on the same page about math
- Want to have a few materials selected
- Discuss meetings with sponsor, preliminary timeline, calculations, mateials
- How to prepare for presentation on October 1st

13:30 – meeting adjourned

**Meeting Minutes 9-24**

11:00 – Clarification on Design
- The gap in the diagram says should be 0.5, and insulation 2.25.
    - Possible solutions gap is larger than in the diagram or entire radius is less than in the diagram
- Reading over Milestone documents

11:30 – Going over Milestone packet
- Ask questions about the milestone packet, specifically the difference between objectives and milestones
- Reword bullet points into full sentences

11:50 – Reword objectives and milestones
- How do we make these sections cohesive?

**Meeting Minutes 9-29**

Meeting with Dr. Schmidt

11:00

Point of the presentation is for people to ask questions and for us to respond

Presentation is a way to prompt questions

Manipulate people to ask the right questions

Get them to ask questions that they have an idea that you know about

Slide 2: relating graph to what was being said. Demand for energy is growing faster, consider using left graph, lead conclusion that the key to meeting demand is nuclear. Make more obvious. Good lead in for scope

Slide 3: let's look at one energy type potential solution nuclear. How many, where are they, land, labor, time for industry. Long hard process. Make more palatable by making modular and palatable (cultural political etc)

Slide 5:

New additional slide, Westinghouse is looking. Stock image of other applications

Blue things, keep consistent

Slide 6: requirements/specifications

- Make thermal, structural, and geometric larger
- Maybe box around the bullet points
- Thermal emphasis

Slide 7: good

Slide 8: good and engaging

- Since longest, break up into more slides with more visuals
- Maybe give examples of different materials

Slide 9: calculations

- Don't try to get it all out, explain enough so that the audience asks questions
- Let calcs hand for someone to ask questions that you can touch upon later

Slide 10: Deliverables slides

- Simulation visual, tie it back together

**Meeting Minutes 9-30**

13:00 – Presentation setup and run through

13:10 – Presentation feedback

- Good presentation for audience understanding
- Maybe
- Meeting the demand for high cost of transporting and delivering to difficult to reach places
    - Terrain
    - Smaller
- Keep audience engaged

13:15 – project goals

- Prototyping for good segway into next team
- Consulting team to make sure deliverables are on target

13:18 – solving and evaluating for K

- Estimated K value from material selection
- Use simulation to validate and confirm estimated value

13:20 – site visit

**Meeting Minutes 10-7**
13:00
Discussion of material selection software
Trouble shooting with Westinghouse?
Using ANSYS

Schools working on this
- Slippery rock
- Grove city
- Point Park
- Gannon

Factorable in a schedule
Cost
Procurement
Time
Email with information and time/date

13:12 adjourned

**Meeting Minutes 11-04**
11:30 simulation
- Familiarizing ourselves with ANSYS
- SolidWorks model reflects materials and layers of system
- Worked on poster notes, layout, draft in PPX.

13:30 Brendan helps us
- SolidWorks model is complete and quartered
- ANSYS material assigned

**Meeting minutes with sponsor 11-11**
1:05
Asking about the flow in the heat pipe
- Capillary vs gravity etc

1:10
Validating hand calculations
Understanding the validity of the given cases
- One solvable problem combining cases
- Flux value specified can be used as a constraint

For heat pipe use a percentage for heat transfer
- Slight temperature drop off
- 5% loss radially
- Set points

Wick

- Solid material
- Metallic
- Groving with directional flow
- Liquid sodium runs through annulus condenses and then runs back through the wick
- Tube in a tube with directional flow
- Slightly smaller than the tube itself
- Super high volumetric flow with little area
- Not a ton of flow
- Mainly relies on phase change

Poster

Temperature distribution contour map

Slides

- Talk about challenges and how we worked through it
- Asking questions, changing along the way, asking the right questions
- Goal slides
    - Emphasize the goal (one liner)
    - New slide for problem statement
    - Trying to emphasize the air vs helium environment

Material selection

- To get the thermal conductivity need to know supplier, grade, etc
- Use minimum thermal conductivity from simulation to then apply to
- List one definitive material
- Supplemental slides with additional options to consider

# 22. Swanson School of Engineering Exposition Poster

We presented the following poster at the Exposition on Thursday, December 4, 2025.