New Nuclear Design for Electric Power Systems

DESIGN DOCUMENT

Team Number: sdmay24-30

Adviser: Dr. James McCalley

Team Members/Roles:
Dana Boor (Team Lead)
Damien Henry (Asst. Team Lead)
Mason Richards (Research and Design)
Zachary Hainline (Research and Design)
Jeremy Yost (Research and Design/Website Curator)
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Revised: 03DEC23 Version 1.0

Executive Summary

Development Standards & Practices Used

The research and proposal of a recommended design for a modern nuclear power plant will involve gathering information and data from a large variety of resources. It is of the utmost importance that our team properly documents and reports the sources of the information incorporated into our project. Our team has elected to use the IEEE standard of resource citing to ensure transparency and accountability for the information that we use in our project.

The quality and accuracy of the information and data that we use is vital to the overall success of our project. To safeguard the integrity and reliability of the information, our team has elected to closely regulate the resources used for information. Resources will primarily consist of government and higher education websites/publications, along with information coming directly from the manufacturers of the nuclear power plant designs we are reporting on.

Summary of Requirements

- Identify practical "New Nuclear" designs that fit into the general guidelines outlined in the project proposal.
- Develop a report outlining the strengths and weaknesses of each identified design/technology and a cost-benefit ratio estimate.
- Identify unique design elements that may be effective in "New Nuclear" energy.
- Identify a single "recommended design" from the researched information and analysis performed.
- Describe and illustrate the recommended design and identify any design flaws.
- Provide an argument for the recommended design in terms of a "Benefit to Cost" ratio showing why the ratio is better than the other designs.
- (Optional) Utilize tools to evaluate the value and usability of a particular nuclear source.

Applicable Courses from Iowa State University Curriculum

EE 303, EE 455, EE 456, EE 457, IE 305.

New Skills/Knowledge acquired that was not taught in courses

- Level Cost of Electricity (LCOE) Assessment
- Use of a Co–optimized Expansion Planning Model Software (Made by Ali Jahanbani Ardakani)
- Nuclear Power System Designs
- Benefit-to-Cost Ratio Analysis

Table of Contents

1 Team, Problem Statement, Requirements, and Engineering Standards

1.1 TEAM MEMBERS

1) Dana Boor 2) Mason Richards

3) Jeremy Yost 4) Zach Hainline

5) Muhammad Syukri 6) Damien Henry

1.2 REQUIRED SKILL SETS FOR YOUR PROJECT

- Knowledge of nuclear reactor design and operation
- Project management skills
- Ability to perform economic analyses on energy production methods
- Experience with electric power distribution and transmission
- Strong mathematic and data analysis skills
- Ability to use software to model electric transmission/distribution systems

1.3 SKILL SETS COVERED BY THE TEAM

Zach - Utility experience with transmission and distribution protection devices. Ability to collaborate with others and integrate into roles needed within a team. Have worked/working in a management role.

Damien - Concurrent MBA student with skills in project management and finance, useful when analyzing the economics and feasibility of each design.

Mason – Utility experience in both the transmission and distribution. Generally good with learning new software or tools. Fairly good with technical documentation.

Dana – Experience operating and maintaining nuclear reactors in the military.

Syukri – Able to tackle intricate mathematical problems, particularly in engineering and electrical contexts, decent knowledge in coding, grasp of basic quality control assessment.

Jeremy – Good with learning/experimenting with different software. I have a perspective of standard nuclear power plant operation from my father.

1.4 PROJECT MANAGEMENT STYLE ADOPTED BY THE TEAM

Team members will be assigned explicit tasks to perform throughout the course of the project. During weekly team meetings, members will be expected to give a status update on their portions of the project. These status updates will give fellow team members the opportunity to provide support and guidance.

1.5 INITIAL PROJECT MANAGEMENT ROLES

Dana – Team Lead

Damien – Team/meeting organization

1.6 PROBLEM STATEMENT

This project seeks to compile data on multiple different new nuclear reactor designs, narrowing down the designs to one final recommendation. The new nuclear power plants have the potential to provide clean and dependable sources of electricity that are practical, safe, and cost-effective. This is important because while nuclear energy is clean and reliable, it is often very expensive and is seen as unsafe by some.

1.7 REQUIREMENTS & CONSTRAINTS

Requirements:

- Identify "New" Nuclear designs that fit within the scope of the project.
- Identify different technologies that might be effective in "New" Nuclear designs.
- Develop report covering strengths and weaknesses of each design/technology.
- Perform a benefit-to-cost analysis of each design.
- Identify a single recommended "New" Nuclear design.
- Develop a report on the cost-to-benefit analysis, strengths, and weaknesses of the recommended design.

Constraints:

- Technology must be feasible/attainable.
- New design must cut down on current costs of Nuclear.
- New design must reduce construction time of current Nuclear.

1.8 ENGINEERING STANDARDS

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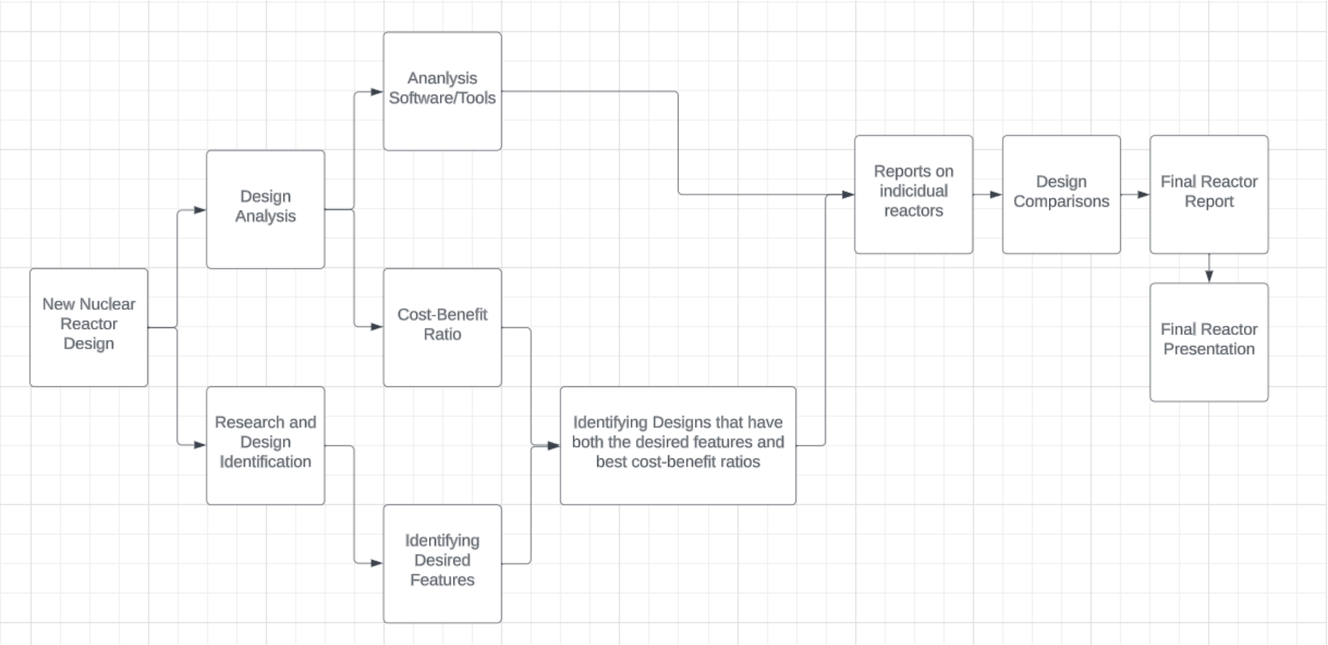
1.9 INTENDED USERS AND USES

The beneficiaries of our project are people that use power and energy in their everyday lives, as well as policy makers, utility companies, reliability organizations, and utility stakeholders. Our project specifically focuses on creating an optimal nuclear design solution for the state of Iowa. The solution we end up choosing would likely be viable and of great use in neighboring states too. This design is important in making sure our electric grid remains reliable and better for the environment. The United States is transitioning to more renewable energy sources such as wind and solar, but these sources can only generate energy when there is wind and sunlight to do so. Nuclear power will be able to supplement these fluctuations in load demand when solar or wind are not available, which is greatly beneficial to all the parties listed above.

