Investigating the Educational Effectiveness of a Science Museum Exhibit on Small Modular Fusion Reactors

by

Margo Alexandra Batie

Submitted to the Department of Nuclear Science and Engineering in partial fulfillment of the requirements for the degree of

Bachelor of Science in Nuclear Science and Engineering

at the

Massachusetts Institute of Technology

May 2014 [June 2014]

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Abstract

Most people are unaware of the tremendous potential fusion reactors and smaller, more modular reactors possess. To inform them, a science exhibit was constructed to investigate whether or not it would more effectively teach the audience which in this case are passersby on the first floor of MIT's building 24, about small modular reactors (SMRs) compared to an executive summary written to explain the same technology. Through the employment of hand written surveys, visitor feedback from the executive summary was compared to visitor feedback on the exhibit. The data indicated that although the exhibit lacked the technical detail of the executive summary, it provided a larger proportion of visitors with sufficient background information and a greater appreciation and understanding of fusion energy and reactor modularity. Future SMR exhibits should employ more elements that encourage visitor interaction, such as a demonstration of plasma behavior, as well more information on the cost and feasibility of the technology.

Thesis Supervisor: Michael P. Short
Title: Professor of Nuclear Science and Engineering

Acknowledgments

First and foremost, I would like to thank my Lord and Savior Jesus Christ for without him none of this would be evven imaginable.

Secondly, I'd like to thank my thesis supervisor Dr. Michael Short for always encouraging me to put my best foot forward and supporting me throughout my thesis work. A huge thank you goes to Jane Kokernak for helping me throughout the writing process of this thesis. Regardless of the time of day or how busy you were, you constantly gave me quality feedback from start to finish.

I also wish to acknowledge Lauren Merriman for all of the hard work she put into this project. You made this thesis so much fun, and I'm happy we had a chance to get closer this year because of this project. Special thanks to my other fellow exhibit designer, Martin Lindsey, along with the rest of the Fall 2013 22.033 class for such a successful collaboration, which eventually lead to the creation of this thesis.

Thank you Mom, Dad, and Matthew for your never ending love, prayers, and support throughout this journey. I love you all more than you can imagine.

Last but certaintly not least, I want to Devin and Elise for being by my side for every step of this journey, and Kelana for always believing in me and consistently challenging me to be better each day. Thank you Dafina for helping me finish strong during my last semester, and thank you everyone else who contributed to me making it to this point. I am truly humbled by all the love and support I received throughout this journey. This is only the beginning.

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Chapter 1

Introduction

As the world's population increases, so does the demand for electricity. Society has accepted the fact that coal power and fossil fuels are finite and not sustainable long term; however, there is no worldwide agreement on what source of energy should be used to meet this growing demand for power. Fusion power has the capability of providing virtually unlimited clean energy from the reaction of naturally sustainable and universally available fuel. Remarkable progress has been made in the field of fusion power, and fusion is currently at an exciting threshold: the long sought-after plasma breakeven point, described as the moment when plasmas in a fusion device release at least as much energy required to produce it[4]. Various designs of fusion devices exist yet the most advanced and most investigated design is the tokamak. The tokamak is a torus-shaped vacuum chamber surrounded by magnetic coils, which create a toroidal magnetic field that confines the plasma[1]. A cross-sectional view of a spherical tokamak is shown in Figure1-1.

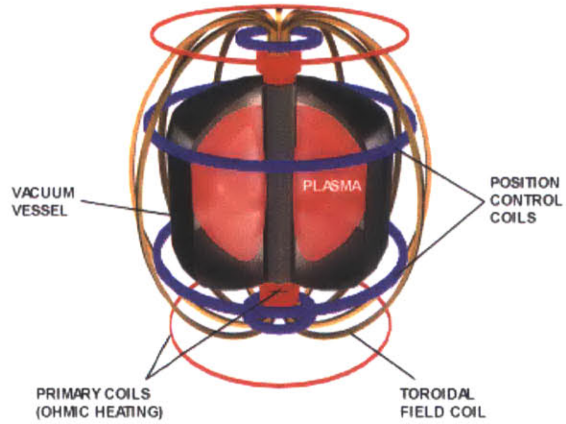


Figure 1-1: A Cross Sectional View of a Spherical Tokamak

Small Modular Reactors (SMRs) are defined by the International Atomic Energy Agency as reactors with an equivalent electric power less than 300 MW [2], compared to present day nuclear plants, which have power outputs on the order of thousands of MW. These compact reactors are factory fabricated and can be transported by truck or rail to the nuclear power site. For this reason, SMRs have the potential to meet this growing need for sustainable energy for hundreds of millions of years, by providing clean, safe, affordable electricity to the world's rapidly changing and diverse markets. SMRs will contribute to local, regional and national technology development, accelerate economic development, stimulate job growth, support workforce development, and improve standards of living for current and future generations. A few of the many applications of the energy produced from these reactors includes desalination, gas refinement, pump modules, and district heating[3, 4]. These small scale reactors offer alternatives for places that do not have access to the main power grid or places which do not require the large amount of energy outputted by modern day reactors, such as Central Africa or Eastern Europe.

In the Fall 2013 Senior Design Project class at MIT, 22.033, students studied the intersection between small modular reactors and nuclear fusion. The students in 22.033 had to design a ready to build small modular fusion reactor and design a science museum exhibit. The exhibit designers had the task of designing an exhibit that ties together concepts of core design, thermal hydraulics, materials, safety, and the SMR design process. The fusion design chosen for this project was a type of tokamak called a spherical tokamak (shown in Figure 1-2). The targeted audience for this exhibit would be anyone walking the halls of MIT, since the exhibit would be placed in the first floor corridor of the Nuclear Engineering building. These passersby would include: Faculty, staff, undergraduate and graduate students, post docs, and tourists. The exhibit must explain to the audience how fusion power works and the benefits of modularity in electricity generation[3]. For this exhibit to be successful it would have to explain the keys issues behind fusion and modularity, provide information, encourage visitors to think critically in order to further understand the real world relevance of fusion and modularity and make educated decisions about nuclear energy policies based on their discoveries. This information must be accurate, concise, intellectually accessible, and stimulating to as wide a range of visitors as possible[6].

Figure 1-2: 22.033 Spherical Tokamak Design

The objective of this thesis project was to investigate whether an interactive exhibit more effectively teaches the audience about small modular reactors and fusion compared to the same audience reading an executive summary written and prepared in parallel with the exhibit design. Different people have different learning styles and an exhibit offers multiple ways to engage the visitor while educating the visitor of the relevance of SMRs. After several iterations, the final exhibit should demonstrate to the public that small modular fusion reactors will redefine the way that we harness energy in a way that is tailors the exhibit to the audience's needs (i.e. is informative, engaging, effective, useful, etc.).On the other hand, an executive summary on small modular fusion reactors offers text and a few illustrations as explanations of SMRs to the audience, and may, or may not, meet the same needs to a different degree.

Surveys of the visitor experiences reading the executive summary and interacting with the exhibit were compiled and compared. The data indicated that the audience was able to comprehend both the executive summary and the exhibit, however the exhibit taught the same information in a more accessible and fun way, and gave the appropriate amount of background information for the variety of visitors. Overall, the exhibit provided a more intuitive experience, giving visitors a greater appreciation for both the technology, its usefulness, and the benefit of public awareness of SMRs.

Chapter 2

Background

An exhibit is a public display of information on a certain topic with the intent of educating the audience, or the people expected to be interacting with the exhibit. In order to design an effective exhibit, the needs of the audience must be taken into account, as well as what material exhibit designers want communicated to this target audience. Exhibits are unique ways to capture and maintain the visitor's attention in order to inform them about a topic that the exhibit designers feel is important for the target audience to be aware of. With these considerations in mind, a science exhibit was constructed in order to illuminate the importance of small modular reactors and the benefits of fusion energy. To optimize this exhibit, multiple prototypes were constructed with the intention of gathering information on what the audience did and did not like. This feedback would then be incorporated into a final exhibit, and a final round of surveys would be dispensed to verify whether or not the exhibit is more effective at teaching than just a text document.

2.1 Communicating with a Target Audience

In every communication, it is necessary to ask: who is the audience and what questions do they want answered? The exhibit designers had certain ideas that they wanted to convey, but focusing solely on those certain ideas might have lad to an exhibit that is boring and difficult to understand. It must be designed to meet the needs of the visitors, the individuals who will be interacting with it, learning from it, and telling their friends about it [11]. To be successful, the exhibit must present to the audience information that they find accurate, concise, intellectually accessible, and stimulating [9].

The audience for this small modular fusion reactor exhibit was chosen based on where it would be placed: the first floor of MIT's building 24 (Nuclear Science and Engineering headquarters). Thus, the audience could be anyone passing through this hallway, including but not limited to faculty, staff, undergraduate and graduate students, post-doctorates, and tourists. To obtain a general idea of what these passersby,—largely the general public—desire, studies of visitor preference were examined. One such study [12], commenting on audiences in general, concluded that visitors who are exposed to new scientific concepts:

- are uncomfortable with scientific uncertainty. Providing them a sense of the relative acceptance of various perspectives can help, meaning if there isn't a concrete solution to the problem introduced, at the minimum offer different angles to the visitor, so that they can draw their own educated conclusions about the topic at hand.

- want a body of information they can rely on as scientific fact.

- want information about the impact of science and technology, not just the facts, since issues are not static and public perception of the issues may be changing.

- must be able to find themselves in any presentation. Multiple perspectives offer a mirror so that members of the audience can see themselves and their point of view in the exhibit. Comparing others' opinions to their own can help them form a unique sense of understanding.

A way to ensure that these needs are met is to regard the exhibit as a means of conveying a core message that answers the questions that the audience has about its subject.

2.2 Core Message

Effective exhibits use the visitor preferences mentioned above to form simply stated, single beliefs or sentences in the visitor's language. The messages of the exhibit can be organized such that there is a core message (usually a single sentence) containing the most important message, which is supported by the entire exhibit. The goal of this core message is that, if one were to interview visitors after they spend time at the exhibit and them for one sentence about its subject, their response would be that same message. To give an example, for an exhibit with the title "Darkened Waters: Profile of an Oil Spill," designers at the Pratt Museum brainstormed the following core message for consideration [12]:

- Alaska is a national treasure and it must be protected.
- It was a huge disaster.
- We couldn't clean it all up.

Of note here is the simple phrasing and use of colloquial language—the core message is what the visitor should understand after leaving the exhibit and must therefore be a thought that the individual constructs, rather than a thought that is implanted by the exhibit's designers.

The core message for this exhibit investigated in this thesis project is that "Small modular fusion reactors have the potential to redefine the way that we harness energy." In order to ensure that this message is effectively communicated to our audience, the designers had to have all exhibit elements support this notion.

2.2.1 Exhibit Elements

Exhibit elements must not only cater to conveying the core message but also to the variety of learning styles the audience possesses and the limited attention span of this audience, who were passersby.

An element's modality (the combination of senses that it engages) is of utmost importance: since each individual has a unique learning style and sensory preference, certain elements will be more effective for certain visitors [13, 7]. For instance, a visual element that only engages one's sense of sight would not be very effective for a primarily tactile learner, who thrives on physical interaction. Furthermore, an element's interactivity (the extent to which action is required on the visitor's part) also calls for careful consideration; exhibits that are more interactive tend to be more enjoyable and are associated with higher rates of information retention [9, 8], but too much interactivity can leave visitors overwhelmed, inhibiting the learning experience [13]. This necessitates a balance between "passive" elements, which allow the visitor to use the tools of comprehension which they are most accustomed to learn, and "active" elements, which guide the a visitor along a conceptual pathway in situations where descriptive labels are insufficient.

A visitor's attention span can be considered a scarce resource. The best example of this is their tendency not to read labels, which is a well-understood phenomenon within the professional exhibit design community [13, 7, 15, 9]. Text is a delicate yet essential component—too little risks leaving the visitor confused and frustrated, while too much is one of the "10 deadly sins" of exhibit design [15]. It is also important that elements of an exhibit appear exciting or unusual at first glance. Care must be taken, though, that an element's ability to capture and maintain a visitor's attention does not detract from its educational capacity.

2.2.2 Exhibit Requirements

Thus, the elements to be included within an exhibit are subject to several (often contradictory) design pressures. When proposing those elements with which to express the core and sub-messages of the small modular fusion reactor exhibit, it was required that the elements collectively demonstrated the following qualities:

- a variety of modalities
- multiple levels of interactivity but not too much overall
- a minimal quantity of [quality] text, only to be used as a last resort

- several visually striking elements
- space availability, universal design guidelines

After consulting with the Administrative Officer in charge of the site about fire safety regulations for the intended location of the exhibit, a set of size constraints were obtained. The rest of the details would depend on a set of universal design guidelines in compliance with the 2010 Americans with Disabilities Act. Below are a few examples of the standards that had to be incorporated [14]:

- minimum of 17 inches of wheelchair pull-under space for surfaces connected to the wall
- reach distance of no more than 20 inches from standing or sitting position for wall-mounted elements
- minimum height of 27 inches for surfaces connected to the wall
- head clearance of at least 80 inches
- angle of 45° for inclined label/touchscreen surfaces

In addition to including these features, it is important that the exhibit is easy to transport and install (i.e. it can fit through doorways and in the back of a pickup truck).

2.3 Previous Prototyping

Multiple prototypes and surveys were constructed to gauge visitor interest and optimize the visitor's experience. Table 2.1 outlines the timeline of prototype fabrication. The data collected from these prototypes were used to construct a final exhibit which was tested to verify whether or not a science museum exhibit on SMRs could more effectively teach the public compared to a short summary of the concepts introduced in the exhibit.

Table 2.1: The Exhibit Prototyping Timeline

Task Description	Time Frame
Preliminary Survey of Audience Interests	September 2013
The First Prototype	October 2013
The Second Prototype	November 2013
Completion of 22.033 Design Course	December 2013
The Third Prototype	February 2014
The Final Exhibit	May 2014
Distribution and Survey of the Executive Summary	May 2014

2.3.1 Preliminary Survey

The informational content of the exhibit was organized into questions that are considered important to the topic of small modular fusion reactor development. Taking note of the most basic queries (who, what, where, when, why, how) that a visitor may have regarding this topic, a list of questions (shown in the following subsection) was constructed. Several questions on this list were deemed absolutely necessary to answer, regardless of visitor opinion. These questions were:

- What does it do?
- When will this be commercially available?
- Which problems does it intend on solving?
- Why should I care?
- How does it compare to alternative sources?
- How safe is it?

A survey was composed to gather data on visitors' interest in each question. The survey was sent to every residential group on MIT's campus. The questions that the exhibit designers wanted to answer were used for the survey, and the visitors were asked to rank the questions on a scale of 1 to 5, one being "Least important/I don't care if this question is answered," and 5 being "Most important/I need to know!" Survey participants were also asked to provide their department, class year, and (optional) any questions they would like answered that was not listed or any other comments or suggestions.

The survey received responses for a period of approximately 72 hours. During those 72 hours, 104 responses were recorded, with representation from undergraduate students, graduate students, and one post-doctorate student. Respondents came from a majority (19 of 23) of courses of study offered at MIT. The sixteen questions that were posed to these survey participants are listed in descending importance according to the survey participants in Appendix A. The seven questions considered to be fundamentally important regardless of audience interest,—shown in bold—, happened to coincide heavily with those in which survey participants were most interested.

The proportion of responses at each level of interest determined the importance of each question, i.e. a question was considered most important if, out of all of the responses for that question, the highest percentage of survey participants deemed it "most important." The "most important" questions were then refined to use in the process of determining the physical components of the exhibit.

2.3.2 Phase One: The Paper Prototype

It is never too early in the design process to open a dialogue with members of the target audience and begin to seek feedback. In fact, the sooner this is done, the better: professional exhibit developers often warn of moments wherein a design is finally shown to a potential visitor and a multitude of unforeseen obstacles to understanding become apparent, requiring an overhaul of one or more elements [5].

To this end, rough drafts of each element were created by hand with 8.5 $\times$ 11 inch printer paper. Text consisted of 50-word segments, and graphics were used liberally. The prototype (Figure 2-1) was constructed using 25 sheets of paper; participants were then politely asked to use their imaginations and give preliminary commentary.

Scanned images of the sheets of paper used to represent the exhibit are included in Appendix B.

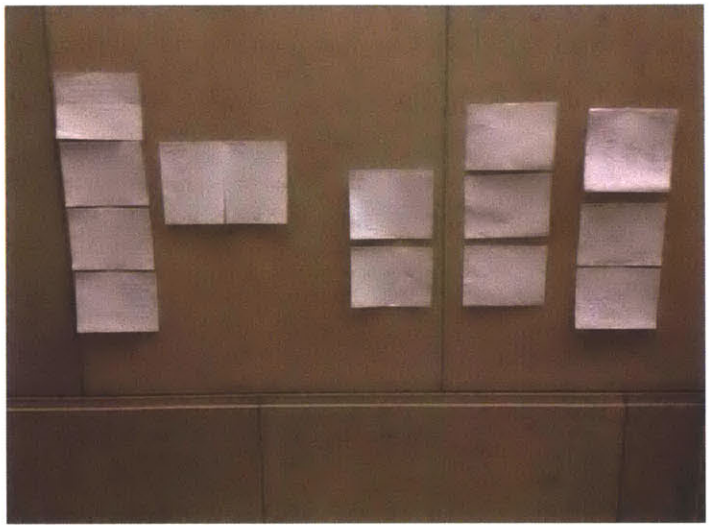


Figure 2-1: The Layout of the Paper Prototype in Lobby 7

This study took place in lobby 7 of MIT's main building over a period of two hours. Because the process was predominantly a means of becoming aware of glaring design flaws, an entry/exit survey was eschewed in favor of verbal requests for the following information:

- visitor affiliation with the Institute and/or (intended) field of study
- visitor's self-described technical background

These details provided valuable context for the feedback collected from the initial prototype.

Approximately 40 individuals provided feedback during the initial prototyping phase. Their commentary is shown in Appendix C. The main takeaways from this exercise were that:

- Many visitors wished to have a clearer framing of the problem the technology is designed to solve, as well as more direct presentation of other practical considerations, such as its stage of development and feasibility. Making the timeline bigger and more central would help with this issue.

- Many participants wound up lost within the content of the exhibit because they began their visiting experience at elements other than the intended "starting point.", which was understood by the designers but not explicitly indicated to the audience Breaking the exhibit up with titles would let elements stand more firmly on their own and allow visitors to more easily navigate the content.

- Despite efforts to keep wording simple, many visitors were still alienated by technical content. Complex topics needed even simpler, more careful explanation than previously attempted; "jargon" such as D (deuterium) and T (tritium) needed to be spelled out consistently throughout the exhibit.

2.3.3 Phase Two: The First Cardboard Prototype

After incorporating feedback collected from the first phase, the next phase of prototyping was conducted via a similar method. Like before, the activity took place over a two hour period in Lobby 7. Unlike before, it occurred during MIT's annual Splash! event, where thousands of high school students flood MIT's campus to take classes taught by MIT students. This event conferred the advantages of higher foot traffic than previously and a different audience (high school students whose technical background provided useful comparison to that of the previous audience). New features included a cardboard mockup shaped to resemble a "slice of a hemisphere" of the spherical tokamak design (see Figure 2-2), a higher graphic-to-text ratio and clearer wording, section titles, printed text, and an active element: a small, battery powered plasma globe to represent the discharge tube to explain its association to fusion energy. An animation documented the pathway of energy from its generation in the fusion core to its application.

Figure 2-2: The First Cardboard Prototype in Lobby 7

A written survey, consisting of the following short answer questions, was presented to visitors after they viewed the cardboard prototype. The purpose of the survey was to identify a minimum amount of text that still imparted adequate explanations of SMRs and fusion, and gauge the effectiveness of an active element to explain plasma confinement.

- What is your affiliation to MIT? (e.g. Splash student, Splash parent, undergraduate, graduate, post doc, professor)
- What did you like about the exhibit? What didn't you like?
- What was the most important thing that you learned from the exhibit?
- What would you liked to have learned more about?
- Did you have enough background information? Was everything easy to understand?
- Any other comments, questions or concerns you had about exhibit?

The second time around received a similar number of participants to the first: 43. The responses to each survey question are recorded in Appendix D.

Common responses were similar to those from the previous exercise, namely:

- sheer number of elements / lack of cohesion. Many participants commented on how many components there were and how it was difficult to tie them together conceptually.

- lack of clear flow through the exhibit. Despite titles, participants were liable to start viewing the exhibit at the wrong part.

- unexplained terms / topics that needed context. The greater the number of specific details included, the less likely a visitor is to pay attention.

- it is also worth noting that very few participants paid attention to both sides of the exhibit, and almost no one looked at the map component. The second prototype was intended to include more specific details of the reactor design and the science that it exploits, but these details required additional explanation and ultimately left test visitors unable to see "the big picture." This made obvious the need to keep the content of the exhibit as simple as possible and to keep the need for background info (i.e. text) at a minimum.

2.3.4 Phase Three: The Final Cardboard Prototype

The next phase of prototyping was similar to the previous one. It lasted approximately two hours in Lobby 7 and Lobby 10, and fewer responses were received since it took place during MIT's Independent Activities Period (i.e., during January Vacation). This translated to significantly less foot traffic since only a fraction of the student body was on campus. This prototype was on cardboard (see Figure 2-3) and new features included: splitting the exhibit to be organized into a Science section and an Engineering section, inclusion of a diagram of how a SMR power plant would look like, and an added "Why Fusion" section. The animation and uses of energy were, as before, represented by images. The objective of this prototype remained the same as the previous phase, which was to identify a minimum amount of text that still imparted adequate explanation.

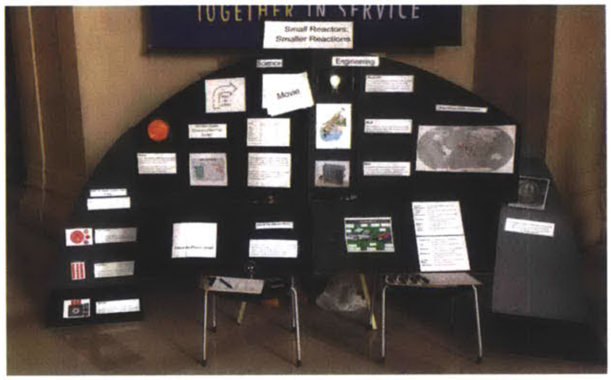


Figure 2-3: The Final Cardboard Prototype in Lobby 7

A written survey with the both short answer and multiple choice questions was presented to visitors after they viewed the prototype:

- What is your affiliation to MIT? (e.g. undergraduate, graduate, post doc, faculty/staff, visitor)
- What did you like most about the exhibit? Why? (fusion infographic, plasma tube and instructions, movie, 3-D diagram of power plant, maps, timeline, other)
- What did you like the least about the exhibit? Why? (fusion infographic, plasma tube and instructions, movie, 3-D diagram of power plant, maps, timeline, other)
- Did you have enough background information? Was everything easy to follow and understand?
- Any other comments, questions, or concerns you had about the exhibit?

A total of 21 responses were received and are tabulated in Appendix E. The primary takeaways from this phase were:

- need better way to not only define but describe how SMRs are better, where they will belong and their size compared to other power plants other than the map. An explanation was given; however, visitors who do not read the entire exhibit may not have come across this explanation. More attention grabbing explanation needed

- no longer hearing stuff like, "too simple." The content is at a level that challenges that majority of the audience!

- maybe use engineering section to talk more about the plant, the weight, the ease of deployment, as opposed to giant sections on applications. Some visitors wanted to know more about how and why SMRs are so beneficial

- people complaining more about medium than what's on it. no more cardboard prototyping since at this point the content is sound

- confusion remained about where to begin from. The idea was to let visitors feel around for what they were interested in learning about within the realm of SMRs but more direction is desired (with arrows, titles, colors, boxes, etc.). These indicators would also be useful for references made in survey that visitors were unfamiliar with.

2.3.5 Suggestions for the Final Exhibit

After the analysis of all the prototyping feedback, a list of improvements consisting of both physical and promotional enhancements was formulated for the final exhibit. The most obvious aspect is the technical specifications: those of the particular devices that it uses (e.g. interactive elements such as a light bulb, Archimedes screw, and radiator to represent possible energy uses), the internal circuitry, and the materials out of which to construct it. These aspects had been considered secondary in the first stages of the development process. The focus had been, more than anything else, an exercise in finding out how to convey as much information as possible within a narrow window of time during which a visitor may or may not even pay sufficient attention.

However, while more conceptual prototyping is certainly necessary, it is also necessary to develop these physical aspects of the exhibit so that

While the prototyping feedback called for more conceptual prototyping, the designers concluded that it was also necessary to develop the physical aspects of the exhibit so that more useful feedback could e acquired. The intermediate constructions of an exhibit can be used to refine the physical details of its design as well as the conceptual details.For example, several elements have yet to progress beyond the illustrated-on-paper version (animation, each example of energy use). In the initial prototyping phases, participants had no choice but to envision on their own how these would be implemented, and the focus was mainly on checking if they found that text made sense. In the final exhibit prototype, more emphasis must be placed on better ways to represent these elements in order to enhance the visitor experience.

Beyond the improvement of particular aspects of the exhibit, it is also vital that post construction and after the unveiling of it, it is adequately publicized. This last step is particularly crucial: the exhibit is meant to be a unique way of engaging the public in an otherwise inaccessible topic of scientific importance, and it is therefore designed at every step for successful exposure to as wide a range of individuals as possible.

Chapter 3

Methods

after sufficient prototyping had taken place, the next step was to test the hypothesis: whether the exhibit is more intellectually accessible and engaging than reading an executive summary describing the same technology. The visitor's experience with the exhibit and with the executive summary of SMRs was surveyed and compared. In this section, the exhibit layout and the executive summary are described, followed by an explanation of how the data were collected for each of them.

3.1 The Final Exhibit

In light of the information gathered via prototyping phases, a simplified scheme, making the conceptual path of the exhibit easier to make sense of, that requires less context, so that the exhibit can stand alone without the designers' input, was proposed: the left side containing the scientific background and context, and the right side containing the details of the engineering design. The science content was designed to provide background for the engineering content, but they are both intended to be easily understood on their own. On the far left is a short blurb about the design process of the reactor and exhibit (to provide context), and on the far right is a label to explain the size and shape of the exhibit. The size explanation is meant to explain the motivation for of the shape of this exhibit.

The overall shape of the exhibit was chosen to resemble a "slice of a hemisphere" of the spherical tokamak reactor design. The radius used in this project ended up being approximately 80% of the designed fusion core inner vessel to fit into the space constraints for the location. The shape and size were chosen to provide visitors with a meaningful sense of just how small these small modular reactors are. All large titles were composed 108 point font, subtitles in 72 point, and all text labels in 42 point font to ensure that all text would be both legible and visible. The final exhibit can be seen in Figure 3-1

3.1.1 The Left Panel: The Power Plant Overview

The far left panel (Figure 3-2) was used to give the visitor an brief three step overview of power generation happens in a power plant. The title, "How Do Power Plants Make Energy?" followed by a label reading: "Most power plants begin with some sort of heat source, whether it be burning coal, fission reactions, or concentrating sunlight. This heat is typically used to boil water and the resulting steam turns a generator. The generator then provides energy to your home."

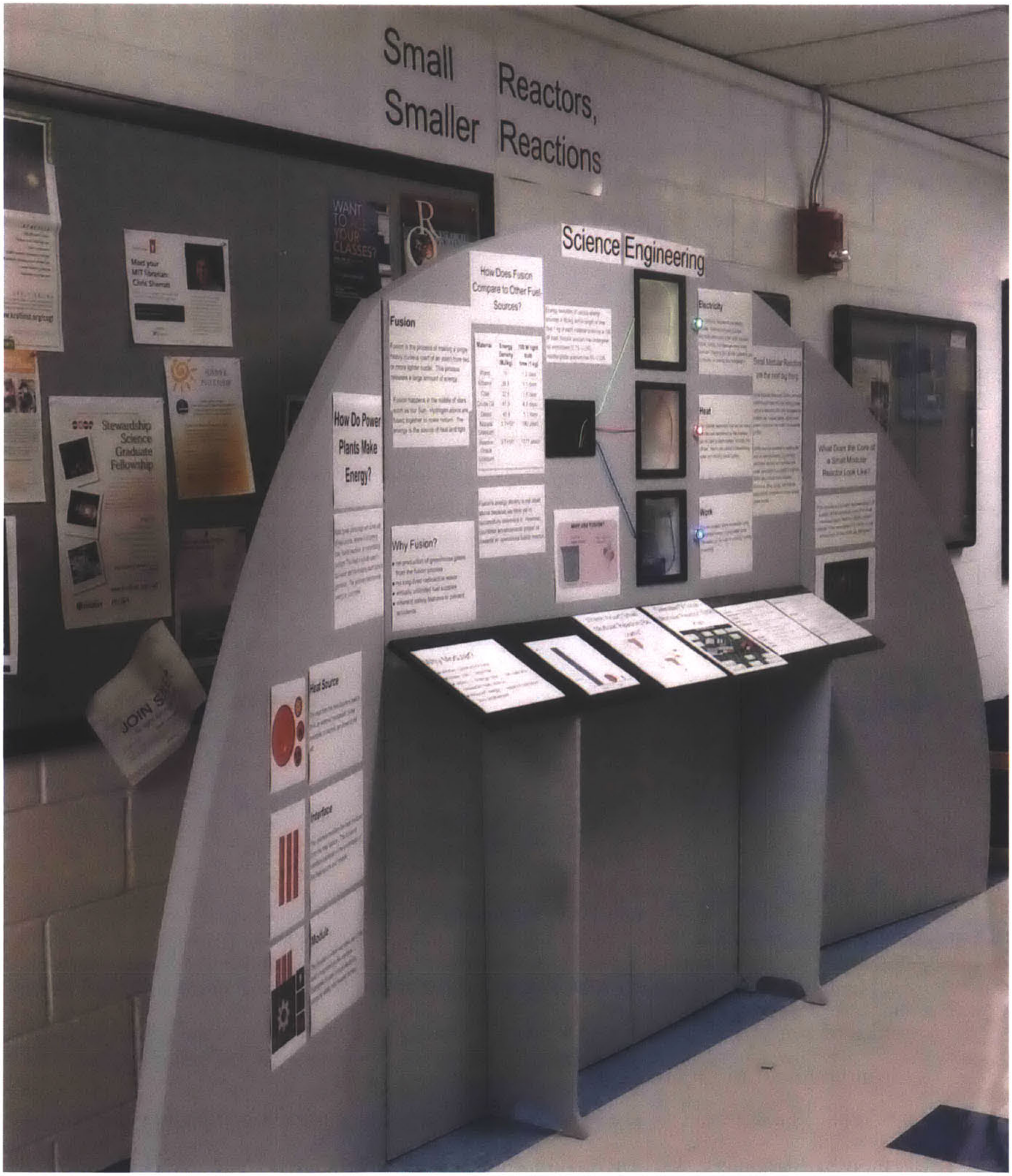


Figure 3-1: The Final Exhibit

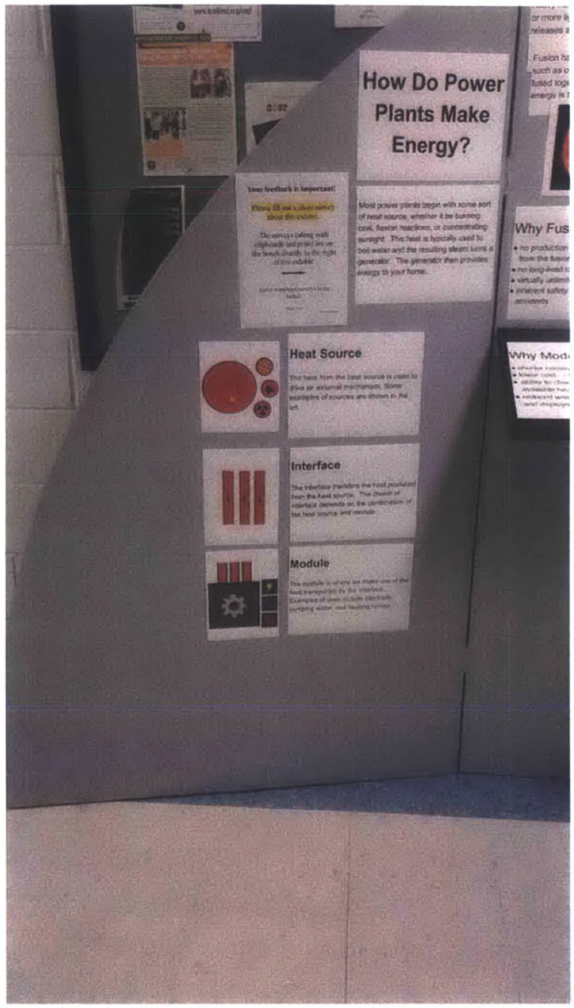


Figure 3-2: The Final Exhibit: The Left Panel

The first step in this process involves a heat source. The heat source label stated, "The heat from the heat source is used to drive an external mechanism. Some examples of sources are shown to the left." The picture associated with the heat source can be found in Figure 3-3A.

The second step in the process is an interface. The interface label reads, "The interface transfers the heat produced from the heat source. The choice of interface depends on the combination of the heat source and module." The interface picture can be found in Figure 3-3B.

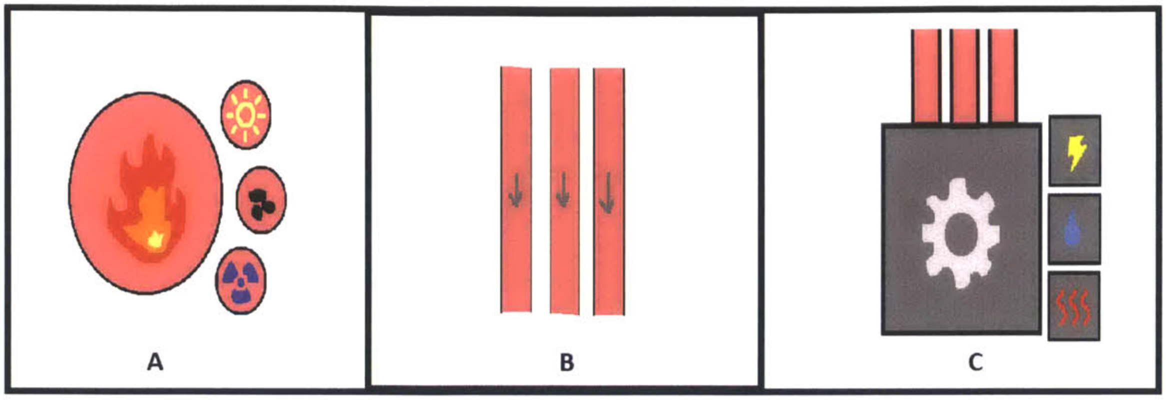


Figure 3-3: The Final Exhibit: A) Heat Source Image; B) Interface Image; C) Module Image

The final step in the process is the module. "The module is where we make use of the heat transported by the interface. Examples of uses include electricity, pumping water, and heating homes." The picture for the module can be seen in Figure 3-3C.

3.1.2 The 'Science' Section

The Science section (Figure 3-4) begins with a short explanation of fusion followed by a photo of one of the most widely known examples of fusion reactions, the sun, shown in Figure 3-5. The label for this section reads, " Fusion is the process of making a single heavy nucleus (part of an atom) from two or more lighter nuclei. This process releases a large amount of energy. Fusion happens in the middle of stars, such as our Sun. Hydrogen atoms are fused together to make helium. The energy is the source of heat and light."