2 Project Plan

2.1 TASK DECOMPOSITION

- Task Dependence Graph:

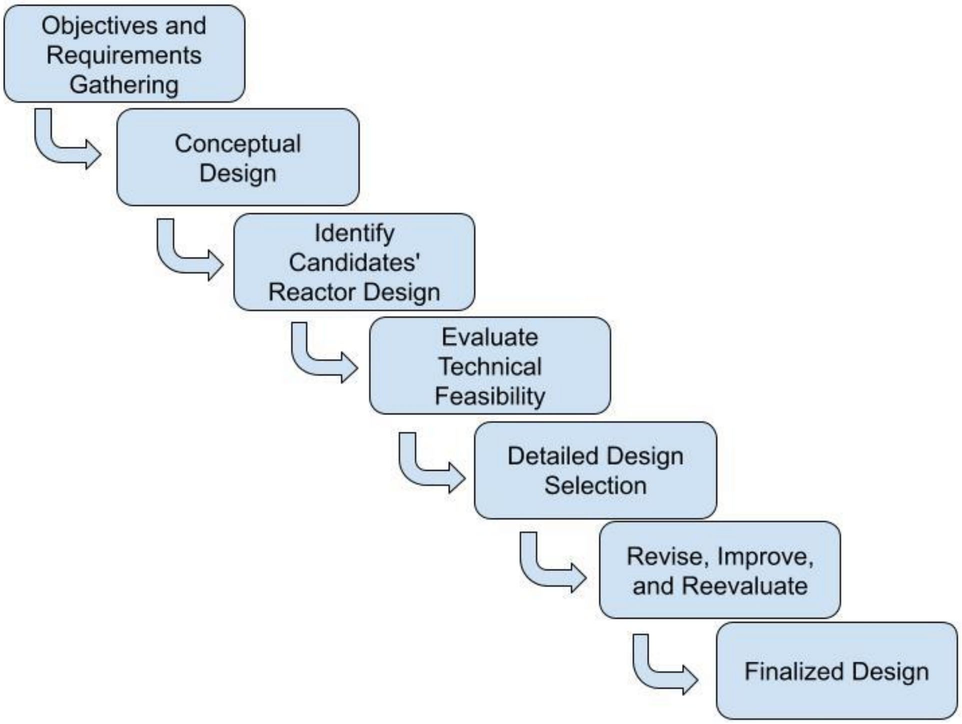


- Description and Justifications:
    - Design Analysis - Analysis of our initial research and designs will help provide quantitative reasoning to help narrow down the designs as we move forward.
        - Cost-Benefit Ratio – Cost-Benefit Ratios are a specific metric identified by the client and project requirements for determining cost effectiveness of the design.
        - Analysis Tools – The client suggested looking into other software to tools to assist in analysis. This would provide us with different types of quantitative data for analysis.
    - Research and Design Identification – Identification of specific features or designs we like will provide the group with qualitative criteria for narrowing down the designs.
        - Identifying Desired Features – Picking a handful of desired features from our initial research will allow us to tailor our final design to the project requirements.
    - Consolidating Research – Identifying the designs that have both a favorable cost-benefit ratio and the desired functionality will funnel everything towards a final design.
        - Reactor Reports – Writing reports on a handful of reactor designs the group identifies will help outline the pros and cons of all remaining

designs and allow for clear and outlined reasoning when we compare them in the final report.
- Comparing Reports – Comparing the reports will allow us to determine the best overall reactor design for our final submission.
- Final Report and Presentation – Writing the final report and making the presentation will tie all the research and analysis performed throughout the entire process.

2.2 PROJECT MANAGEMENT/TRACKING PROCEDURES

For our project, the Waterfall project management style is well-suited due to its structured, systematic, and safety-oriented approach. It aligns with the project's long-term goals, regulatory requirements, and the need for comprehensive documentation, making it a suitable choice for this complex and safety-critical endeavor. Our team will be using Google teams to track progress throughout the course of the current and the next semester.



1. Objectives and Requirements Gathering:

Define project goals, objectives, and technical and safety requirements.

2. Conceptual Design:

Formulate and select the initial concepts for the new reactor design. For this project, we have chosen a Small Modular Reactor as our base concept for the nuclear reactor.

3. Identify Candidates' Reactor Design:

Conduct extensive research on existing nuclear reactor designs. Select several designs that meet the technical criteria.

4. Evaluate Technical Feasibility:

Perform detailed technical feasibility studies that involve engineering analyses and simulations. These studies should address critical technical aspects of the major components of the reactor, such as cooling systems and fuel handling.

5. Detailed Selection of Design:

All of the design alternatives will be compared. The best design will be chosen based on the technical and design criteria evaluated.

6. Revise, Improve, and Reevaluate:

Analyze the feedback and identify areas where the design may be weak or improved. Start making iterative changes to the design based on the prioritized improvements. Reevaluate.

7. Finalized Design:

Ensure that the design has been reviewed and approved by the advisor, clients, team members, and any other decision-makers. Address any concerns or feedback they may have.

2.3 PROJECT PROPOSED MILESTONES, METRICS, AND EVALUATION CRITERIA

As our team has progressed through our project a little bit, the needs and proposed milestones have been slightly modified. Outlined below are our new milestones.

Milestone 1) Identify all reasonably practical “new nuclear” designs that have been suggested so far. Develop a summary report of these technologies that identifies their strengths and weaknesses. Estimate the Benefit to Cost ratio for each design.

Each team member will select 3 new nuclear power plant designs to consider for a recommended design. Each reactor plant design will be evaluated for cost, benefits, size, reactor design type, heat rate, fuel type, maturation level, and safety level.

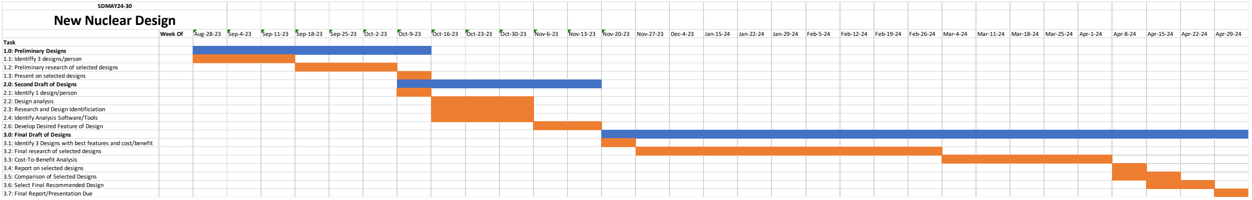
Milestone 2) Identify and evaluate tools useful in designing and assessing the performance of the nuclear power plant. See how programs such as CEP, or Co-optimized Expansion Planning, can be utilized to help illustrate the performance of nuclear power plants.