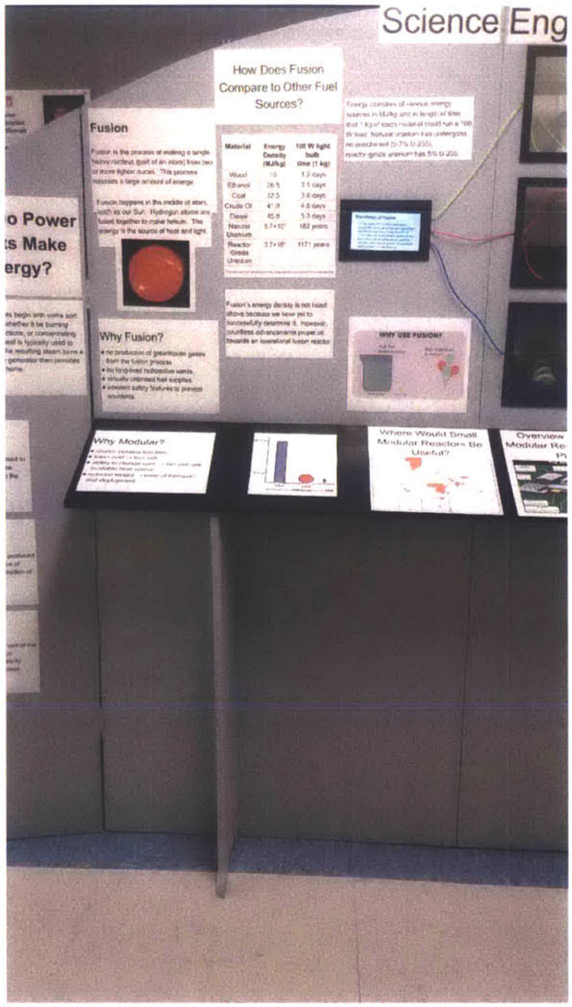


Figure 3-4: The Final Exhibit: The Science Section

The exhibit must also convey to the visitors why fusion is the beneficial source of heat to use a small modular reactor. The 'Why Fusion' label was written directly and simply with four bullet points.

- production of greenhouse gases from the fusion process
- no long-lived radioactive waste
- virtually unlimited fuel supplies

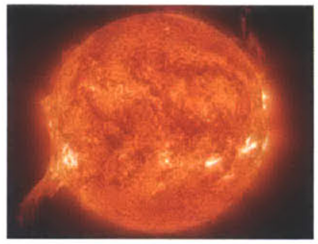


Figure 3-5: Final Exhibit Fusion Overview Image

- inherent safety features to prevent accidents

To accompany the fusion overview and 'Why Fusion' section, which are word intensive for most visitors, the 'How Does Fusion Compare to Other Fuel Sources?' and 'Why Use Fusion' infographic were created to utilize different exhibits to express more of the benefits of fusion. The Fusion comparison employs a table (Table 3.1) to show the energy densities of various materials often used for power generation. The table also gives the visitor a better idea of how much energy 1 kg would provide by indicating how long this energy source would light a 100 watt light bulb. A short label accompanies the fusion comparison table to explain its contents: "Energy densities of various energy sources in MJ/kg and in length of time that 1 kg of each material could run a 100 W load. Natural uranium has undergone no enrichment (0.7% U-235), reactor-grade uranium has 5% U-235. Fusion's energy density is not listed above because we have yet to successfully determine it. However, countless advancements propel us towards an operational fusion reactor."

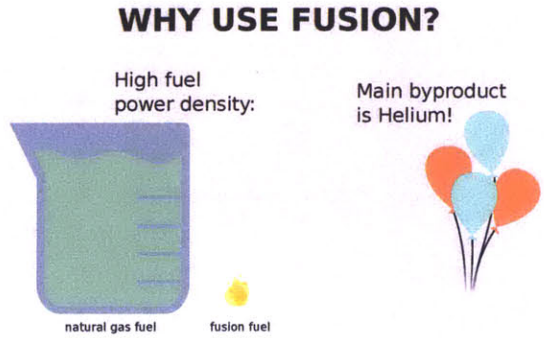


Figure 3-6: Final Exhibit 'Why Use Fusion' Infographic

Table 3.1: Final Exhibit 'How Does Fusion Compare to Other Energy Sources?'

Materials	**Energy Density (MJ/kg)**	**100 W light bulb time (1 kg)**
Wood	10	1.2 days
Ethanol	26.8	3.1 days
Coal	32.5	3.8 days
Crude Oil	41.9	4.8 days
Diesel	45.8	5.3 days
Natural Uranium	5.7×10^5	182 years
Reactor Grade Uranium	3.7×10^6	1171 years

Table (adapted from http://www.whatisnuclear.com/articles/nucenergy.html)

The 'Why Use Fusion' infographic was meant to be a fun and attractive way (but not to scale) picture to explain part of what the energy density comparison had shown. A picture of this infographic can be found in Figure 3-6.

Similar to the 'Why Fusion' section, a 'Why Modular' section lies right below it to emphasize the benefits of not only a fusion reactor but one that is modular as well, organized into four short bullet points as well:

- shorter construction time
- lower cost → less risk
- ability to change core → can use any available heat source
- reduced weight → ease of transport and deployment

To accompany the 'Why Modular' section, the exhibit featured another infographic to show the viewer how our proposed SMR compared in size to other reactors, specifically a small modular fission reactor designed by Westinghouse[4]. A cartoon figure was placed next to the SMRs to give the viewer a sense of scale (see Figure 3-7)

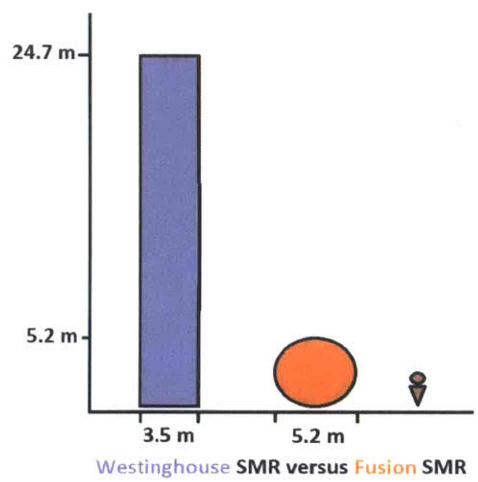


Figure 3-7: Final Exhibit Westinghouse SMR versus Fusion SMR Graph

Another element that was employed by this exhibit was a map that showed where small modular reactors would be useful. This map (Figure 3-8)consolidated the four maps from previous prototypes which showed on a world map the specific uses of the SMRs would be usefully on a world map, namely, desalination, gas refinement, district heating, and pump modules.

Figure 3-8: Final Exhibit World Map of Where SMRs Would be Useful

The last and most visually appealing component of the 'Science' section of the movie; the slides of the movie can be found in Appendix F. This movie consists of a sideshow covering the motivations for the development of fusion power, which includes a timeline showing important events in fusion power history and predictions for its future, and two infographics. The first infographic is about nuclear fusion, covering in broad (and straightforward) terms the details of the nuclear reaction that occurs in the core. The next infographic gives a detailed three-step process of energy production in a reactor, starting with heat generated from neutrons in the spherical tokamak, and proceeding to that heat being transferred through the printed circuit heat exchanger to the super critical CO_2 cycle which ultimately converts the heat to electricity. This element makes use of bright colors and elementary principles of graphic design to appear visually interesting. It is also an excellent method for minimizing text.

3.1.3 The 'Engineering' Section

The movie details the path energy takes from within the fusion core where it is generated, through the interface's heat exchangers, into the power cycle where it is converted into useful work, and finally to a technology that utilizes it. In the engineering section (Figure 3-9), the visitor may select the step along this path depicted in the movie, and is able to further select a particular use (of the energy demonstrated immediately to the right of the screen). Each end use has a red, green or blue flowing effect wire that remains illuminated, connecting it to the movie screen and a small light to serve as a visual queue that illuminates when a particular use is selected via the user pushing a glowing button.

Figure 3-9: The Final Exhibit: The Engineering Section

The following applications of SMR power generation were chosen to be interactive elements in the final exhibit (shown in Figure 3-10): a light bulb representing the use of electricity, a toy Archimedes screw by Tedco Toys representing the use of mechanical work (in this case to move water uphill, such as in a pump), and an electric heating pad with a liquid crystal sheet that turns colors when the heating pad is powered on, to represent direct use of the generated heat.

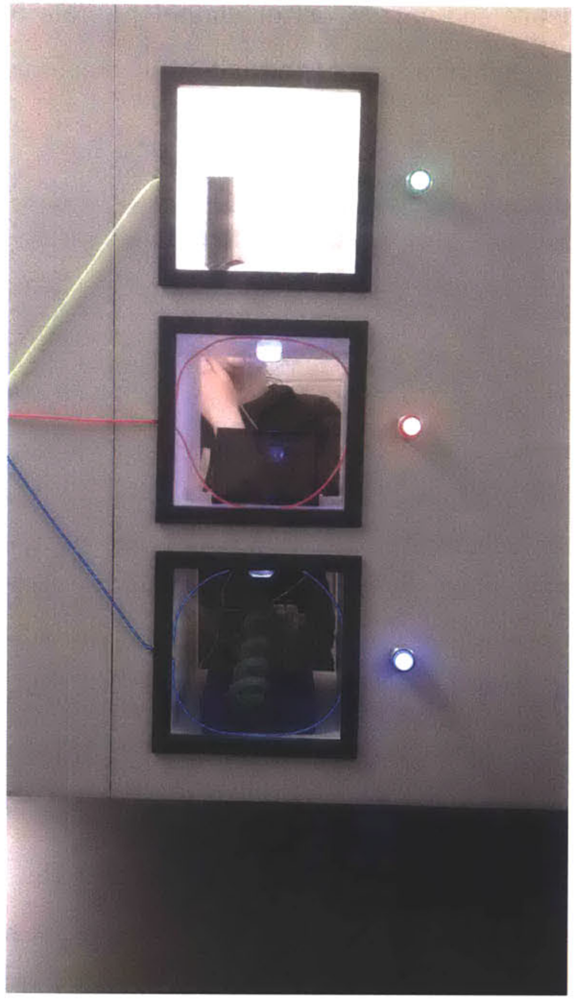


Figure 3-10: The Final Exhibit:Three Applications of the Energy Produced in an SMR: Electricity (green), Heat (red), and Work (blue)

A diagram was included on the surface underneath the animation and uses of energy. In response to suggestions to include more concrete visuals, this element presents visitors with an actual picture of what a small modular fusion reactor looks like. The elements above it (animation, end uses) provided an explanation of the technology's inner workings. The diagram of a hypothetical site where the technology is installed is adapted into an image containing concise, simply worded explanations of each component (see Fig.3-11). A table with these definitions included in larger font than that of the power plant diagram is included directly to the right of the diagram, to be of service to those who cannot read the smaller print. Along with a number of comparisons between the specifications of the design and those of existing technologies in the science section, a visitor should be able to gain a sense of the novelty and potential impact of a small modular fusion reactor.

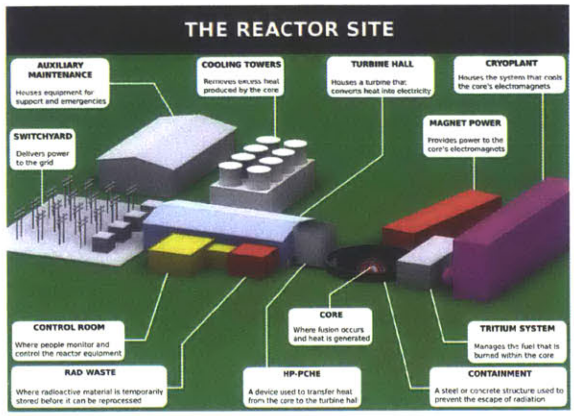


Figure 3-11: Final Exhibit SMR Reactor Site Diagram

In previous prototypes, visitors often complained that the term SMR was never explicitly defined in the exhibit, and that caused confusion. A section entitled "Small Modular Reactors are the next big thing" was created to solve this problem by defining the term SMR and giving a brief blurb about why they are the next big thing. The associated text for this section reads: "Small Modular Reactors (SMRs) are small scale nuclear reactors that have a power output of less than 300 MW, compared to present day nuclear plants, which have power outputs on the order of thousands of MW. SMRs have the potential to redefine the way we harness energy by providing affordable, secure, and emission-free power generation to a variety of markets. SMRs also provide more flexibility (financing, siting, sizing, and end-use applications) compared to larger nuclear power plants."

3.1.4 The Right Panel: SMRs and the Shape of the Exhibit

The right panel (Figure **3-12**) clarifies the motivation behind the shape of the exhibit. The entire right panel was devoted to explaining this concept. The label reads, " This exhibit is a scaled representation of a slice of the spherical core of a small modular fusion reactor (SMR) shown below. This hemisphere is ~80% of the actual size of the SMR we designed." The figure featured below that label is the spherical tokamak core designed in 22.033, shown in figure 1-2.

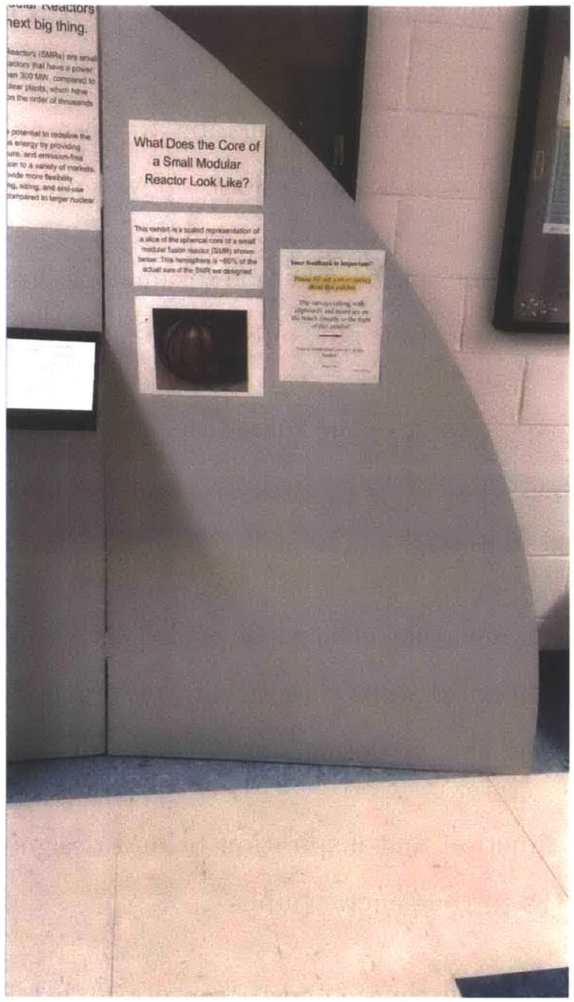


Figure 3-12: The Final Exhibit: The Right Panel

3.2 The Executive Summary

In the senior design course (22.033), not only was a final report written to document the research done in the course, but an executive summary was composed as well.

This executive summary (see Appendix G) was created to provide a short (2-3 page) synopsis of the work done in the course, with the goal that it would be accessible to the same audience as the exhibit: anyone walking the halls of MIT. The executive summary included six sections:

1. the Overview-a brief one paragraph summary of what is presented in this summary, namely: the core, interface, power cycle of a Small Modular Reactor for Fusion (SMURF), and a museum exhibit to raise public awareness of this technology and its potential to revolutionize power production.

2. the Core-the specifications of the spherical tokamak design chosen for the SMURF, including: estimated power output, output temperature, chosen materials, etc.

3. the Interface-an explanation of the role of the interface in a SMURF plant, the design and configuration of such an interface, reasoning for selection of this design and related materials

4. the Power Cycle-justification of type of model used to predict the SMURF's performance, accompanied what components are required to obtain the highest efficiency based upon this model

5. the Exhibit- the function and inspiration behind designing a museum exhibit to explain SMURFs to the general public

6. Total Size and Cost-the estimated cost, transportability, and size of a SMURF power plant.

3.3 Surveys of the Exhibit and the Executive Summary

The final step in the evaluation process was to gather information regarding what visitors did and did not like about both the executive summary of SMURFs and the

SMR Final Exhibit. After data were gathered, the accessibility of the information was assessed.

The final exhibit was placed on the first floor of MIT's building 24, and signs were posted on the exhibit encouraging passersby to fill out a survey about the exhibit. In addition, the executive summary survey was given to students walking the halls of the first floor of building 24 to ensure the same audience is sampled. The surveys given to exhibit visitors and executive summary readers were almost identical. Both surveys were on paper and consisted of the following short answer and multiple choice questions:

- What is your affiliation to MIT? (e.g. undergraduate, graduate, post doc, faculty/staff, visitor)
- Did you learn anything from the executive summary/exhibit? If so, what?
  - ES Summary Multiple Choice Options: Overview, Core, Interface, Power Cycle, Exhibit, Total Size and Cost
  - Exhibit Multiple Choice Options: Title, Movie, Small Modular Reactor Plant Diagram, Energy Applications, Map, Fusion Explanation and Comparison, Power plant Overview, SMR/Modularity Explanation, Explanation of the Shape of Exhibit
- What did you like the most about the summary/exhibit? Why?
- What did you like least about the summary/exhibit? Why?
  - ES Summary Multiple Choice Options: Overview, Core, Interface, Power Cycle, Exhibit, Total Size and Cost
  - Exhibit Multiple Choice Options: Title, Movie, Small Modular Reactor Plant Diagram, Energy Applications, Map, Fusion Explanation and Comparison, Power plant Overview, SMR/Modularity Explanation, Explanation of the Shape of Exhibit

- Did you have enough background information? Was everything easy to follow and understand?