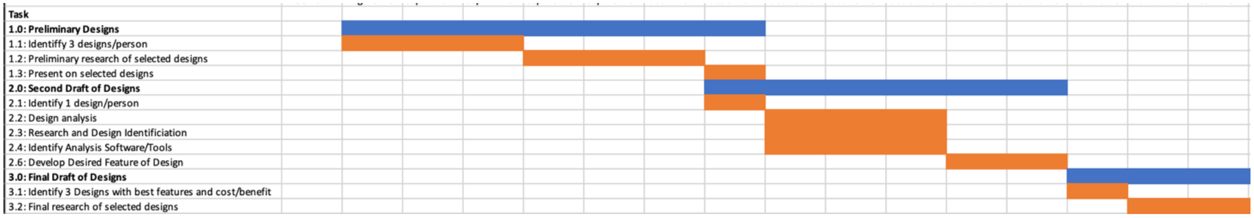
Milestone 3) Based on the various technologies surveyed in step 1, our team will identify a “recommended design” (RD). The RD could be one of the technologies surveyed, or it could be an extension of one of them, or it could be an integration of two or more of them.

Milestone 4) Illustrate and describe the RD in detail. Identify any significant problems with the design and describe solutions for these problems. Provide a convincing argument that the RD’s Benefit to Cost ratio is better than all other designs considered.

2.4 PROJECT TIMELINE/SCHEDULE

The original proposed project schedule can be found below, with the second picture noting the schedule for the first half of our project.

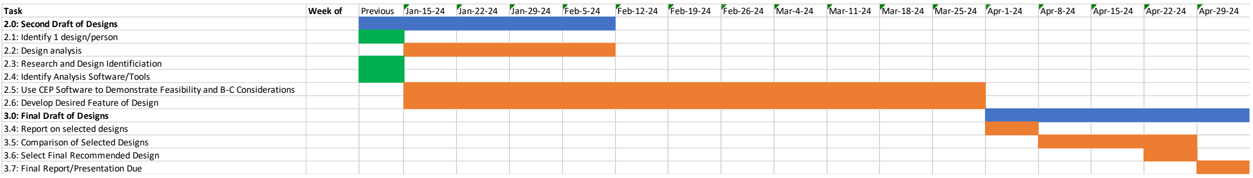




As noted in the Gantt Chart, we have split this project up into three major phases: the preliminary designs, the second draft of designs, and the final draft of our recommended designs. The plan for our project originally was as follows:

> We originally selected 3 proposed reactor designs per team member to research. After spending a few weeks researching each of these designs, we will narrow this list down to 6 selected designs. There are a few criteria we are using to select the 6 designs to move forward with, including: the stage of development (i.e. how far along this technology is), the feasibility (cost, construction time), and the amount of information available on each design.
>
> After narrowing down our list of selected designs to 6, we will have each team member research one of the proposed designs for another few weeks. After spending enough time researching each of the 6 designs, we will narrow our list of proposed designs down to 3. Criteria used to select these three designs will be as before, but with more emphasis placed on the feasibility of each proposed design.
>
> We will then take a deep dive into the three designs that we chose for the remainder of the semester and next. We would like to allocate this much time to researching the final three designs to conduct valuable, complete research on each of the selected designs. After this research is done, we will also be conducting research to develop a cost-to-benefit ratio for each reactor. This will take a considerable amount of time as much of the cost and benefit to consider will be ambiguous and require well researched, thought-out assumptions.
>
> Finally, we will develop a final recommendation, selecting just 1 recommended design from the final 3. The recommended design will depend on many factors, but with a very heavy weight placed on the cost-to-benefit analysis.

Most of the ideas outlines here are still relevant, however we will now be using our CEP software much earlier in the process to demonstrate both how nuclear power may fit into a portfolio with wind and solar energy, as well as our benefit-to-cost considerations. The new schedule for the remainder of our project can be found below.



Task	Week of	Previous	Jan-15-24	Jan-22-24	Jan-29-24	Feb-5-24	Feb-12-24	Feb-19-24	Feb-26-24	Mar-4-24	Mar-11-24	Mar-18-24	Mar-25-24	Apr-1-24	Apr-8-24	Apr-15-24	Apr-22-24	Apr-29-24
2.0: Second Draft of Designs		🟦	🟦	🟦	🟦	🟦												
2.1: Identify 1 design/person		🟩																
2.2: Design analysis			🟧	🟧	🟧	🟧												
2.3: Research and Design Identificiation		🟩																
2.4: Identify Analysis Software/Tools		🟩																
2.5: Use CEP Software to Demonstrate Feasibility and B-C Considerations			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧					
2.6: Develop Desired Feature of Design			🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧					
3.0: Final Draft of Designs														🟦	🟦	🟦	🟦	🟦
3.4: Report on selected designs														🟧				
3.5: Comparison of Selected Designs															🟧	🟧	🟧	
3.6: Select Final Recommended Design																	🟧	
3.7: Final Report/Presentation Due																		🟧

2.5 RISKS AND RISK MANAGEMENT/MITIGATION

<u>Task 1 - Analysis of Three Reactor Designs per Member</u>

- <u>Risk 1 - Overlap between reactor research (Risk Factor: 0.7)</u>
    - Since each member was given free rein to find new nuclear designs that are being built or researched there is a high chance, we might have multiple people doing preliminary research on the same designs. This risk doesn't greatly affect our project however it could cause an unnecessary expenditure of energy and uses time that could be used for more productive aspects of this project.
    - **Mitigation** - A way of mitigating this risk would be to use time in our weekly meeting to discuss all our current compiled designs and decide if we have an overlap that should be addressed. It could be addressed in various ways like finding other designs, so everyone truly has three designs or by altering the workload split slightly so the workload differential isn't large between members.
- <u>Risk 2 - Designs could lack relevant publicly available information (Risk Factor: 0.6)</u>
    - A number of these reactor designs are still in an early prototyping phase or in a theoretical phase where the companies are sharing their idea with potential supporters and the Department of Energy in hopes of creating it someday. With it being so early in their development some of these may have very limited data that can be used.
    - **Mitigation** - We have some built in mitigation to this risk with us starting out with 18 different reactor designs. That way if some are lacking needed information it can be naturally sifted out during our narrowing down process.
- <u>Risk 3 - Suggested Analysis tool may not work as expected (Risk Factor: 0.45)</u>
- Neither our group, nor our client, Dr. McCalley, has worked with the suggested Analysis tool, Aspen. We do not truly understand the full possibilities of the program yet. So, there is a risk in us relying on it too much before we learn how to use it.
- ***Note: This risk ended up coming to fruition, as we found that ASPEN was not a suitable software for our project. However, we did not invest significant resources into utilizing this tool before making this conclusion. Our CEP software, however, has clearly demonstrated that it will be of significant benefit to this project.***

<u>Task 2 - Narrow Selected Reactors Down to One Design per Member and Write a Brief Report Outlining its Features, Benefits and Limitations</u>

- <u>Risk 1 - Each group member might base their choice of a reactor on different features or specifications (Risk Factor: 0.3)</u>
    - When we write our report, we will want to primarily cover certain specifications that can be compared between all the reactors we research, that way we have solid data that will be used in our narrowing down process. This risk is relatively low because we have discussed the desired criteria in multiple team meetings.

- Risk 2 - Deadline for report could be missed - Oct 23rd (Risk Factor: 0.2)
- The deadline for a report on each reactor design could be missed. However, we are confident in our team's ability to complete it in a timely fashion, thus assess this risk to be relatively low.

Task 3 - Narrow Reactor Selection Down to Three Total, Split into Three Groups to Write a More In-depth Report on Remaining Reactors

- Risk 1 – Could have varying qualities and lengths to reports (Risk Factor: 0.5)
    - There is a moderate risk currently that one reactor design will look better than another just because the report was written will more detail. This is mainly only a risk because this task is still far out, and we haven't discussed the necessary lengths and details needed in this report. After we do this the risk will drop, additionally we will meet with each other while writing our reports to keep things consistent.

Task 4 - Narrow our Choices to One Final Design & Do Lengthy and Detailed Research on Design for Final Report.

- Risk 1 – Lack reliable figures for our data (Risk Factor: 0.55)
    - Many of these reactors have never been built for non-testing purposes, so we are likely going to struggle finding totally reliable build costs, fuel costs, and other similar data.
    - **Mitigation** – Some of our data may have to be based on assumptions using "old" nuclear data. Where we will indicate that this data is based on old data as the new data will not be available until more testing is done with the new Reactor designs.
- Risk 2 – CEP Software does not prove to be useful for our project (Risk Factor: 0.4)
    - There is a small chance that the CEP software does not provide us clarity in how nuclear fits into a portfolio with wind and solar energy and/or provides us with information on our benefit-to-cost analysis.
    - **Mitigation** - Our team is currently carefully looking at the CEP software, and if it is not found to be useful, we will discontinue use.

2.6 Personnel Effort Requirements

Team Members	Task 1 – Identifying all practical "New Nuclear" Designs	Task 2 – Narrow down "New Nuclear" Designs to research	Task 3 – Identify a "New Nuclear" design to recommend and move forward with	Task 4 – Illustrate and outline all aspects of the recommended design	Task 5 – Identify any helpful or useful design/performance tools for modeling nuclear power plants	Total Hours
Total Hours Per Person Estimated	18	18	12	36	18	102
Dana	3	3	2	6	3	17

Mason	3	3	2	6	3	17
Jeremy	3	3	2	6	3	17
Syukri	3	3	2	6	3	17
Damien	3	3	2	6	3	17
Zach	3	3	2	6	3	17

Textual reference:

Task 1 – The concept of this project is to identify the most practical "New Nuclear" design to possibly pursue in the coming years. In this first task, we strive to seek out all these new technologies and document all our findings for further discussions as a group.

Task 2 – In this second task we take our findings from task 1 and narrow down the findings to the most reasonable and promising designs. As a group, we will pick out 3 designs to further pursue and research.

Task 3 – Upon researching the 3 designs from task 2 we will have some further discussion on our finding for these designs and narrow it down to 1 recommended design.

Task 4 – Having now narrowed down our research to one recommended design from task 3. We will now proceed with an in-depth analysis of all aspects of this recommended design. This includes all the pros/cons of this design, how it works, and the cost-to-benefit ratio.

Task 5 – After finishing our primary goal of recommending a design with ample research. We can go ahead and start evaluating different design tools for nuclear power plant modeling. This includes the CEP software.

2.7 Other Resource Requirements

The materials required to complete this project will be a widespread of internet articles and postings regarding "New Nuclear" designs. Additionally, we will be using the CEP software as previously mentioned.

4 Design

4.1 DESIGN CONTENT

This project seeks to find a new nuclear design that is cost-effective and provides a clean and reliable source of electricity while prioritizing safety for both users and the environment. Our primary objective is to innovate a nuclear power plant design that offers a dependable source of clean electricity characterized by practicality, reliability, and efficiency.

4.2 Design Complexity

The new nuclear design has to be evaluated based on the levelized cost of electricity (LCOE). LCOE is a comprehensive metric that helps assess the cost of generating electricity by considering all costs associated with the plant's entire lifecycle. LCOE provides a standardized and fair way to compare the economic viability of unequal life spans, project size, different capital costs, risk, return, and capacities. The new nuclear design comprises several key components, and their performance and economic viability are assessed through the Levelized Cost of Electricity (LCOE).

The design will be evaluated based on the following:

- Capital Costs
    - This includes the initial investment required for designing, constructing, and commissioning the nuclear power plant. It involves engineering principles related to construction and project management.
- Maturation Level
    - The longer it takes to deploy the reactor, the higher the capital costs may become due to inflation and the opportunity cost of the capital invested. As a result, a longer deployment time can increase the LCOE by raising the initial capital costs.
- Fuel Type and Costs
    - For a nuclear power plant, fuel costs mainly involve the cost of uranium or other fissile materials. Scientific principles of nuclear physics and reactor operation are essential to understanding and managing fuel costs.
- Operating and Maintenance Costs
    - These include the expenses associated with day-to-day operations, routine maintenance, and periodic equipment upgrades. Engineering principles related to system efficiency and reliability are crucial here.
- Safety Features
    - Advanced safety systems, monitoring, and redundancy reduce the risk of costly disruptions. Examples such as shields against radiation and natural disasters, will limit long-term financial risks. Ongoing safety improvements through research and testing minimize costs related to safety incidents and regulatory issues, enhancing economic viability.
- Decommissioning and Waste Management Costs
    - These costs relate to the eventual decommissioning of the plant and the safe disposal of radioactive waste. Engineering and scientific principles are vital to managing these costs safely and effectively.

4.3 Modern Engineering Tools

A variety of modern engineering tools are being used to aid our design. Some of these tools include:

- Benefit-to-Cost Analysis
    - Used to determine which reactor designs are the most beneficial for the best price. One of the main criteria for determining which reactor designs and features are the best.
- Iterative Design
    - Creating iterations of our design will allow us to build upon and change specific features to improve efficiency and cost of the overall design.
- Economic Analysis
    - CEP allows for power plant simulations and analysis that will provide useful information in helping us evaluate power plant designs from an economic standpoint.

4.4 DESIGN CONTEXT

There are quite a few relevant considerations related to the project that are outlined by the categories below:

Public health, safety, and welfare:

- Power plants, by nature, are in close proximity to the public. In the interest of public health, any emissions and waste produced by our design will need to be minimal and safely contained. A plant of this type would also require personnel to run it, so there would likely be more jobs being created.

Global, cultural, and social:

- Nuclear power plants specifically, are somewhat unpopular in the United States because of misconceptions surrounding their safety. The installation of a nuclear power plant may be unpopular without data and more information showing the multitude of safety systems.

Environmental:

- Environmentally, this power plant would be beneficial because of the intent to use it to supplement renewable forms of energy like wind and solar. With the projected power output, nuclear power plants would likely start to replace non-renewable methods of power production. The overall carbon emissions of the new systems implemented would be less than the current coal and natural gas plants currently in use.

Economic:

- There are significant economic benefits that can come from the potential cost of energy from these new nuclear plants. The ability to supplement the renewable forms of energy would also help to reduce the cost of energy during peak loads, as well as times when the renewable production is lower. Conversely, the up-front cost of the development and construction of a reactor of this type may be quite high for initial constructions.