- Any other comments, questions, or concerns you had about the summary/exhibit?

Chapter 4

Results

Printed surveys were distributed to passersby during the month of April 2014 to gauge visitors' opinion on the final exhibit and the executive summary. A total of 11 written responses were received for the exhibit, and 7 responses for the executive summary.

4.1 Survey of the Final Exhibit

The final exhibit was placed on the first floor of building 24 outside of room 24-117 for approximately one week. A total of 11 responses were received. Although the number of respondents is significantly lower than previous prototypes, each of the respondents provided quality feedback can be viewed in Appendix H.

The main take aways from visitor feedback were:

- the applications were great, people enjoyed pushing buttons. This is a definite improvement from previous prototypes, having visuals seemed to be a great supplement to the text on the exhibit

- "much needed lessons for the public!" Visitors not only recognized the importance off learning about revolutionary technology (such as SMRs), its advantages, and why they're useful/necessary, but that this information needs to be shared as well

- the map needed an explanation. Visitors were curious why the highlighted countries were selected.

- better flow/directionality. More directions (i.e. where to start when visiting the exhibit) are still desired by the visitors

- SMR explanation and the plant diagram were extremely helpful. Gave the visual learners a better image of the technology and usefulness

4.2 Survey of the Effectiveness of the SMURF Executive Summary

The Small Modular Universal Reactor for Fusion (SMURF) executive summary surveys were distributed and collected on the floor of building 24 during April 2014. A total of 7 responses were received and can be viewed in Appendix I. Listed below are reoccurring themes observed in the visitors' feedback.

- Overall, the executive summary did a great job concisely summarizing the overall layout, components and feasibility of a SMURF.

- The pictures helped facilitate the understanding of the material, and it was suggested that more pictures and charts be included to maximize comprehension

- the summary was sometimes called "too verbose" or contained "too much jargon." Visitors who were not familiar with the topic struggled with some of the concepts. Simpler explanations and definitions of acronyms are needed for people without adequate background in the material

- Over half of the respondents (4 out of 7) selected the exhibit as their favorite part of the summary because of its improved accessibility to a broader audience. One visitor said, "I am a visual learner, so real life representations and specific details help me store information, as well as enhance my understanding. I was instantly captivated [by the concept of an exhibit]."

Chapter 5

Discussion and Further Recommendations for the Exhibit

The final step in evaluating the effectiveness of the science exhibit is to compare survey results between the exhibit and the executive summary. Further recommendations for the exhibit will be discussed later to improve on its ability to attract and maintain the visitors' attention and educate them on small modular reactors.

5.1 Insights from Surveys

Some of the similarities noticed between both the executive summary and the exhibit responses were that the visitors appreciated the different modalities that each offered. In the summary, multiple figures were used to provide the reader with a visual representation of certain concepts. The exhibit provided an ever wider variety of modalities, ranging from active elements (i.e. the movie and the applications) and passive elements such as infographics, tables, etc. In the summary survey responses, although 71% of participants noted and appreciated the inclusion of figures which assisted in the visualization of this technology, multiple requests were made for more diagrams in order to cater to visual learners. 67% of exhibit respondents indicated that their favorite part of the exhibit was an active element (such as the movie, energy applications, or SMR plant diagram). Elements such as these facilitated the learning process by making the the exhibit not not only visually appealing, encouraging visitors to approach and interact with it in the first place, but also making these interactions "really interesting and pressing the buttons and interacting with the presentation was fun." In this sense, the exhibit more effective at not only capturing visitors' attention but maintaining their attention through an array of elements.

Another similarity worth noting is that the importance of sharing these facts with the public was recognized by both subsets surveyed. In the both surveys, all questions were optional. Every respondent, except for a single faculty member, indicated that they learned something from both the executive summary and the exhibit. This means that both mediums presented information that the audience was not previously aware of, whether it be the usefulness of modularity, or what a fusion reaction is, every visitor walked away with a greater understanding of some concept relating to small modular fusion reactors. One of the primary reasons for creating an exhibit is to inform the audience about a topic they were previously unaware of. The exhibit successfully accomplished this and instilled in the audience the importance of educating the public about this type of technology. One exhibit visitor agreed that the concepts taught in the exhibit are "much needed lessons for the public!"

The main difference observed between the exhibit responses and the executive summary responses was that in the 100% of executive summary responses, there was some sort of comment about the wordiness or verboseness of the document. The document was said to be extremely well written, however every person complained that there was "too much jargon", the summary was "too verbose/technical", or not enough background information for someone without a background in nuclear engineering. In contrast, there was an overwhelming appreciation for how approachable the exhibit was. Although some visitors struggled with directionality of the exhibit, no negative feedback was received to indicate that the content was educationally inaccessible. This, supplemented by comments such as "it was easy to understand, the material was well-explained/summarized," supported the hypothesis that the exhibit would be more accessible to more people.

Although the executive summary provided more detail about the specifications and design of a SMR, this was at the expense of the visitor's comprehension or attention. The sacrifice of technicality in the exhibit was compensated for by the fact that the exhibit encouraged its visitors to think critically about the material and draw their own conclusions about the effectiveness/necessity of such technology. An effective exhibit not only educates its visitors, but guides them along a didactic path that facilitates the visitor's formulation of their own educated opinion on the topic. In a comment about the exhibit's heat/work/electricity applications a visitor stated these applications "demonstrated why we need energy and made people question where energy comes from (which of the public doesn't do often)." On the other hand, the responses in the "Did you learn anything..?" executive survey questions all related to the layout, design, and functionality of a SMURF; these details, although important, are not critical thoughts or reflections formulated by the visitor, but merely reiteration of facts found in the executive summary. It seems that the purpose of designing a SMURF, which is to revolutionize the power generation industry, was either not recognized or emphasized enough.

Table 5.1 summarizes and compares the qualitative findings of both surveys is shown below.(Note: these percentages are subjective interpretations of survey responses).

Table 5.1: A Summary of the Effectiveness of the Exhibit versus the Executive Summary

	SMR Exhibit	SMURF Executive Summary
Total Number of Respondents	11	7
Respondents who learned something	82%	100%
Respondents who didn't have sufficient background	25%*	57%
Respondents who indicated an element they disliked	75%	88%
Respondents who liked more than one element the most	0%	25%
Respondents who recognized the 'bigger picture'	42%	29%

(*denotes that this value included non-response)

Although the exhibit was proven more effective in some aspects, there are limitations to the exhibit as well. For one, the number of respondents could be greatly increased for a wider perspective. The main respondents of both surveys were primarily undergraduate students, and although these students make up a sizable subset of our target audience, they are not the entirety. A longer, more diverse collection of responses could lead to more useful feedback. Relating to overall design, the exhibit could be more effective if it were larger, providing more space between the printed elements. These elements could also be printed on a four large sheets of poster board (for each of the four sections of the exhibit) for a more refined presentation of information, as opposed to individual sheets of semi gloss paper densely positioned on the exhibit. Lastly, if the exhibit were more strategically placed on campus, in an area that gets even more traffic than the first floor of building 24 (say Lobby 7 for example), more of the associated MIT public could benefit from learning about this technology. The goal of any educational endeavor is to teach as many people as possible. Relocation would be a great way to introduce more people to the great potential of small modular fusion reactors.

5.2 Further Recommendations for the Exhibit

If there were to be another prototype of this exhibit, improvements could be made on various aspects of the exhibit to improve visitor retention and further refine the visitor's learning experience. Such enhancements are listed below:

In the final cardboard prototype a small plasma globe was included, and this globe was usually the first thing that exhibit visitors noticed, since it is the most unusual-looking element in the exhibit. This plasma globed served the dual purpose of sparking the interest of passersby and demonstrating an exciting scientific principal of which the fusion core technology makes use. After much consideration, it was decided that a larger plasma discharge tube would both attract visitors to adequately support and enrich our core message and make it possible for the visitor to easily relate the plasma discharge tube to the description of the plasma within the fusion core. The objective is an intuitive demonstration of the mechanism by which—and the difficulty with which—plasma is magnetically confined. The preliminary prototypes only included a store bought spherical plasma globe but after communicating with vendors of plasma discharge tubes, there has been reassurance that for future prototypes, it is possible to "fabricate most any shape(s) [one] can conceive.[10] " The proposed geometry is a plasma discharge tube that has a spherical section with a hole running through it, resembling a cored apple, to mimic the geometry and basic operation of a fusion core. A wire would run through the hole, carrying a current so that it approximates the magnetic field provided by the central column in the spherical tokamak (see Fig. 1-2). For conceptual consistency, the central column of the exhibit houses a set of minimal controls with which visitors are invited to vary the current that the wire carries. The expectation is that as a visitor varies the current, the plasma within the tube will undergo a dramatic shape change, offering a simplified representation of what happens when the fusion core is in operation. The plasma will be brightly colored to increase the likelihood that someone walking by spends time at the exhibit, and its surrounding glass tube will be a concrete visual replica that allows visitors to imagine the inside of a small modular fusion reactor. This element will require a brief, simple description of plasma physics and, if possible, information about the distinction between the plasma the visitor sees and the plasma that resides in the fusion core.

Another idea that never made it past the drawing board, which could be included in a future iteration of the exhibit was the transformation of the diagram of the fusion reactor site diagram into a three dimension printed diagram so that the visitor would be more drawn to learn about the plant and the energy generation process. With better preparation, the 3D diagram can be ordered far enough in advanced so that the problems encountered during this prototype (i.e. the MIT 3D printer having a waiting list of multiple weeks for one of a four part diagram) can be avoided.

In future prototypes the layout of the exhibit would be optimized, meaning a larger screen for the movie to play on, and arrows or numbers to show the ideal sequences of elements the visitor should interact with. The reason these were not featured in this prototype of the exhibit is because it was observed in previous prototypes that visitors never truly started in one place (although it retrospect this might be due to the fact that a starting point was never indicated in the exhibit). The designers decided to not have a starting point, but rather split the exhibit into two sections (Science and Engineering) so that if the visitor did start anywhere on the exhibit there would be some sort of organization but not strict guidelines on what they should and should not read next. The educational path was projected to be more hands-off, but according to feedback, more directionality would be welcomed.

The addition of a "Cost and Feasibility" section in the exhibit would be beneficial. The executive summary possessed this and feedback from the summary indicated that respondents appreciated this information. It can therefore be inferred that exhibit visitors will recognize the usefulness of such information since the same audience was sampled for both surveys.

Updates to various exhibit elements would include:

- the Energy Density Table (Table 3.1) should add a row indicating the energy density of a fusion reaction, and that efficiencies be taken into account for the listed processes. Multiple visitors inquired about these calculations, and even if only estimates are made, these projections should be included in the exhibit for consistency's sake; a fusion exhibit should at least estimate the efficiency of such reactions, so that visitors can compare energy densities values themselves

- the fusion infographic (Figure 3-6) initially served the purposed of giving the visitor a broad (but not completely accurate) idea of how voluminously different materials could provide the same amount of energy. The audience could only benefit further if this infographic was made to scale.

- a map was included in the final exhibit design (Figure 3-8) to illustrate where in the world SMRs could be useful, however a description explaining why these areas are highlighted areas was missing. For future prototypes, multiple maps could be overlain to indicate which countries could benefit from the specific applications of SMR power generation, such as desalination, gas refinement, pump modules or district heating.

5.3 Summary

After multiple prototyping phases, a science exhibit focusing on small modular reactors and fusion energy was created and unveiled on the first floor of building 24 on MIT's campus. The purpose of creating such an exhibit was to educate the public on those two topics in a way that is more accessible to a variety of learners, compared to plain text. Handwritten surveys were distributed and completed by 11 exhibit goers and compared to the feedback of 7 respondents who read an executive summary on Small Modular Universal Reactors for Fusion. These surveys indicated that although the exhibit lacked the technical detail of the executive summary, it provided a larger proportion of visitors with sufficient background information and a greater appreciation and understanding of fusion energy and reactor modularity. Thus, the exhibit was successful at more effectively teaching the target audience about SMRs and fusion. Future SMR science exhibits should bring more attention to the cost and feasibility of such reactors and fusion reactions.

Appendix A: Preliminary Survey

Question to be answered	Response proportions per level of interest (%)		
	Least	Indifferent	Most
What is it?	1.15	4.6	94.25
How does it work?	1.35	13.51	85.14
How does this technology compare to other energy sources?	0	24.5	75.5
How is it safe?	5.1	30.5	64.4
Why should I care about it?	4.69	31.25	64.06
How does it affect the environment?	5.77	36.53	57.7
Why isn't it a reality already?	7.84	45.1	47.06
How does this technology fit into the global energy picture?	7.02	47.37	45.61
What makes it difficult to implement?	0	57.41	42.59
What is it made of?	10.56	52.6	36.84
How soon will this technology be available?	3.18	63.49	33.33
Where will this technology be implemented?	10	72	18
What are the details of its modularity?	16.67	66.66	16.67
What is the history of this technology?	27.27	63.64	9.09
How can I get involved?	54.24	37.2	6.47
Where is research for this technology being conducted?	30	66	4

Table 5.2: Questions and Their Corresponding Proportions of Responses at Each Level of Interest.

Appendix B: Scanned Paper Prototype

Below are the scans of the 8.5 $\times$ 11 inch printer paper pages used to represent the exhibit in the first phase of prototyping. These were constructed by Margo Batie, Martin Lindsey, and Lauren Merriman in the 22.033 design course.

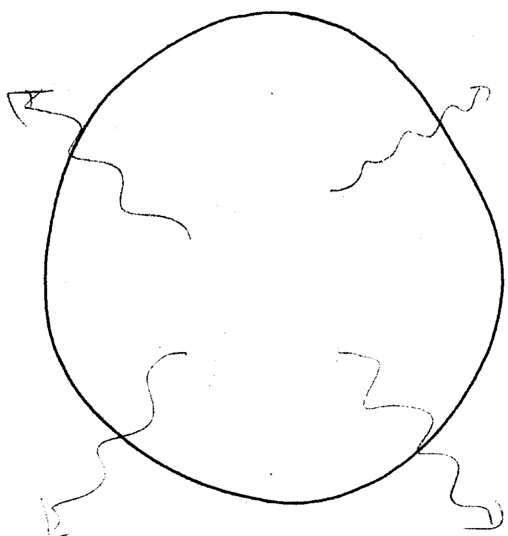
overview page (50 words)

How do power plants make energy? (6)

Most power plants begin with some sort of heat source, whether it be burning coal, fissioning molecules, or fusion. This heat is used to boil water producing steam and the steam turns a generator. The generator then provides energy to your home. (42)

LHS Title Space

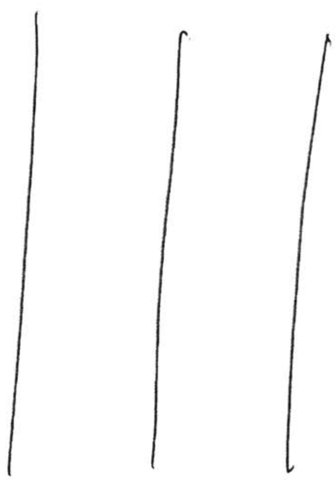
heat source



a heat source is a device that provides usable heat that drives an external mechanism (in this case, one or more modules)

some examples of heat sources are fossil fuel combustion, geothermal energy, sunlight, fission reactions, or, in the present case, fusion reactions (43)

Interface



The interface is the component of 6
the system which carries away the 6
heat produced from the interchangeable core. 6
The interface is designed to act 6
as a universal plug that can connect 7
to a variety of heat sources and 7
be an industry standard for heat 6
transfer from the module producing heat. 6

module

The module is where we'll be using the energy we've produced. (11)

Examples include:

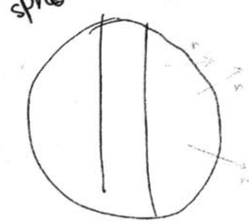
- electricity generation
- desalination
- direct heating
- refinement of natural gases
- pumping water (13)

Watch the movie to your right to see all this in action and check out the map to find out where this energy could be used. (26)

(50 total)

033 design infographic

spherical tokamak



①

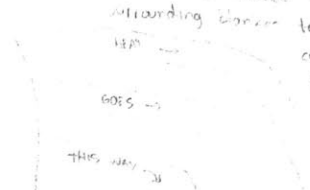
deuterium, a naturally abundant isotope of hydrogen, and tritium, another isotope of hydrogen, combine to create helium and high-energy neutrons.

②

these neutrons travel outwards and are caught in a layer of surrounding material, heating it up and producing more tritium through nuclear reactions.

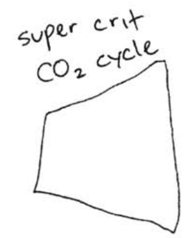
③ *

The heat is carried from the surrounding blanket to a set of conversion modules that use it to generate electricity



LHS graphics/text

033 design infographic

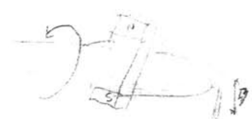


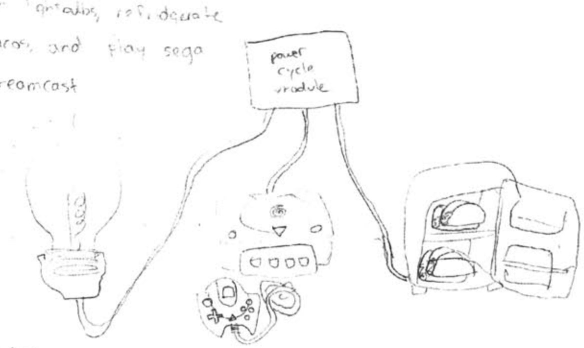
4.a)

the conversion module uses the high temperature carried to it from the interface to heat up CO_2 gas and runs it through a turbine.

4.b)

the turbine is connected to a magnet that spins inside a coil of wire, generating electricity so you can turn on lightbulbs, refridgerate tacos, and play sega dreamcast





LHS graphics/text

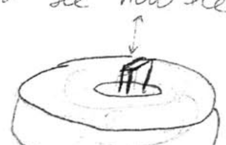
ball instructions

Notice the plasma's shape! It is currently following the path of least resistance within the plasma tube.

1) Grab a magnet from the central solenoid and place it near the tube.

2) Vary the orientation of the magnet & how close it is to the plasma tube. This changes the magnetic field the plasma is subject to

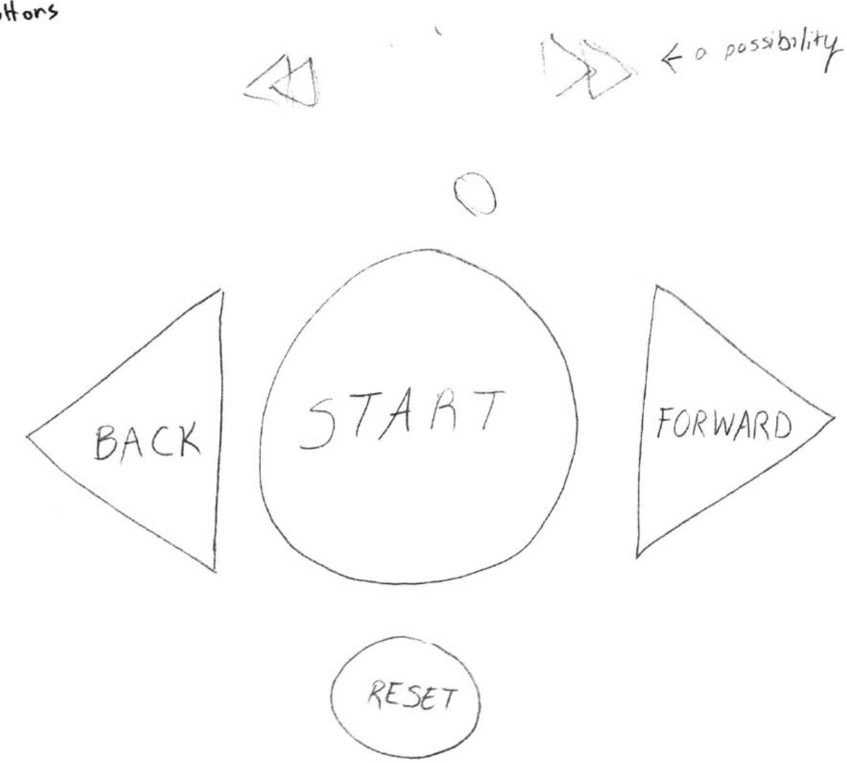
3) place the magnet within the 'slot' and see how the plasma reacts. This is similar to what happens in a reactor to keep the plasma from touching the wall.



Imagine how large of a magnet field is generated by the central solenoid (column to your right). It has to be super strong to confine the hot hot plasma.

LHS text

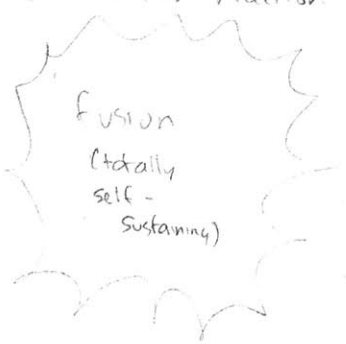
movie buttons



RHS vertical

movie — beginning

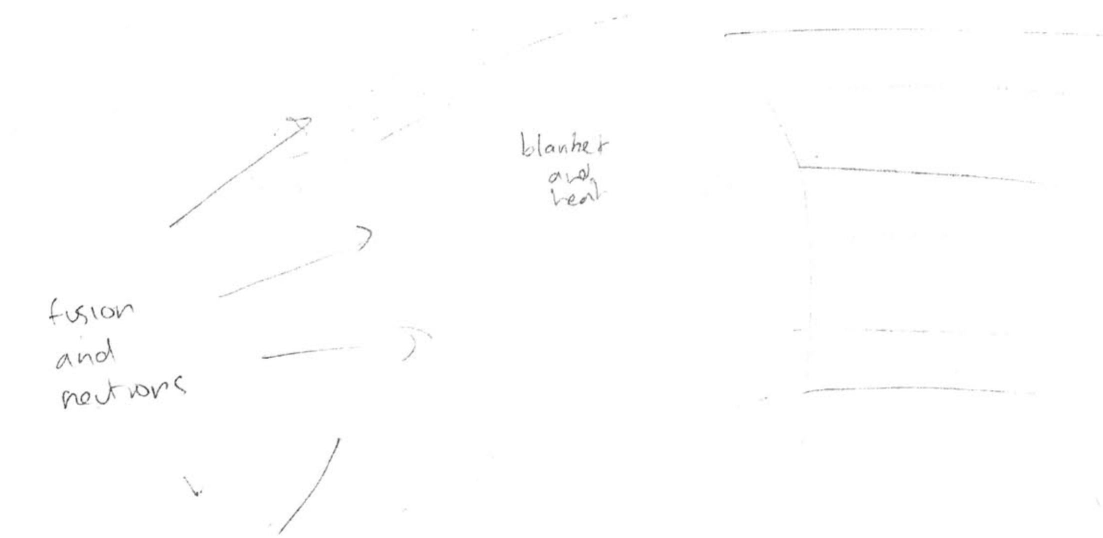
strong magnetic fields are used to contain plasma as it is heated to, like, millions of degrees, leading to a self-sustaining nuclear fusion reaction

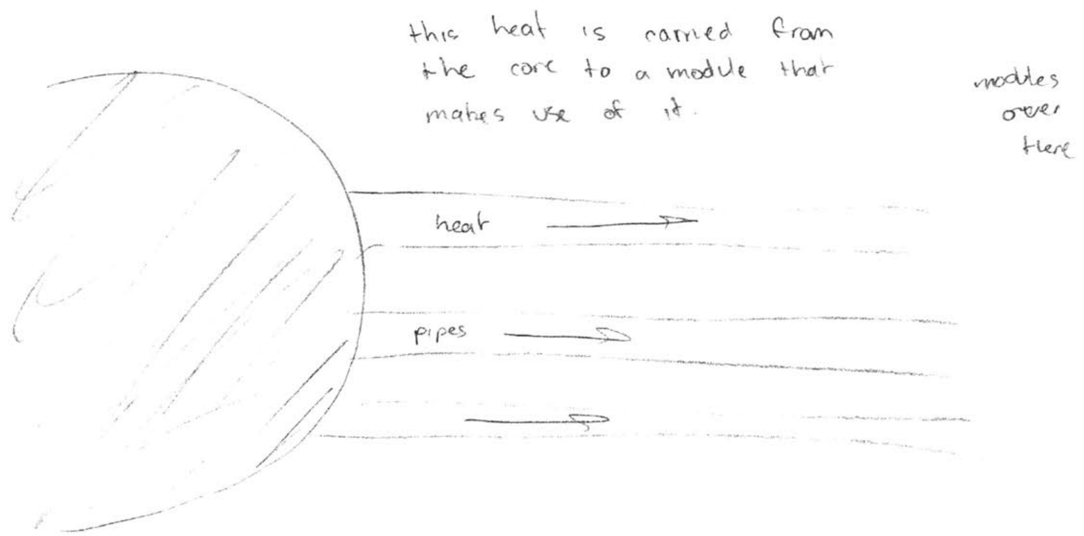


magnet

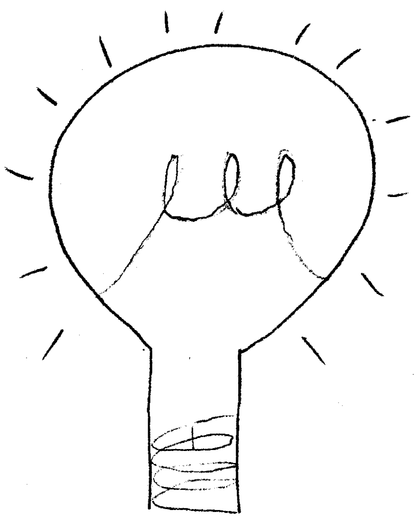
$D + T \rightarrow \alpha + n$

a D and a T fuse, producing a helium atom and a high-energy neutron the neutron travels into the layer of surrounding material, under-going a nuclear reactor that produces heat in addition to another T

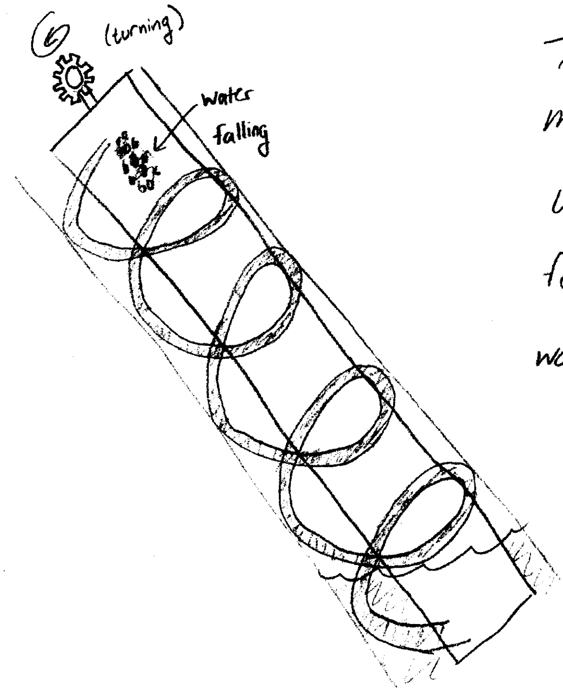




The end product, heat, can be used to create energy in a multitude of ways. Push one of the buttons to the right labelled "Light", "Work", or "Heat" to see how the heat your neutron has created could be utilized. (40)

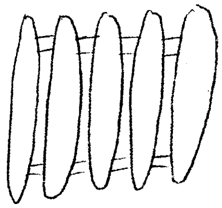


This lightbulb represents the electric unit/module. It shows one way to utilize electricity produced by the small modular fusion reactor, but there are many more, such as: charging your phone, powering your sega dreamcast, or lighting your refrigerator. (39)



This Archimedes' screw represents mechanical energy to bring water uphill. This water can be used for drinking, bathing, or washing. 120

radiator – on



This radiator represents the heat module. Heat can be used to warm homes, schools, and offices. Heat is also useful in desalination and refinement of natural gases. Place your hand near the radiator to feel the heat. (37)

RHS vertical

timeline - fusion

late 1930s
Hans Bethe recognized that hydrogen atoms fuse to form deuterium, and there is a subsequent release of energy

2006
Seven Members (China, India, Japan, Russia, South Korea, the USA, + European Union) signed to construct ITER (International Thermonuclear Experimental React.

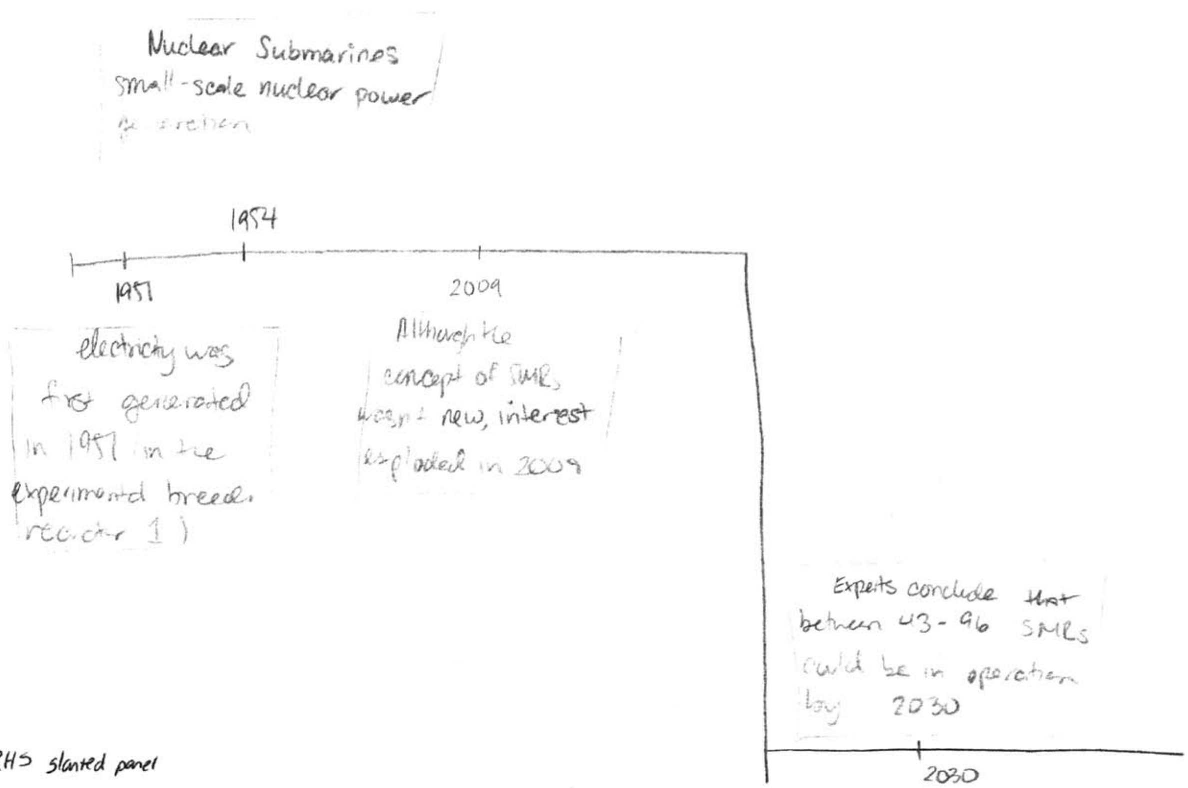
1934
Rutherford + his colleagues show deuterium and deuterium fuse to form Helium

1951
The tokamak (torus-shaped magnetic chamber) was designed by Soviet Physicists, Andrei Sakharov + Igor Tamm

2026
The first Deuterium-Tritium plasma is expected at ITER

RHS slanted panel

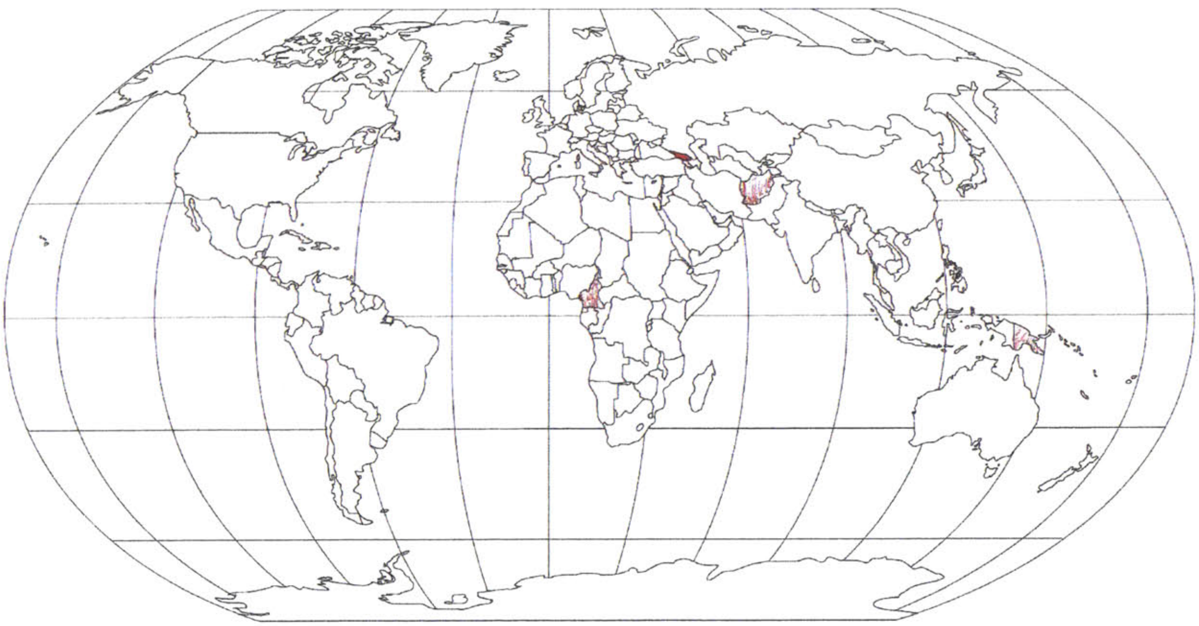
timeline - SMR



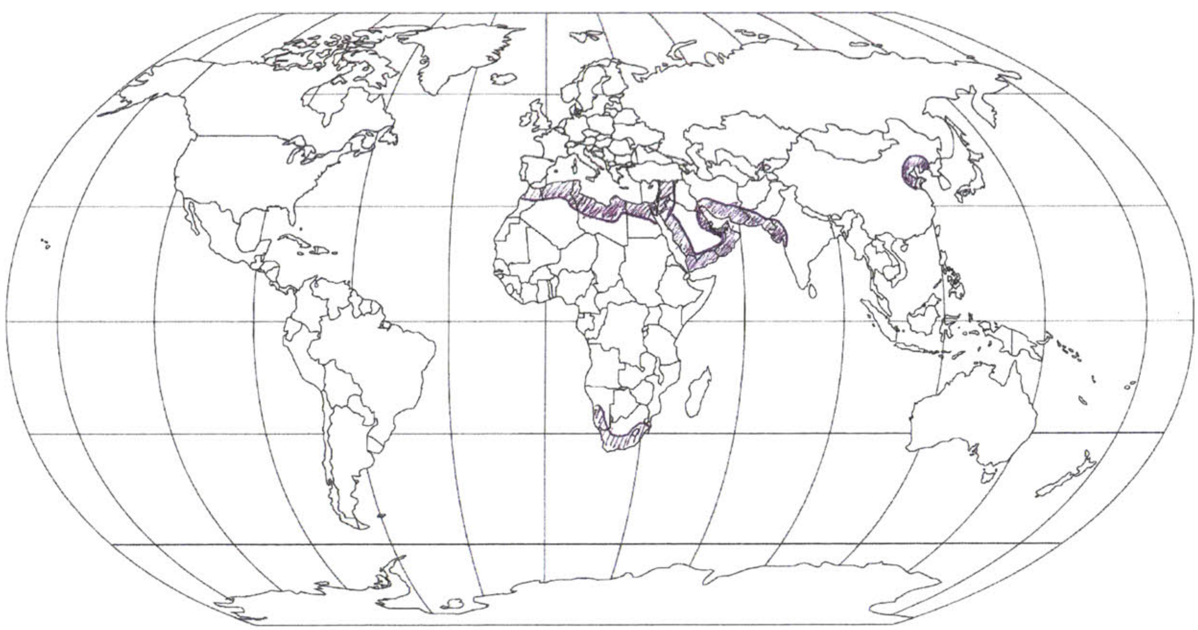
RHS slanted panel

gas refinement

(places that have large reserves of natural gas but low production)