4.5 Prior Work/Solutions

The use of nuclear fission to generate electricity is not a new concept. The overall idea of harnessing the energy released from controlled fission events and using that energy to produce steam, eventually spinning turbine generators and producing electricity, has been employed in commercial power generation for decades. However, the traditional approach to utilizing this power has several significant drawbacks:

- Traditional large reactor designs have high capital costs and long construction times [1].
- The long-term plan for storage and disposal of nuclear waste is unclear [1].
- The operation and maintenance costs of traditional nuclear reactor plants are extensive and costly [1].

The shortcomings of large nuclear reactor plants caused a noted decline in the prevalence and interest in nuclear power. However, with the rise of carbon-free energy sources, such as solar and wind, a renewed interest in nuclear power has emerged. The advantages of nuclear power as an energy source are numerous, with two of the most notable being the following:

- The ability to produce electricity regardless of environmental conditions, making up for the shortcomings of solar and wind generation.
- Producing all its energy carbon-free, unlike coal and natural gas.

The most recent work in nuclear power generation has been in researching and developing small modular reactor designs as opposed to large reactors. Our team's efforts are centered on investigating these new developments in reactor design and safety to determine a design that will be the most reliable, safe, and cost effective.

4.6 DESIGN DECISIONS

With the nature of our project, we do not have to make typical design decisions that you may see in a senior design project. However, we have had (and will have) several key decisions to make throughout the project. The key decisions that we have made so far include:

1. **What designs we deem worthy of conducting research on**. Criteria used for evaluating this decision include the amount of information available, the recency of the technology, and the practicality of each design found.
2. **Metrics to measure the strengths and weaknesses of each design**. There are quite a few different metrics that we decided to use to determine the strength of each design. Some of the metrics we have used are levelized cost of energy (LCOE), construction cost, construction time, stage of development, and general safety features, benefits, and weaknesses.
3. **Which 6 reactor designs to pursue further.** Initially, each team member researched 3 designs each for a total of 18 designs being researched. This last week, we reduced the number of designs to 6, or one per team member. This decision was made based on a combination of factors outlined in decisions 1 and 2 – with emphasis based on the amount of information available, the stage of development, and construction time and costs.

We will also need to make some significant decisions in the future as we further reduce the number of designs and ultimately make a final recommended design. Some of these decisions include:

4. **Which 3 reactor designs to pursue further.** After spending some time researching 6 designs, we will again need to come together and narrow our focus down to 6 reactors. We will take into account the same criteria before, but with more weight placed on costs, construction time and benefits.
5. **What factors to include in our cost to benefit analysis**. While researching the final three designs, we will be conducting cost to benefit analysis. Because all of these new technologies are emerging, there is not an abundance of information on either the costs or the benefits. As a team, we will need to make a decision on the base assumptions to be made and the variables to be considered in this analysis.
6. **The final recommended design.** At the end of this project, we will need to recommend one final nuclear design. This decision will mostly be based off of the cost to benefit analysis, but all previously mentioned factors will be considered.

4.7 Proposed Design

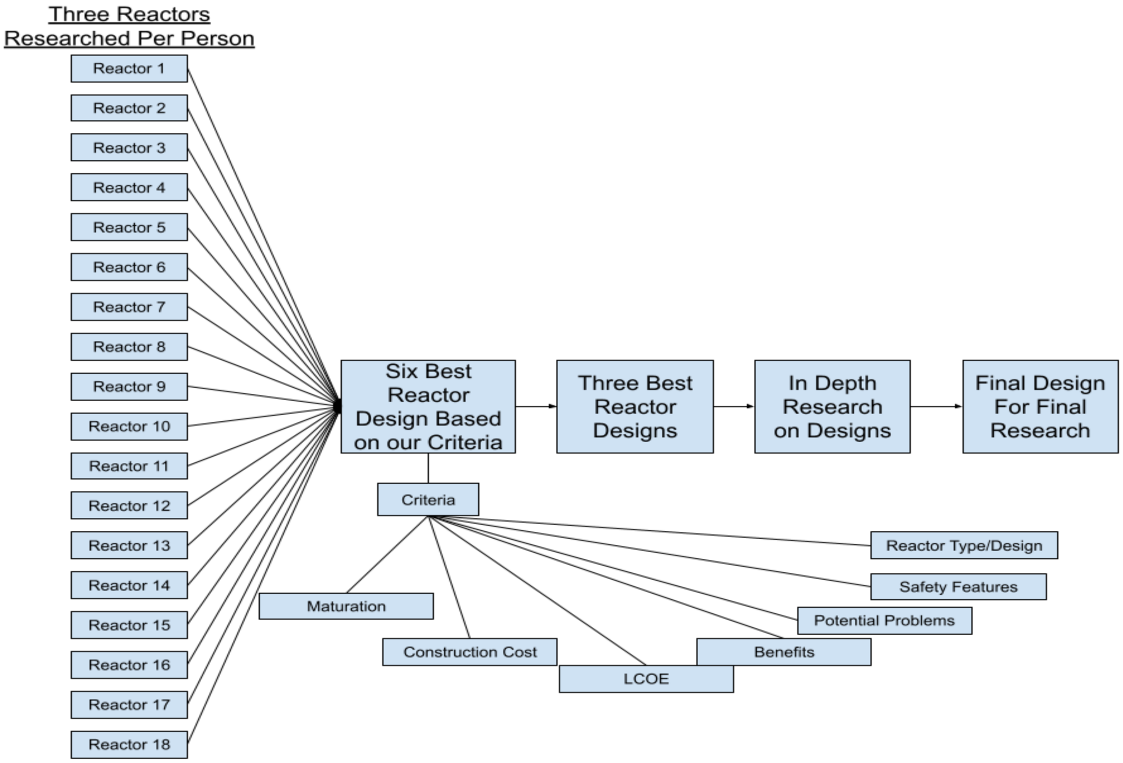
Our team began our research into modern small modular reactor designs by canvasing to see what options are currently available. We found a wide array of potential designs, each with their own strengths and weaknesses. Our team evaluated each design against the following set of criteria: construction costs, levelized cost of electricity, safety features, reactor design type, benefits of the design, power output, maturation level, and potential problems associated with each design.

Below is a table of the reactor designs our group has researched so far:

Natrium by TerraPower	eVinci Microreactor
VOYGR SMR by NuScale	Prism GE Hitachi
Integral Molten Salt Reactor (IMSR) by Terrestrial Energy	Moltex Stable Salt Reactor (SSR)
BWXT Advanced Nuclear Reactor (BANR)	Arc-100 SMR
GE Hitachi BWRX-300	Vogtle Unit 3 and 4
Kairos Power FHR	China Thorium Nuclear Reactor
Holtec SMR	ITER Fusion Reactor
HolosGen Holos Quad	

4.7.1 Design 0 (Initial Design)

Design Visual and Description



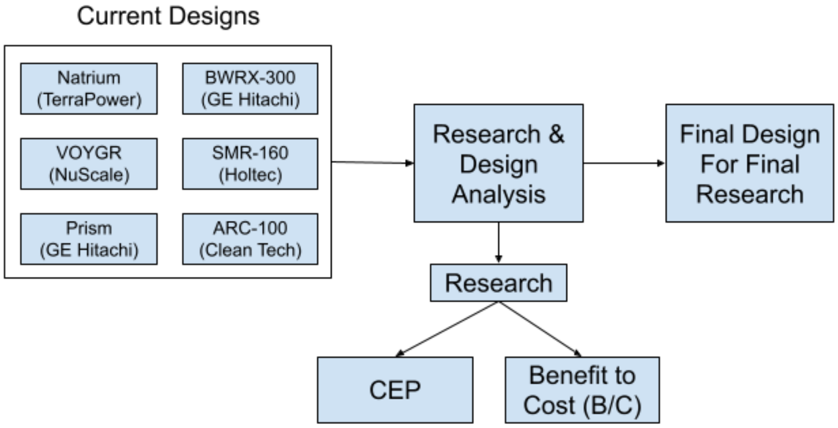
1. Each team member was expected to select three nuclear reactor designs that looked promising. Where the teams as whole would have a total of eighteen.
2. The team member will briefly research each reactor to find data pertaining to the criteria.
3. As a team narrow down design to six total, or one per member.
4. Complete a little more in-depth research on remaining designs, completing a one-page report on each.
5. Narrow down to three, split into groups of two to complete multiple page report outlining any details that may help with determining our final reactor design.
6. Narrow down to one final reactor and discuss how we will write our final report.