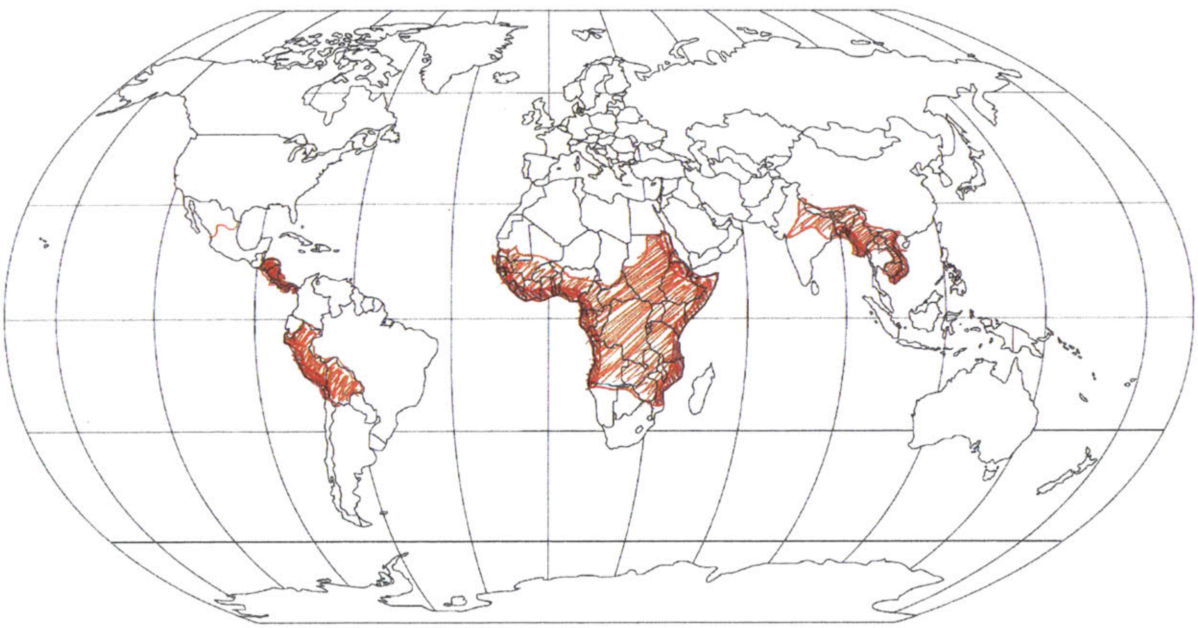


desalination
(places that have
water scarcity and
are near the ocean/sea)



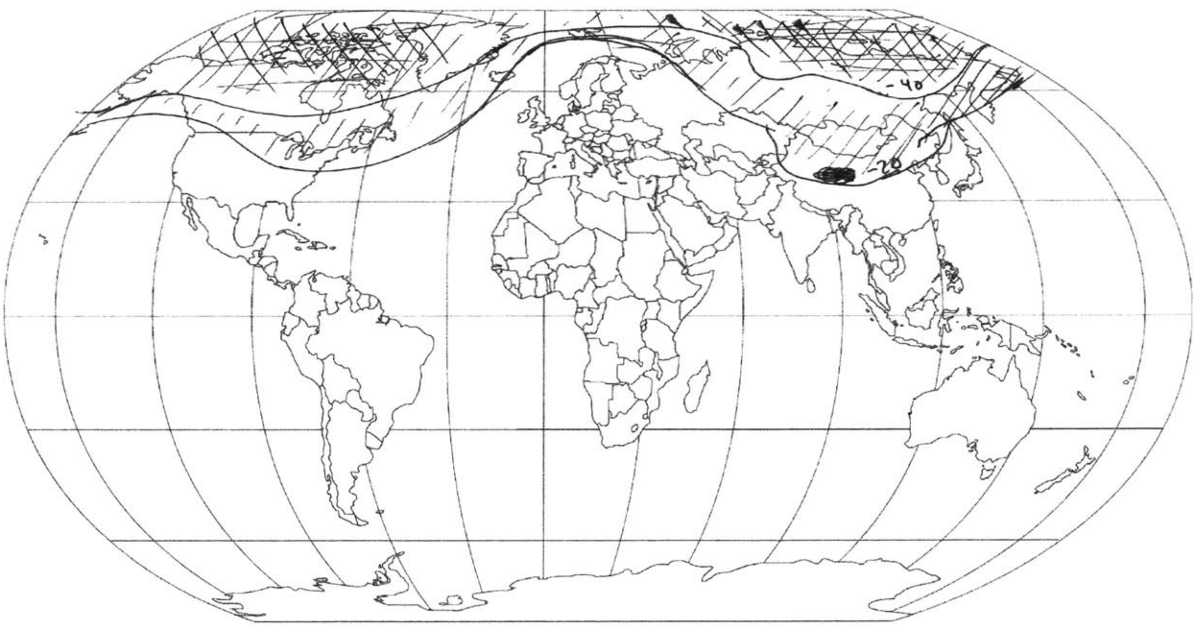
pump modules

places with insufficient water infrastructure

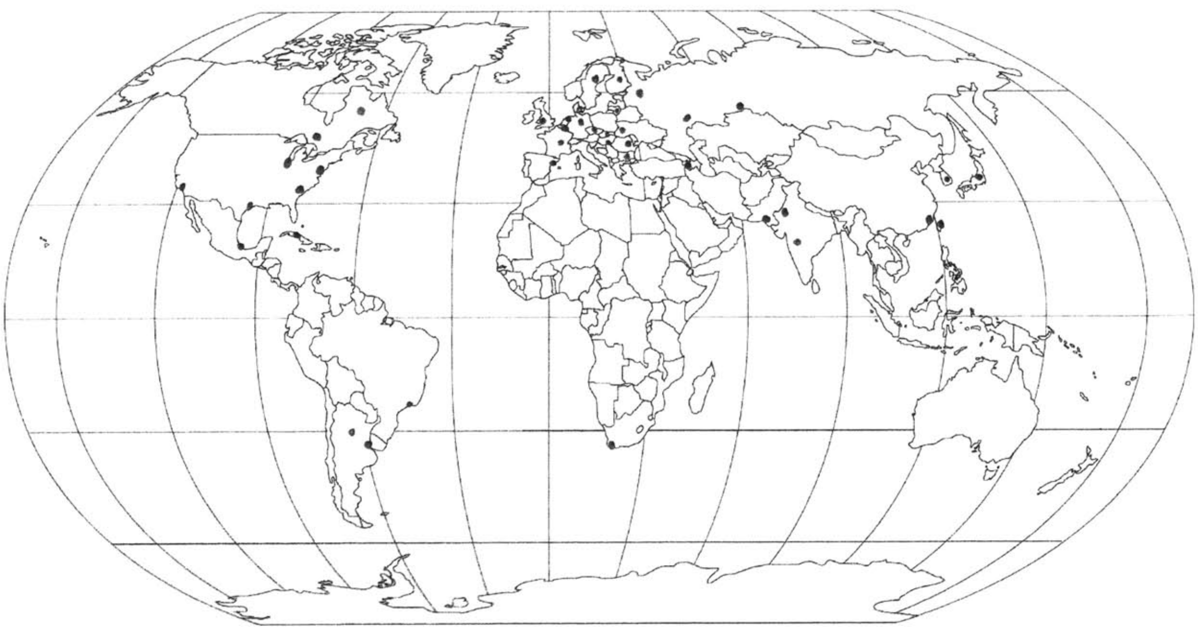


district heating

cold places where people live

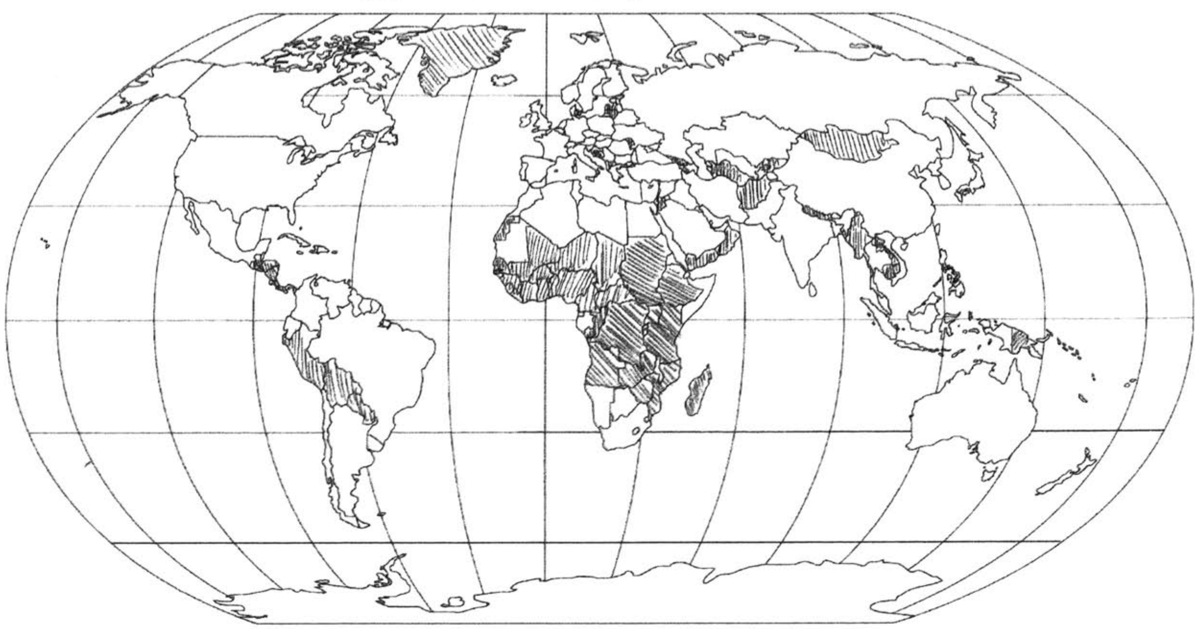


Operational Year 5



Where SMRs would be useful

SMR:
(electricity)



Appendix C: Prototyping Phase One Survey Responses

Commentary recorded from exhibit Paper Prototype test subjects

Visitor Number	Description	Commentary
1	Individual with non-technical background	The lighting was poor and it was difficult to read the handwritten labels. "It doesn't need to be so complicated... I didn't mind at all... I felt like I learned something and I was entertained."
2	MIT freshman interested in mechanical engineering	Looking at the infographics/intro panel: "that is a lot of stuff." Suggested a lift-the-flap strategy to help break up the text. Liked the QR code idea.
3	MIT junior studying physics	Did not prefer the iPod-style buttons. Relied heavily on explanation. Needed clarification on distinction between fission and fusion; wanted more specific details.
4	MIT freshman interested in chemical engineering	Liked the pictures.
5	MIT senior studying civil engineering	"From what I had time to look at I liked it."
6	Individual with non-technical background	Liked the movie idea, and interactive element ideas. "Really strong."
7	Individual with non-technical background	Confused by paper maps, suggested one transparent map with different overlays.
8	Individual with some technical background	Had to read interface label multiple times before understanding it. Commented that the handwriting was hard to read. Wanted more prominent timeline (such as 2040).
9	MIT senior studying humanities, arts, or social sciences	"I don't know what 22 is [sic]." "Generator" in intro label needed clarifying. The interface label was hard to understand and longer words are bad for comprehension. The heat source label was good. Excited about the animation. The more pictures the better.
10	MIT materials science and engineering alum	Found interface label wording vague and hard to follow. Wanted more specific details, felt condescended by level of wording. Suggested titling each element and carefully labeling each map. "Nobody knows what an Archimedes' screw is." "[Timeline predictions by] experts in science or politics?"
11	Individual in hallway	Interest grabbed by mention of "small modular fusion reactor," promptly left after five seconds.
12-13	Two MIT freshmen	"Seemed to understand" what was going on. Liked many components.
14	Student from local college studying health sciences	Preferred iPod-style animation controls. Asked for more information on the timeline. Suggested to make sure it is low-commitment.
15	Individual who "competed in a science fair" at least once	Claimed familiarity with tokamaks, generally would have liked more details. Wanted more information about other heat sources/possibilities. Suggested a one paragraph abstract as an overview. Wanted to know a lot more about the safety of the reactor.
16	MIT undergraduate*	Would have liked more pictures and visuals. Suggested to start with problem and give concrete examples to create a conceptual scaffolding.
17	MIT undergraduate*	Asked for clarification on charged/uncharged particle dynamics.
18	MIT undergraduate*	Emphasized importance of title. Would have liked to see more details on fusion. Would like to know how/where it would work and more about safety.
19	MIT undergraduate*	Interface label unclear.
20	Student from local college with non-technical background	Connection between elements unclear.
21	MIT senior studying biology	"I have class in half an hour---what do you want?" Found infographic easy to follow. Asked "what is D and T?", emphasizing necessity of clarifying terms throughout. "Didn't make me feel as dumb as I thought it would." Found timeline confusing and supported idea of interactive uses of energy.
22	MIT freshman	Commented that the timeline should be easier to follow but the exhibit is generally understandable.
23	Individual with non-technical background	Infographic was slightly harder to understand due to the jargon; intro/overview was good though. More visuals is better!
24	MIT undergraduate	No idea what an Archimedes' screw is.
25	MIT freshman	Asked "what is the interface made of?" Appreciated level of explanation---not too complex, not too simple. "Makes sense."
26	Individual with technical background	Wanted to see a definition of fusion. Believed there was a lot of text, suggested cutting it down. Suggested adding titles to help with flow and approachability.
27	MIT undergraduate	Asked about feasibility. Would have liked more fusion info and to have seen the timeline more prominently.
28	MIT graduate student	Suggested keeping a list of acronyms, bemoaned quantity of text. "What's an Archimedes screw?" Suggested maps needed explanation and that everything needs titles. Suggested timeline should be more explicit, merging isn't clear. Questioned the right-to-left flow.

Visitor Number	Description	Commentary
29	MIT junior studying aero- & astronautical engineering	Suggested that maps needed more labeling so that they are intuitive.
30-36	Group of 7 individuals with non-technical backgrounds	“Looks cool.” “Good luck.” “That's awesome.”