Functionality

Our research is intended to decide based on available data what reactor we believe the State of Iowa should investigate more if they decide to go the nuclear route for clean energy.

Right now, our research is spread thin between eighteen reactors. As we narrow down our reactor selections, we should have increasingly more data on the reactors to be more persuasive on why we believe one design is better for the State's needs than the others.

4.7.2 Design 1 (Design Iteration)



Design Visual and Description

In this design, we narrowed down our Research from 18 reactor designs down to 6. Where now we are gathering data on the designs. With the data gathered, we should have all the necessary information to complete a benefit to cost analysis and use the CEP software. Upon completion of the analysis, we should have enough data to decide on a final design to be the basis of our final recommended design. Additionally, we will look for aspects of other reactors we believe may increase the appeal of our final recommended design if integrated together.

4.8 TECHNOLOGY CONSIDERATIONS

(Section will be completed once testing is conducted).

4.9 DESIGN ANALYSIS

(Section will be completed once testing is conducted).

5 Testing

5.1 UNIT TESTING

There is a variety of testing required for this project. Starting with the 6 reactor designs that the group has narrowed down; the following will be the criteria we are using for testing each design:

- Design Criteria:
    - Overall design criteria have been provided by the client that the final design will need to conform to. Each design will be tested to ensure it meets all of the following criteria:
        - Capital Costs – Cost cannot be excessively expensive and needs to be competitive enough to justify its construction and use.
        - Maturation Level – The design needs to be mature enough to be realistically implemented in the near future.
        - Fuel Type and Costs - Fuel should be cost effective and relatively easy to obtain.
        - Operating and Maintenance Costs - O&M cost of the reactor should be comparable, if not better than other, already existing nuclear reactors.
        - Safety Features - Reactor should comply or be able to comply with the appropriate safety standards.
        - Cost for Decommissioning and Waste Management – Decommissioning and waste management cost should be comparable to existing reactor solutions.
- Cost/Benefit Analysis:
    - Each proposed reactor design/feature will have key benefits that will contribute to the overall cost/benefit ratio of the design. Analyzing and testing which reactors or features will give us the best cost/benefit ratio will help determine whether the design is viable.
- CEP (Co-optimized Expansion Planning) Software Simulation:
    - Identifies GTD investments (what, when, where, how much) to minimize NPV invests + operations over 20 year period. Allows us to assess each reactor design to see if it's viable in today's power grid and for the future.

5.2 INTERFACE TESTING

While wind and solar are great energy resources, they lack the ability to follow changing loading conditions and provide consistent power during all weather and environmental conditions. Our motivation for wanting to implement a new nuclear design is to provide evidence that nuclear power can compete with coal and natural gas to provide a reliable, practical, and economically viable energy production method to pair with wind and solar. Interface testing for our recommended power plant designs will consist of CEP, or Co-optimized Expansion Planning, simulations designed to determine if our nuclear plants can be placed into service on a power grid with wind and solar plants.

CEP is engineering software that allows power systems engineers to plan, analyze, and test power generation and transmission systems. Given the operating specifications of our recommended designs, our goal for this portion of testing will be to show whether the design is worthy of additional investment and development when compared to coal and natural gas plants. With the results obtained from the CEP simulation, we will see how each of our new nuclear power plants compare to both carbon-based fuel plants and to other new nuclear technologies.

Our overall plan for testing the grid-interface capability of our recommended nuclear plant designs with wind and solar is as follows:

1) Build a model power grid in CEP that includes power generation from wind, solar, coal, natural gas, and nuclear.
2) Enter in plant-specific data, such as heat rate, variable operations & maintenance cost, fixed operations & maintenance costs, and fuel prices.
3) Observe and record the investment recommendations that the CEP software produces for each technology.

5.3 INTEGRATION TESTING

There will be two pieces of integration that our team will be testing: using different technologies from multiple designs in a single design and ensuring that nuclear can integrate with solar and wind energy to follow load demands.

The first round of testing regarding integration of multiple technologies into a single design is much less “testing” than it is retrofitting. The idea behind this integration is that if we like one piece of technology from one nuclear design (example: a storage element) that we believe could integrate with another design (perhaps one without a storage element), we would like to explore the possibility of combining these technologies into a singular design. The testing part comes in when we need to ensure technology compatibility. We will need to be sure all technologies are properly rated and meet operation requirements. This could mean one technology will need to be able to operate at a higher temperature and/or pressure than it was originally designed to.

The second piece of testing we will need to do is to ensure that nuclear energy successfully solves the problem of load variation. As it currently stands, wind and solar energy do not produce energy on a consistent (i.e. straight line) basis. Wind produces when it's windy, and solar when it’s sunny. As a result, there are times (most of the time) when wind and solar energy peak outputs do not coincide with peak demand. We are aiming to solve this problem with nuclear energy – as a supplement to what wind and solar are able to produce. We will be testing this using PSSE, modeling average wind and solar generation patterns to be supplemented with the power output of the different nuclear plants we are researching.

5.4 SYSTEM TESTING

The objective of system testing is to verify the effective integration of multiple components of nuclear power into a grid that includes wind and solar generation. System-level testing for a new nuclear design in a power system is a critical phase to ensure that each unit sufficiently works together as a system and meets its specified requirements and functions as intended. In the context of integrating a nuclear power plant with solar and wind plant, some of the system tests include:

I) To validate the communication between individual components (is each different component suitable to work with each other).
II) Using PSSE (Power System Simulation for Engineering) as a tool to demonstrate the operational capabilities of the proposed design.
III) Simulate varying power demand scenarios to ensure the system can balance loads effectively.
IV) Evaluate the nuclear design's ramping capabilities, ensuring it can adjust power output effectively.

This testing approach ensures that the new nuclear design does not only work on its own but integrates seamlessly into a diverse energy grid. This aligns with our motivation to position nuclear power as a competitive alternative to coal and natural gas.

5.5 REGRESSION TESTING

Bringing together different aspects of various Nuclear Power plant designs is a task that could be very difficult since we have little experience with nuclear power. Determining if the components can be integrated is just the first problem we will need to focus on when integrating different designs. Another thing we should be aware of is whether the integration adversely affects our original goals for the reactor, such as the benefit-to-cost ratio, the power production, size, and various other aspects that could be important when determining if the reactor is worth building.

The benefit-to-cost ratio is one of the most important aspects of our design that we will need to ensure that we stay within our defined criteria. Based on our discussions with our client, Dr McCalley, this ratio is one of the most important aspects to consider when evaluating designs. After integrating each new component into an existing design, we will have to reevaluate the Benefit-to-cost ratio to ensure it is still within the region of tolerance. If the ratio falls below 1, we must come together and decide if we remove the new component or if our benefit-to-cost ratio formula requires reevaluation because it does not model all the benefits the new component provides.

5.6 ACCEPTANCE TESTING

To ensure that all design requirements are being met from a functional and non-functional perspective we will be referring to our client's document that was provided to us at the start of senior design.

These requirements are listed below:

- Identify “New” Nuclear designs that fit within the scope of the project
- Identify different technologies that might be effective in “New” Nuclear designs
- Develop report covering strengths and weaknesses of each design/technology
- Perform a cost-to-benefit analysis of each design
- Identify a single recommended “New” Nuclear design

- Develop a report on the cost-to-benefit analysis, strengths, and weaknesses of the recommended design
- Identify a method of expressing and displaying the incorporation of nuclear within our electric grid

Prior to and during each of these milestones we will present to our client how we envision conquering and accomplishing said goals. In this process, we will either proceed with our original plan if our client agrees with what we presented. Otherwise, we will adhere to our client's comments and concerns. In which we will change our approach and attack to adhere to our client's request.

5.7 SECURITY TESTING (IF APPLICABLE)

This section is not applicable for our project at this given time.

5.8 RESULTS

We currently haven’t gained any applicable results from our testing. This is due to the stage we are currently in of our project. A testing plan is in place and this section will be updated accordingly.

(Section will be completed once testing is conducted).

6 Implementation

Describe any (preliminary) implementation plan for the next semester for your proposed design in 3.3. If your project has inseparable activities between design and implementation, you can list them either in the Design section or this section.

6.1 CURRENT STATUS

Throughout our first semester of senior design, we have done preliminary research on 15 different reactor designs. Based on Criteria such as

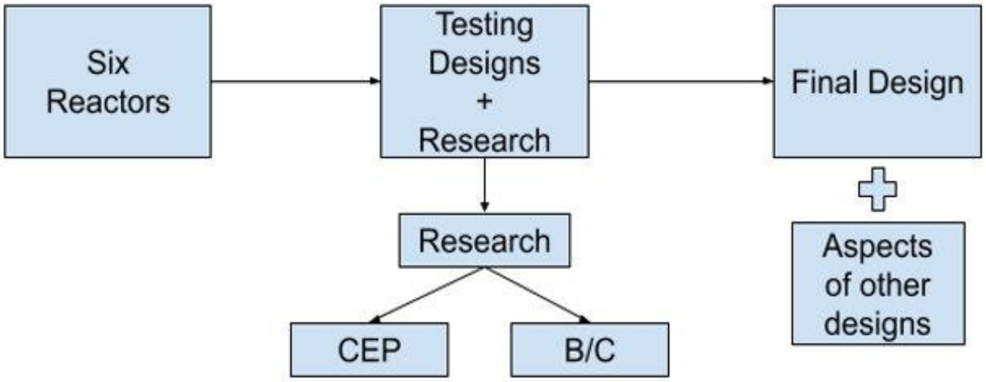
- Safety
- Maturation (e.g. Technical/Manufactuing Readiness Level)
- Construction costs
- Levelized Cost of Electricity
- Fuel costs & type

We reduced our reactor design pool down to 6 total reactors that we like and believe would be best to continue researching.

6.2 NEXT SEMESTER

Our plan for the next semester is to find accurate data for the Benefit to Cost (B/C) and for use in the CEP software for all six remaining reactors. One we are happy with the quality of the data we will analyze the reactors using B/C and CEP.

Following our analysis, we plan on selecting one reactor to be our base reactor for the recommended design (RD). Following that selection, we will integrate aspects of other designs we have researched in an attempt to raise the B/C ratio well above all the designs we have researched.



7 Professionalism

This discussion is with respect to the paper titled "Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment", *International Journal of Engineering Education* Vol. 28, No. 2, pp. 416–424, 2012

7.1 AREAS OF RESPONSIBILITY

Area of responsibility	**Related IEEE code of ethics standards**
Work Competence	IEEE Ethics standards #5 and #6 most closely relate to work competence. These standards discuss the importance of accepting and providing constructive criticism in technical work, and the importance of technical competence in task completion.
Financial Responsibility	The IEEE code of ethics does not relate directly with financial responsibility.
Communication Honesty	IEEE Ethics standards #1 and #3 most closely relate to communication honesty. These standards describe the importance of transparency as it relates to public and environmental safety, along with the significance of addressing conflicts directly with professionalism and respect.
Health, Safety, Well-Being	IEEE Ethics standards #1, #7, #8, and #9 most closely relate to health, safety, and well-being. These standards emphasize the need to protect the public and environment, and to reject all forms of harassment and discrimination,
Property Ownership	IEEE Ethics standard #5 most closely relates to property ownership by stressing the importance of giving credit where it is due.
Sustainability	IEEE Ethics standard #1 most closely relates to sustainability by highlighting our responsibility to protect the environment.
Social Responsibility	IEEE Ethics standards #1, #2, #7, #8, and #9 most closely relate to social responsibility. These standards speak clearly on the topics of harassment and discrimination, along with delineating our responsibilities to protect the public and environment.

7.2 PROJECT SPECIFIC PROFESSIONAL RESPONSIBILITY AREAS

Area of responsibility	**Team Performance and Professional Context**
Work Competence	Team Performance = High The team has worked extremely well with one another. Taking responsibility and having integrity to uphold their portion of the project and ensure it's done well. Good communication has ensured everything is organized and allowed us to gather the results we were after.
Financial Responsibility	Team Performance = High While in our project we haven't had to budget for any of our research or designs. We still need to think from a financial perspective when evaluating our designs. Since this is one of the most important factors in developing "New Nuclear"
Communication Honesty	Team Performance = High

	For our project it’s extremely important to be transparent on all aspects of our “New Nuclear” design. There is already a consensus around nuclear being extremely dangerous. However, these worries, while warranted, just aren’t the case in modern day.
Health, Safety, Well-Being	Team Performance = High Looking at the health, safety, and wellbeing is extremely important within our project. One of the main driving forces for new nuclear is to improve the quality of life for the people. While also ensuring additional reliability.
Property Ownership	Team Performance = High In our project we are doing lots of research on various reactor designs. It’s extremely important that we credit the websites we visit for information.
Sustainability	Team Performance = Medium Nuclear isn’t considered a renewable source but it is better than the alternative options of Coal and Natural Gas plants. We are keeping in mind the waste nuclear produces and how to adequality make sure the environment isn’t impacted.
Social Responsibility	Team Performance = High It’s extremely important that we respect all people’s opinions within our project. Additionally, it’s important to hear the public’s concerns and address them. It’s our goal to give the public some ease and educate the public on all aspects of “New Nuclear”

7.3 MOST APPLICABLE PROFESSIONAL RESPONSIBILITY AREA

The most applicable professional responsibility area for our project is work competence. It is of the utmost importance that our team works with integrity and diligence during all stages of our project to yield accurate and trustworthy results.