Appendix D: Prototyping Phase Two Survey Responses

What is your affiliation to MIT?	What did you like about the exhibit? What didn't you like?	What was the most important thing you learned from the exhibit?	What would you have liked to learn more about?	Did you have enough background information? Was everything easy to follow and understand?	Any other comments, questions or concerns you had about the exhibit?
Splash Participant	Plasma globe was cool good and colorful diagram	fusion in the real world		A little bit learned a little about fusion in chem	maybe # the order you want people to read it
Splash Participant	-interactive component -lay is confusing, hard to follow -good timeline	-teaching about fusion power	how it all fits together	each section was good, but hard to tie togehter	Good luck!
Splash Participant	I didn't like seeing the tape. the simple short explanations were nice	How nuclear generators work?	How they got the CO2		
Splash Participant	good: simple bad: neater, more attractive prezi needed	tokamaks not sure	plasmas		
Splash Participant	Good: clearly divided into sections based on topic bad: diagrams unlabeled and pretty useless	Doesn't really count since I already have a decent background in fusion. Again, more labels on diagrams and more continuity between them (as in "A" leads to "B" etc..) would be great	I have no idea what the "How it Works" Section is doing-> I imagine the movie would fix that		
Splash Participant	Hands on! Accessible explanations				
Splash Participant	good graphics	how power plants generate energy	how the design fits with tiny stars	I believe so.	Seemed a bit sparse
Splash Participant	good layout	about fusion energy	why the title says tiny stars	the hardest part was teh spherical tokamak	
Splash Participant	I personally prosper from interaction verbal/oral and I would have liked to be able to hear what is going on and ask questions				
Splash Participant	Loved it	uses for fusion	environmental consequences	yes	
Splash Participant	I liked the plasma ball	I learned how plasma can make power	I didn't realize it was focused on fusion reactors until I was handed the survey	everything was really easy to understand	none
Splash Participant	I liked how the text was short and to the point. It kept me interested the whole time =:)	It was cool to learn about how heat can be used to produce energy. It doesn't seem to impact the environment much.	It was simple enough that I could learn without prior research, which is really good. Thanks =:)		
research assistant, BA in economics			how a tokamak works, the printed circuit heat exchanger	not sure what level it's aimed at. "tokamak" is used without explanation--people who know that word don't usually need to be told that lightbulbs use electricity	currently it's a bit crowded. Making it larger, if possible, would help with that.
visitor	images to help explanations				
visitor	the images in the design were helpful		where is the CO2 heated?	everything made sense	
visitor	Like: - a clear explanation/example of fusion reactor design -title Dislike: - need larger print for older eyes	Overall explanation of fusion reactor energy production	current state of research- how close are we to practical application	followed all	interactive-plasma globe nice more interactive features
Splash Participant	I like that it is simple	teach us about fusion	nothing	easy to understand everything makes sense	why is the title tiny stars
Splash Participant	I liked the simplicity		I would like to know how the reactions are controlled and what the dangers of a leak would be	Everything was simple enough	connections to how it can be used instead of fossil fuels would make it more audience friendly
Splash Participant	I like the plasma ball. I like it will look cool when finished. The text looks like a 3rd grade report. Maybe change?	How fusion works, and how to make it do what you want		the layout was tricky	
visitor	love the enthusiasm of the presenters! -Clean Language -real life examples	how a reactor works, and its uses	nothing	easy to follow but I am limited in the area maybe add numbers or arrows to follow information flow	I am still confused about the plasma and how it fits in
Splash Participant	easy to follow. good layout	I believe that this was trying to inform public about alternate sources of energy for the future	I don't think it needed much more, everything was explained really well and it was easy to understand	The part that was hardest to understand was the design and the easiest part was how it works	really cool idea!
Undergraduate Student	the plasma globe	how fusion works and why it is important	further applications	from left to right: the "where is it going" should be further to the left	
Splash Participant	I like the layout it was easy to read	I learned how fusion works	I don't think I need much more information	the transition from topics was hard to follow	
Splash Participant	very short tibbix	spherical tokamak	thermonuclear plasma	fusion, PCHE	nope
Splash Participant	I loved the depth of the design section. disliked how vague the intro is	the history of fusion reactors	the intro on how power plants produce energy		

What is your affiliation to MIT?	What did you like about the exhibit? What didn't you like?	What was the most important thing you learned from the exhibit?	What would you have liked to learn more about?	Did you have enough background information? Was everything easy to follow and understand?	Any other comments, questions or concerns you had about the exhibit?
Splash Participant	i like how it was a light bulb thing and it makes people want to see it. I like the organization	I learned what fusion was	How it works	I did understand most of teh exhibit	It is interesting, cool and interactive
Splash Participant	I liked how it was very organized, not all overwhelming, crisp and clean	the design of it and how it works	some of the vocabulary	the design was the hardest to follow. how it works was the easiest	I liked how organized and crisp it was, but ad a little more pizzazz, maybesomething to draw your eyes to the more important part
Splash Participant	I thought the text was good, explanatory but the demo was good, nice timeline, maybe keep it all on one sheet	how the reactor actually works			
Splash Participant	certain texts were too small. needs color	electricity (how it works)	plasma	mostly easy	
Splash Participant	very broad in topics that focus into one main point. plasma ball	tritium is produced and the size is relatively small	the merchandise of the machine	it was very straight forward	I'm not sure of the target audience but electricity, work and heat are understood by much.
Splash Parent	The font was a little too small	why a toroid shape is used	how practical this is and when	i would have liked more side bar detail	
Undergraduate Student	more pictures				It's not immediately clear what this exhibit is about. "tiny stars" doesn't mean anything unless you already know what the exhibit is about. And then it's not clear where to look, there are clearly 4 sections, but I started with "How it Works" and wondered why I was looking at a light bulb, an archimedes screw, and a radiator
Graduate Student	I don't know what a tokamak. Ilearned the demos/figures	I really enjoyed the timelines basically different loads of energy cycles/how to create it etc.	maybe more equations to explain some of the concept	I would have preferred a more obvious flow (read this then this etc)	very excellent work :)
Splash Participant	for the most part, clear and explanatory	fusions less hypothetical than I though	-what is a plasma? How does your finger change its properties? -Where is the fluid in the tokamak blanket? -why are there 2 heat conducting fluids not just 1?		
Splash Participant	aweomse info and the plasma globe	how nuclear reactors work	what is the movie?	what is the CO2 cycle?	there is too much blank space
Splash Parent	clean organized, must have some knowledge of it, assumes	people actually stop. Fusion through the ages. energy transfer i think	not sure what this has to due with fusion reactors relevance		
Splash Participant	not immediately apparent where to start reading and what it is about				
Splash Participant	good layout; good explanations and helpful images	the process of fusion and how it works	the design, "PCHE"	Yes (both questions) hardest: PCHE	N/A
Splash Participant	plasma ball! Yes! how it works hardly relates to teh reactor	fusion is possible! and really cool!	why fusion should be used as a power source	yes! everything seemed straightforward, although it wasn't explained why the different fluids are made or what they are	plasma ball! interactivity is important
Splash Participant	It's clear and informative, easy to understand. good ratio of pictures to text	the potential usage of fusion in power plants in teh future, how it works	how is this better than the methods already in use (more on this)	it was very clear to me, short and informative texts are a good idea	it could use some aesthetic work, but i quite like it, right now. Maybe a little more explanation of how much energy you can get would be useful P.S. sorry about my spelling, english is not my first language :)
	-don't know how tokamak reactors work -what is a plasma? -How does nuclear reactions make heat? -what is work? -different types of reactors	how fusion reactors work	some texts small order and placement, maybe place in order of what happens nuclear reactions-> heat -> work	hard-> nuclear reaction->heat-> work	
Splash Participant	the explanations of temperature changes might be better shown by a visual representation of particles being scattered	fusion is a viable energy source	why plasma is significant		

Appendix E: Prototyping Phase Three Survey Responses

What is your affiliation to MIT?	What did you *most* like about the exhibit?	Why?	What did you *least* like about the exhibit?	Why?	re	Any other comments, questions, or concerns you had about the exhibit?
Faculty/Staff	Movie	It's simple and organized	Fusion infographic	The order of the information seemed off.	No it would be great eto have an introduction adn terms that are related to each other	an actual movie would be great (maybe someone can let you borrow an ipad)
Post Doc	Fusion infographic	Because it's what I know least about.	Table of data	It is boring/non-engaging way to get the info across.	You might want to talk about the past challenges fusion has faced. It is way more storied than just the science.	It didn't seem clear where to start. Definitely make the path clearer. Put the SMR (and definition) front and center. Media + screen/features! Nothing below eye level!
Visitor	Plasma tube and instructions	Making connection between electrical work/heat not obvious from materials to uninitiated. need to follow some concepts from 1 stage to the next				
Undergraduate Student	Plasma tube and instructions	It was the most interactive component	Movie	It was a large amount of information stored in one spot, that took effort and reaching to traverse (it also weighed down the board)	the background information was very accessible to someone with a basic science background	It would be nice to see more of the flow for the board, I started on the far left and read from there but I wasn't sure...I'd like to see the SMR highlighted mo
Undergraduate Student	plasma globe	I like that you can actually touch it and interact with it. But from the sound of it, the other will-be interactive stuff will be cool!	Movie	I don't have a clear picture of what the movie will be like yet. Lots of text/slides? Moving graphics?	I think I do. But see comment below.	It might be nice to be some guidance on where to start looking through all of the components. Would be nice if you also include other info about how feasible this reactor will be (cost, space needed).
Faculty/Staff	Plasma tube and instructions	I like touching exhibits ;)	Maps	Did not define SMRs	Yes. It was cool.	More talking in the movie
Undergraduate Student	Plasma tube and instructions, Maps	Interactive pieces catch my eye.	Fusion infographic	Doesn't quite make point carry across, movie or more pictures might help.	Yes, easy enough to follow.	Try having more interactive pieces instead of just pictures if possible.
Undergraduate Student	Plasma tube and instructions	The 3-D diagram of power plant might be cool once it is built. I'm like a little kid when it comes to learning new science things so interactive parts of exhibits are the most appealing to me.	Movie	What's the timeline? I think I missed it... Got very technical pretty quickly I'm not course 22 so I soon got confused and stopped "watching"	For the most part yeah - minus the movie thing. I missed an explanation of why the SMRs would be useful in those countries.	I also missed the explanation at the end explaining the shape. It also seems to be like the engineering side has a lot less info than the science side.
Undergraduate Student	Plasma tube and instructions	It's really cool :D I think it'd be cooler if the description tells us how touching it affects the electromagnetic properties. I also like the movie. Since it's broken up, it doesn't always feel like I'm walking in the middle.	Maps	There's no explanation I can see that discusses what is happening and why SMRs are useful there.	No. It was pretty easy to follow. Sometimes it feels patronizingly simple instead of purposefully simple to avoid technical detail, though.	Wow Lar lar. Such rude. Much kidnap.
Undergraduate Student	Fusion infographic	The "WHY USE FUSION" diagram + the table comparing energy from generated fusion really made a strong impression. I really got the sense of the great potential for energy creation from fusion.	Maps	The map needs a bit more explanation as to why the SMRs would be useful in certain regions of the world? How are socioeconomics involved (as an example)?	There was enough background info.	More use color in the text could help the reader quickly absorb certain information. For instance, heat could be orange.

What is your affiliation to MIT?	What did you *most* like about the exhibit?	Why?	What did you *least* like about the exhibit?	Why?	re	Any other comments, questions, or concerns you had about the exhibit?
Undergraduate Student	3-D diagram of power plant	Informative!	Low-hanging "wings"	Hard to read even without a crowd. impossible to see with other people around	Yes	I like the division into the "science" and "engineering" halves. The examples under "engineering" are pretty lame though.
Undergraduate Student	Plasma tube and instructions, 3-D diagram of power plant, Maps	The 3-D diagram of power plant was not my favorite but interesting. Eye catching + good visuals/interactive	Timeline	B/c I don't know what it is	didn't read everything but easy to follow what I did read	Margo Batie rocks my world.
Undergraduate Student	Plasma tube and instructions	globe? something that I could touch.	table from whatisnuclear.com	not clear what the purpose of the chart is. Needs a title and description below is not obviously related to it.	Yes.	
Undergraduate Student	Movie, 3-D diagram of power plant	Nice and visual, informative.		Information could be more informative, poster a little more crisply done.	To the extent at which I understood, yes.	
Faculty/Staff	Movie	Story w/ images	Plasma tube and instructions		Yes, but seemed a bit disjointed-	
Visitor		It's cool.	Maps			
Undergraduate Student	Plasma tube and instructions	Very interesting to play with	Maps	Too small, makes it hard to read	Was easy to understand, hard to follow on board	Didn't know where to start, started at globe. Is this project goal to use SMR to create electricity from fusion.
Post Doc	Movie, 3-D diagram of power plant	It would be better to place the "movie" slides separately, easy to see. Comment: Thank you for bring this important topic to MIT community attention. reference or bar code would be useful and add some page with references. Also, I think the size of the slides should be bigger than #4.				
Undergraduate Student	3-D diagram of power plant		Maps	Too small	It's not clear where I should start reading. Title at the top?	The text is accessible - the exhibit is not imposing or intimidating. It's nicely put together.

Appendix F: Movie Slides

In the Final Exhibit, a movie was included to demonstrate the production and utilization of energy within an SMR. Below are the slides displayed in that movie.

The History of Fusion...

In 1934, Rutherford and his colleagues showed that isotopes of hydrogen (deuterium and tritium) can fuse to form helium[1]. In 1951, Soviet physicists Andrei Sakharov and Igor Tomm[2] proposed a device, called the tokamak, which would control the deuterium-tritium reaction to make energy.

The History of Fusion...

The first tokamak ever built was in Russia in 1955.

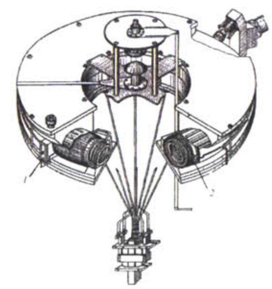


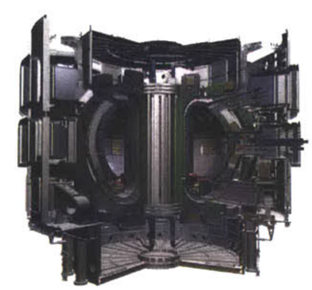
Image from [2].

The Future of Fusion...

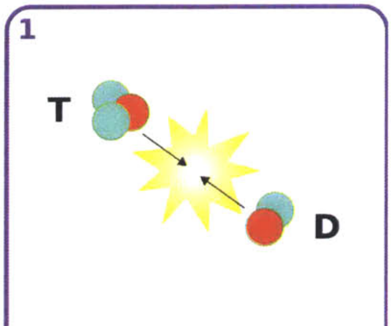
Energy has yet to be harnessed from the fusion reaction. In 2006, China, India, Japan, Russia, South Korea, the USA, and the EU agreed to construct ITER (International Thermonuclear Experimental Reactor), the world's largest fusion project.

The Future of Fusion...

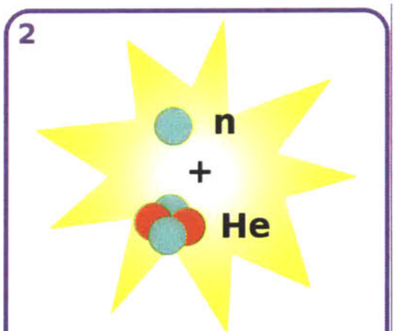
Deuterium-tritium fusion experiments will begin at ITER in 2026.



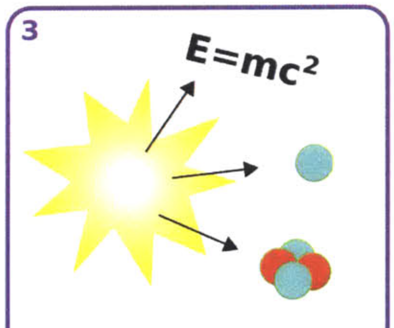
Now Learn About Fusion in Three Easy Steps!



Two isotopes of hydrogen, Deuterium (D) and Tritium (T), collide.



They fuse together to create Helium (He) and a neutron (n).

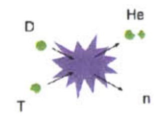


The reaction releases energy.

How the energy produced by fusion is utilized in a Small Modular Reactor (SMR) plant

SPHERICAL TOKAMAK

The spherical tokamak creates powerful magnetic fields to hold the plasma. Neutrons produced within the plasma are captured in a surrounding blanket of metal, where they generate heat.



In the plasma, two isotopes of Hydrogen, Deuterium (D) and Tritium (T) fuse to form Helium (He) and a high-energy neutron.

The high-energy neutrons travel outwards into a blanket made of a mixture of Fluorine, Lithium, and Beryllium. They cause nuclear reactions within the blanket, generating heat.

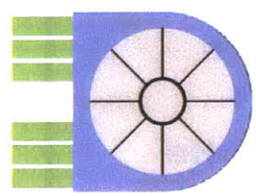
PRINTED CIRCUIT HEAT EXCHANGER (PCHE)

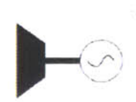
The PCHE connects the tokamak and the power cycle with tubes that allow the transfer of heat between their respective fluids.

Hot fluid from the tokamak blanket flows through one side and heats up tubes filled with liquid mixture of Sodium and Potassium. The tube then transfers its heat to a third fluid that the power cycle uses.

SUPERCRITICAL CO_2 CYCLE

The supercritical CO_2 cycle ultimately converts the heat into electricity by turning a magnet in a coil of wire, just like in a large-scale power plant. The only difference is that this cycle is about 10 times smaller!





The hot CO_2 flows through a turbine that is connected to a magnet inside coils of wire. As the turbine spins, usable electrical current is produced.

The end product, electricity, can be used to power light bulbs, refrigerate taco ingredients, and play sega dreamcast.

The small modular fusion reactor proposed here might not ever be built, but experts estimate that between 43-96 SMRs will be in operation[4] by 2030.

Works Cited

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[3] ITER: The World's Largest Tokamak, ITER Organization, Accessed on 4/30/2014 <http://www.iter.org/mach>. Web.

[4] Small Nuclear Power Reactors, World Nuclear Association, Accessed 11/23/2013

Appendix G: The Executive Summary of Small Modular Universal Reactor for Fusion (SMURF)

Below is the executive summary from the 22.033 design course. This summary, accompanied by a survey was given to participants to gauge the effectiveness of the summary.

Executive Summary

Overview

The SMURF (Small Modular Universal Reactor for Fusion) power plant design concept seeks to provide a long-term solution to the current worldwide energy crisis. Paving an alternative path to fusion power, the core, interface, and power cycle of the SMURF have been optimized for modularity and efficiency within a very compact system. A block diagram of the entire power plant can be seen below in Figure 1. With the design of the SMURF comes a strategic public awareness campaign employing a museum exhibit through which the public will be educated on small modular fusion and its potential to revolutionize power production.

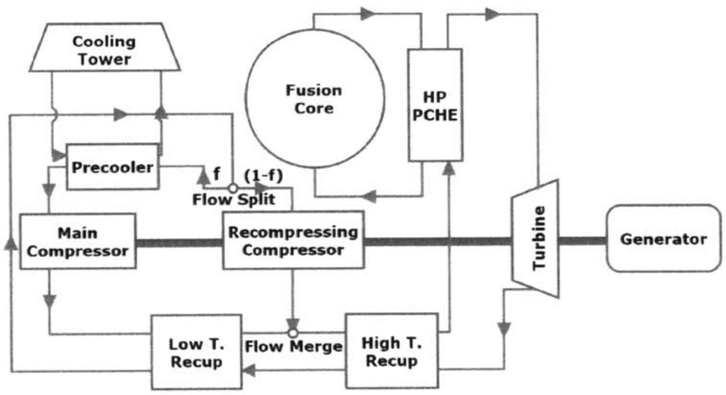

Figure 1: A schematic representation of the SMURF power plant design concept

The Core

At the heart of this small modular reactor system will be a low aspect ratio (R/a=1.57) spherical tokamak (ST) magentic D-T fusion device. The major and minor radii of the device are 1.1m and 0.7m, respectively. The SMURF system utilizes YBCO coated condutors in the cable-in-conduit conductor design to achieve power break-even. The centerpost has a radius of .12m and carries a current density of $500 MA/m^2$. The SMURF core will generate 800MW total fusion power, 80% of which will be extractable. Factoring in that 20% of the total fusion power is in alpha particles that are used to heat the plasma and is therefore inaccessible, the total thermal output of the core is 640MWt.