8 Closing Material

8.1 DISCUSSION

The project scope has been narrowed down to six reactor designs that we are continuing to research and analyze. Reactor analysis is being performed with the help of CEP (Co-optimized Expansion Planning) software that allows us to look at each proposed design and determine which reactors and features are the most effective economically and functionally. Of the project requirements shown below, we have completed requirement #1 and are in the process of completing #2 and #3. The final steps for all remaining requirements will be completed in full next semester.

1. Identify all reasonably practical "new nuclear" designs that have been suggested so far. Develop a summary report of these technologies that identifies their strengths and weaknesses. Estimate the Benefit to Cost ratio of each design.

2. Based on the various technologies surveyed in step 1, identify a "recommended design" (RD). The RD could be one of the technologies surveyed, or it could be an extension of one of them, or it could be an integration of two or more of them.

3. Illustrate and describe the RD in detail. Identify any significant problems with the design and describe solutions for these problems. Provide a convincing argument that the RD's Benefit to Cost ratio is better than all other designs considered.

4. Identify and evaluate tools useful in designing and assessing the performance of the nuclear power plant.

8.2 CONCLUSION

In summary, up to this point, our team has:

- Identified 15 potential reactor designs
- Researched these designs
- Carefully developed several criterion to assess the strength of these designs
- Presented our designs to our faculty mentor
- Narrowed our list of 15 designs down to 6 based on our evaluation criteria
- Performed in depth research of the selected 6 designs (ongoing)
- Used CEP software to study how nuclear may fit in with wind and solar (ongoing)
- Used CEP software to assess the costs and benefits of our selected 6 designs (ongoing)

To reiterate our goals, by the end of the spring semester we would like to consolidate our 6 selected designs into one final recommended design. The RD will be selected based on our evaluation criteria and our benefit-to-cost analysis. We would also like to demonstrate via CEP software that a portfolio of wind and solar with nuclear as a complement is both feasible and desirable.

The tasks we must complete by the end of the semester include:

- Perform in depth research of the selected 6 designs
- Use CEP software to study how nuclear may fit in with wind and solar

- Use CEP software to assess the costs and benefits of our selected 6 designs
- Do in-depth analysis of benefit-to-cost ratio of selected 6 designs
- Make recommendation on one final design
- Illustrate our recommended design in detail

Up to this point, our team has not hit any major roadblocks in completing our project. This is due to our high level of commitment, and carefully selecting and planning ahead for the work that needs to be done. By carefully following these tasks, our team is confident that we will conclude with a successful project.

8.3 REFERENCES

[1] "Advantages and challenges of nuclear energy," Energy.gov, https://www.energy.gov/ne/articles/advantages-and-challenges-nuclear-energy (accessed Dec. 3, 2023).

8.4 APPENDICES

8.4.0.1 – There were complications with the software we had planned on using for generator analysis because of some misconceptions about what each software could effectively do. We originally looked at using Siemens PSSE or Aspen HYSYS, but ended up being provided with a tool called CEP that is better suited for the analysis we were wanting to perform.

8.4.0.2 – A presentation was created to demonstrate the bulk of the early research that was performed on many of the reactors. The presentation is linked here and outlines a variety of the specifications the various reactors had to offer.

8.4.1 Team Contract

Team Members:

1) Dana Boor
2) Mason Richards
3) Jeremy Yost
4) Zach Hainline
5) Muhammad Syukri
6) Damien Henry

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:

   Advisor/Client Meeting: Coover 1115 Tuesday 4:00pm to 5:00pm

   TA Meeting: Coover 1301 Monday 1:00pm – 1:30pm

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face): Microsoft Teams
3. Decision-making policy (e.g., consensus, majority vote): Majority vote.
4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived): Team members are expected to record notes individually during team meetings.

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings: Team members are expected to attend all team meetings. However, should conflicts arise, team members should notify other team members 24 hours prior to meeting (if possible). Team members are expected to report to meetings prepared to share the status of their portion of the project.
2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines: Team members are expected to meet established deadlines. However, should a conflict arise, team members are expected to notify other team members as soon as possible.
3. Expected level of communication with other team members: Team members are expected to respond to communication within 24 hours (weekdays).
4. Expected level of commitment to team decisions and tasks: Team decisions are expected to be adhered to by all team members. All members are expected to put forth their best effort on assigned tasks.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):

Dana – Team Lead

Damien – Team/meeting organization

2. Strategies for supporting and guiding the work of all team members:

Team members will be assigned explicit tasks to perform throughout the course of the project. During weekly team meetings, members will be expected to give a status update on their portions of the project. These status updates will give fellow team members the opportunity to provide support and guidance.

3. Strategies for recognizing the contributions of all team members:

Team members will be held accountable for their portions of the project. The completion of assigned tasks will allow our team to recognize the contributions of individual team members.

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.

Damien – Concurrent MBA student with skills in project management and finance, useful when analyzing the economics and feasibility of each design.

Zach - Utility experience with transmission and distribution protection devices. Ability to collaborate with others and integrate into roles needed within a team. Have worked/working in a management role.

Mason – Utility experience in both the transmission and distribution. Generally good with learning new software or tools. Fairly good with technical documentation.

Dana – Experience operating and maintaining nuclear reactors in the military.

Syukri – Able to tackle intricate mathematical problems, particularly in engineering and electrical contexts, decent knowledge in coding, grasp of basic quality control assessment.

Jeremy – Good with learning/experimenting with different software. I have a perspective of standard nuclear power plant operation from my father.

2. Strategies for encouraging and support contributions and ideas from all team members:

By assigning specific tasks to each team member, our team will ensure that everyone gets to contribute and be an equal part in the final product. Each team member will have the opportunity to share ideas at our weekly team meetings, as well as in our Microsoft Teams chat.

3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)

Team members will attempt to resolve differences at the lowest level possible first, i.e., attempting to talk to one another first and with fellow team members. If issues persist, our TA and faculty advisor will be notified of the situation and asked to assist our team in finding solutions.

Goal setting, Planning, and Execution

1. Team goals for this semester:
   a. Identify all reasonable, practical "new nuclear" designs that have been suggested so far. Develop the summary report together with the design's strengths and weaknesses.
   b. Based on technologies surveyed in step a, identify a recommended design or two to further investigate upon.
   c. Illustrate and describe the RD in detail. Identify any significant problems related to the design and potential solutions. Provide a convincing argument that the RD's benefit-to-cost ratio is better than all other designs considered.
   d. Identify and evaluate tools that are useful in designing and assessing the performance of a nuclear power plant.
2. Strategies for planning and assigning individual and teamwork:

Team members will be assigned explicit tasks to perform individually. Weekly team meetings and collaboration online in Microsoft Teams will allow members the opportunity to bring ideas together and receive feedback from fellow team members.

3. Strategies for keeping on task:

By setting and adhering to deadlines and specific project milestones, our team will ensure that our project will reach completion by its due date.

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?

Team members who are not following the expectations set forth in this contract will first be contacted by fellow team members.

2. What will your team do if the infractions continue?

If infractions persist, team members will contact Dr. McCalley and our TA advisor to discuss further intervention.

****

a) *I participated in formulating the standards, roles, and procedures as stated in this contract.*

b) *I understand that I am obligated to abide by these terms and conditions.*

c) *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*

1) Dana Boor	DATE 09/09/2023
2) Zachary Hainline	DATE 09/10/2023
3) Muhammad Syukri, Ahmad Zainal	DATE 09/10/2023
4) Jeremy Yost	DATE 09/10/2023
5) Mason Ricards	DATE 09/10/2023
6) Damien Henry	DATE 09/10/2023