The spherical tokamak core will use FLiBe as a cooling blanket. Unlike some other common blanket materials, FLiBe is not reactive with air or water. In the event of structural damage to the core, the system will not be vulnerable to explosions. FLiBe was also chosen for its tritium breeding capability. Fusion neutrons interact with the lithium in FLiBe to produce tritium, which can be recycled and used as fuel. The beryllium-9 in FLiBe undergoes an (n,2n) reaction, effectively multiplying the population of neutrons that can interact with lithium to yield tritium. Tritium-breeding fusion reactors are distinguished by a figure of merit known as the tritium breeding ratio, defined as the ratio of tritium production to tritium consumption. The spherical tokamak in the SMURF system is designed to achieve tritium self-sufficiency and has an MCNP-calculated tritium breeding ratio of ~1.14. The tritium that is bred in the blanket will be extracted by a disengager system, useful here because tritium has low solubility in FLiBe. In this system, tritium gas will diffuse out of the FLiBe and be collected by a vacuum system.

The output temperature from the fusion core will be 915K, as calculated from nuclear heating using MCNP tallies of neutron energy deposition. SMURF will employ a system of evenly distributed helical pipes to conduct this heat away from the core. The design also includes a 2cm tungsten reflector outside the pipes which will reflect neutrons that have not been absorbed by the coolant. All the heat deposited into the FLiBe and reflector will be carried away into a heat exchanger. The use of helical pipes presents a particularly interesting design challenge in terms of pressure drop and pumping power. The pressure drop in one loop of the helical pipe is calculated to be approximately 1MPa, or 105m of head loss. This pressure drop is substantial and is powered by large steam-driven pumps requiring 2MW of power at 30% efficiency for each loop. The total pumping power of 4MW is less than 1% of the total power produced by the power cycle.

The Interface

The interface of the SMURF design is the critical component in connecting the spherical tokamak fusion core to the power cycle for power production. The design will employ a printed-circuit heat exchanger (PCHE) module that is divided into 100 identical heat pipe cells and is capable of transferring between 6 and 7 megawatts of heat. Thus, in order to transfer 640MW of thermal heat from the spherical tokamak, approximately 92 PCHE modules are required. The heat pipes are 8 meters in height and 4cm wide, and is surrounded on both sides by 4 meter tall PCHEs. The pipes employ a rectangular grooved wick to assist pushing the fluid vertically back to the evaporator. The PCHE material is 2mm thick.

The section of the PCHE that comes into contact with the reactor core fluid will be made of tungsten. Tungsten is an optimal choice for this interface because it is highly resistant to corrosion from FLiBe, even at very high temperatures. Two different kinds of stainless steel will also be used in the PCHE. The section that comes into contact with the power cycle fluid will be made of SS430, and the heat pipes will be made of SS316. Like tungsten, stainless steel is corrosion-resistant and thus is feasible for use in the interface between the fusion core and the power cycle.

The high thermal expansion of the SS316 will allow the heat pipe to lock into its slot within the PCHE. A contact-lock feature utilizing thermal solder, either gold or silver alloy, between the heat pipe and the PCHE enables the heat pipes to be easily inserted and removed during installation and maintenance. In addition, SS316 was chosen as the optimal heat pipe material because its stress intensity remains below yield limits even beyond the range of the operation temperature, thus ensuring non-plastic deformation in the case of a thermal transient. The interface heat pipes will be a self-contained system, preventing any leakage of the highly reactive liquid sodium working fluid.

The Power Cycle

The SMURF system employs a supercritical carbon dioxide Brayton cycle (SCBC) with an optimal pressure of 7700kPA, a pressure ratio of 2.6, and a CO_2flow rate of 1523 kg/s (for a 325MWt unit). The SCBC is designed to achieve high thermal efficiencies at lower operating temperatures. The main components of the super critical CO_2power cycle unit are three heat exchangers, a gas turbine and two compressors. Each of these major components of the power cycle unit can be placed within a single vessel. The turbine, compressors and electric generator are mounted coaxially so that the turbine can be used to operate both the generators and the compressors. The precooler is placed at one end of the vessel, while the recuperators surround the compressors and turbine, making the system very compact. The total output of the SMURF power plant is 225 MWe and 640 MWt.

The Exhibit

On the front of public awareness and education, an informational exhibit of small modular fusion supplements the SMURF design. Drawing inspiration from responses to a survey administered to the MIT community regarding small modular fusion, a museum exhibit was designed for the purpose of demonstrating the feasibility of the SMURF design. The exhibit itself resembles a slice of a hemisphere, using a circle of similar radius (7.87 ft) to the core of the SMURF spherical tokamak. The exhibit features a central column, resembling the centerpost of the spherical tokamak. On the face of the exhibit exist a number of informational panels, moving logically form left to right. The leftmost panels introduce the scientific background and context of nuclear fusion and fusion power generation, while the rightmost panels explain the engineering design and more technical aspects of fusion power. The exhibit also includes an explanation of the design process of the SMURF reactor and exhibit, as well as directions to visit a website for further information regarding fusion power. A digital rendering of the exhibit design is shown below in Figure 2.

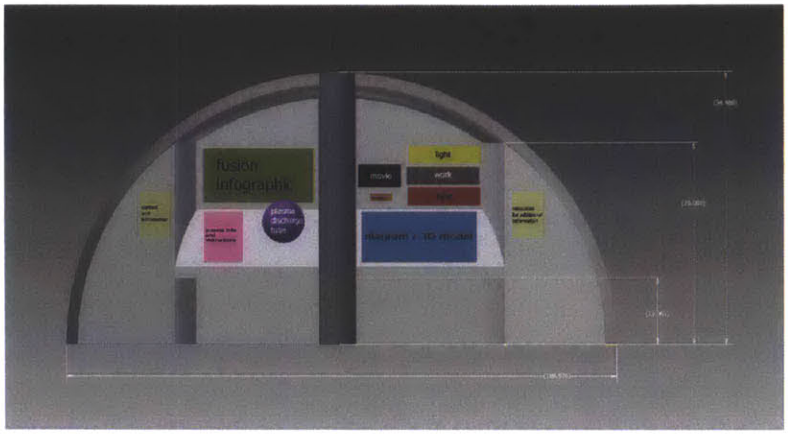

Figure 2: A model of the small modular fusion exhibit

On the left side of the central column, a plasma discharge tube is displayed to mimic the geometry and operation of the fusion core of SMURF. The tube itself is designed for interactivity, allowing visitors to vary the current in the plasma and thereby change the plasma's shape. This experience is crafted to provide exhibit visitors with a hands-on demonstration of how a fusion core is operated. This section requires a brief description of plasma physics and a note about the difference between this tabletop plasma and the fusion plasma that exists in a magnetic fusion device. Along with this plasma demonstration, a timeline of the history of nuclear power will be shown to provide context into the design of SMURF. Particular attention is paid to the numerical comparisons between fusion and other energy sources.

The panel to the right of the central column features a video that shows how energy moves through a small modular fusion reactor, beginning with the fusion neutron, traveling through the interface and power cycle and into the grid for power consumption. Visitors are able to select a specific end use for the fusion power produced, providing an interactive experience. In addition, a model of the entire small modular reactor system is shown and key differences between this design and existing technologies are highlighted.

Total Size and Cost

The SMURF power plant will have a maximum geographic footprint of 25 acres. This total size includes the space needed for the core, interface, and power cycle components but is mostly comprised of exclusion space to keep nearby buildings safe. Operating on the definition of 'small' as 'transportable by eighteen wheelers', the final size of the core vessel was determined according to the size and weight limits of an eighteen wheeler. A 3D model of the entire power plant site is shown in Figure 3 below.

The total cost of the fusion core is \$1.3 billion, and the total cost of the interface and SCBC are \$42 million and \$50 million, respectively. Assuming that the centerpost and core vessel will be replaced yearly, and that the interface will be replaced every ten years, the electricity cost of SMURF is determined to be 5.5cents/kWhr. In addition to material costs, this calculation assumes that the SMURF plant will employ 200 workers that cost \$100,000 each year as well as a cost of \$5,000,000 for plant maintenance.

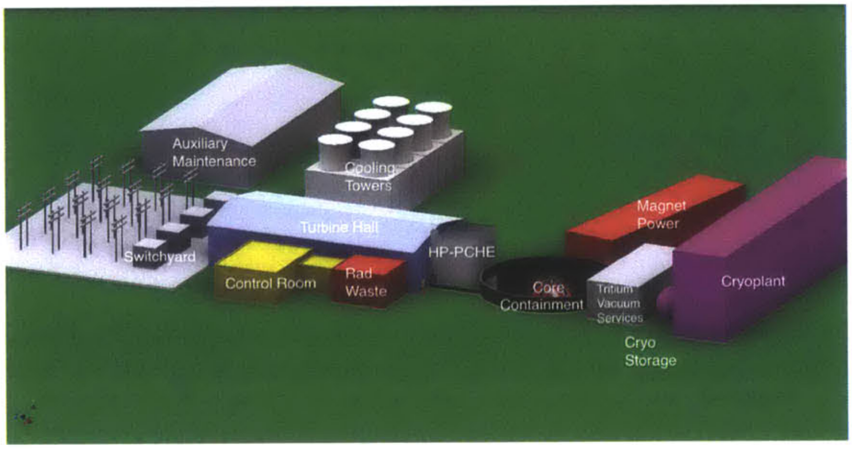

Figure 3: A 3D model of the SMURF powerplant concept site in full

Appendix H: Scanned Surveys from the Final Prototyping Phase

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- (●) Undergraduate Student
- ( ) Graduate Student
- ( ) Post Doc
- ( ) Faculty/Staff
- ( ) Visitor

Did you learn anything from this exhibit? Is so, what?

the relative size difference between a fission SMR and fusion SMR is substantial.

What did you *most* like about the exhibit?

- ( ) Title
- ( ) Movie
- ( ) Small Modular Reactor Plant Diagram
- ( ) Heat/Work/Electricity Applications
- ( ) Map
- ( ) Explanation of fusion, its uses and how it compares
- ( ) Powerplant Overview
- (●) Explanation of SMRs/Modularity
- ( ) Explanation of Shape of Exhibit

Why did you like this the most?

I feel like people know the least about this.

✓

What did you *least* like about the exhibit?

- ◯ Title
- ◯ Movie
- ◯ Small Modular Reactor Plant Diagram
- ◯ Heat/Work/Electricity Applications
- ● Map
- ◯ Explanation of fusion, its uses and how it compares
- ◯ Powerplant Overview
- ◯ Explanation of SMRs/Modularity
- ◯ Explanation of Shape of Exhibit

Why did you like this the least?

No explanation of why these nations were selected.

Did you have enough background information? Was everything easy to follow and understand?

It was for me — but I think it wouldn't be easy to follow for a lay person.

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

It needs more empty space to clearly delineate the different sections. Great job on the work/heat/electricity demos!

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this exhibit? Is so, what?

Pushing buttons ~~&~~ is fun
No idea that SMR's could do fusion
statistics about Fusion SMR's vs.
fusion

What did you *most* like about the exhibit?

- [ ] Title
- [ ] Movie
- [x] Small Modular Reactor Plant Diagram
- [ ] Heat/Work/Electricity Applications
- [ ] Map
- [ ] Explanation of fusion, its uses and how it compares
- [ ] Powerplant Overview
- [ ] Explanation of SMRs/Modularity
- [ ] Explanation of Shape of Exhibit

Why did you like this the most?

Interesting design as far as a fusion perspective goes, supremely cost effective and the energy efficiency

Development? Future research?

What did you *least* like about the exhibit?

- ◯ Title
- ◯ Movie
- ◯ Small Modular Reactor Plant Diagram
- ◯ Heat/Work/Electricity Applications
- ◯ Map
- ◯ Explanation of fusion, its uses and how it compares
- ◯ Powerplant Overview
- ◯ Explanation of SMRs/Modularity
- ◯ Explanation of Shape of Exhibit

Why did you like this the least?

Did you have enough background information? Was everything easy to follow and understand?

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

✓

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this exhibit? Is so, what?

Email

What did you *most* like about the exhibit?

- [ ] Title
- [x] Movie
- [ ] Small Modular Reactor Plant Diagram
- [x] Heat/Work/Electricity Applications
- [ ] Map
- [x] Explanation of fusion, its uses and how it compares
- [ ] Powerplant Overview
- [ ] Explanation of SMRs/Modularity
- [ ] Explanation of Shape of Exhibit

Why did you like this the most?

They were the most informative

What did you *least* like about the exhibit?

- [x] Title
- [ ] Movie
- [ ] Small Modular Reactor Plant Diagram
- [ ] Heat/Work/Electricity Applications
- [ ] Map
- [ ] Explanation of fusion, its uses and how it compares
- [ ] Powerplant Overview
- [ ] Explanation of SMRs/Modularity
- [ ] Explanation of Shape of Exhibit

Why did you like this the least?

No particular reason, just had to choose 1

Did you have enough background information? Was everything easy to follow and understand?

Yes, I am an NSE student

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

This is awesome! Good work

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- ◯ Undergraduate Student
- ◯ Graduate Student
- ◯ Post Doc
- ☒ Faculty/Staff
- ◯ Visitor

Did you learn anything from this exhibit? Is so, what?

—

What did you *most* like about the exhibit?

- ◯ Title
- ◯ Movie
- ◯ Small Modular Reactor Plant Diagram
- ◯ Heat/Work/Electricity Applications
- ◯ Map
- ◯ Explanation of fusion, its uses and how it compares
- ☒ Powerplant Overview
- ◯ Explanation of SMRs/Modularity
- ◯ Explanation of Shape of Exhibit

Why did you like this the most?

What did you *least* like about the exhibit?

- ◯ Title
- ◯ Movie
- ◯ Small Modular Reactor Plant Diagram
- ◯ Heat/Work/Electricity Applications
- ◯ Map
- ☒ Explanation of fusion, its uses and how it compares
- ◯ Powerplant Overview
- ◯ Explanation of SMRs/Modularity
- ◯ Explanation of Shape of Exhibit

Why did you like this the least?

Wood 10 MJ/kg → 100% efficient conversion of chemical stored energy.

Fusion 350M [kJ/g] → 100% efficient conversion of nuclear energy from D-T reaction

YOU CAN CALCULATE THIS!!!

Did you have enough background information? Was everything easy to follow and understand?

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

✓

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- (●) Undergraduate Student
- ( ) Graduate Student
- ( ) Post Doc
- ( ) Faculty/Staff
- ( ) Visitor

Did you learn anything from this exhibit? Is so, what?

energy densities of various sources

What did you *most* like about the exhibit?

- ( ) Title
- (●) Movie
- ( ) Small Modular Reactor Plant Diagram
- ( ) Heat/Work/Electricity Applications
- ( ) Map
- ( ) Explanation of fusion, its uses and how it compares
- ( ) Powerplant Overview
- ( ) Explanation of SMRs/Modularity
- ( ) Explanation of Shape of Exhibit

Why did you like this the most?

It gives a nice background to everything. :)

What did you *least* like about the exhibit?

- ◯ Title
- ◯ Movie
- ◯ Small Modular Reactor Plant Diagram
- ◯ Heat/Work/Electricity Applications
- ◯ Map
- ◯ Explanation of fusion, its uses and how it compares
- ◯ Powerplant Overview
- ◯ Explanation of SMRs/Modularity
- ◯ Explanation of Shape of Exhibit

Why did you like this the least?

Did you have enough background information? Was everything easy to follow and understand?

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

✓

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this exhibit? Is so, what?

No, but I was in 22.033 with you, so I can't answer this question anyway :)

What did you *most* like about the exhibit?

- [ ] Title
- [x] Movie
- [x] Small Modular Reactor Plant Diagram
- [ ] Heat/Work/Electricity Applications
- [x] Map
- [x] Explanation of fusion, its uses and how it compares
- [ ] Powerplant Overview
- [ ] Explanation of SMRs/Modularity
- [ ] Explanation of Shape of Exhibit

Why did you like this the most?

Intriguing
Colorful

*Movie should be on bigger screen!

What did you *least* like about the exhibit?

- ◯ Title
- ◯ Movie
- ◯ Small Modular Reactor Plant Diagram
- ☑ Heat/Work/Electricity Applications
- ◯ Map
- ◯ Explanation of fusion, its uses and how it compares
- ◯ Powerplant Overview
- ◯ Explanation of SMRs/Modularity
- ◯ Explanation of Shape of Exhibit

Why did you like this the least?

Applications seem disjointed? They take up too large a % of the exhibit space per amount of new information provided (Big space, little learning) ← just my gut feeling!

Did you have enough background information? Was everything easy to follow and understand?

Enough info, but I was unsure of the direction in which I should read. I found myself going top to bottom, then at times left to right (inconsistent?)

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

Y'all are wonderful :) great job! be proud of it

-Cam

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this exhibit? Is so, what?

Fusion SMR design was interesting
Energy Density chart

What did you *most* like about the exhibit?

- [ ] Title
- [ ] Movie
- [x] Small Modular Reactor Plant Diagram
- [ ] Heat/Work/Electricity Applications
- [ ] Map
- [ ] Explanation of fusion, its uses and how it compares
- [ ] Powerplant Overview
- [ ] Explanation of SMRs/Modularity
- [ ] Explanation of Shape of Exhibit

Why did you like this the most?

~~The [illegible]~~
Interesting, new thing or an original concept

/

What did you *least* like about the exhibit?

- ○ Title
- ○ Movie
- ○ Small Modular Reactor Plant Diagram
- ○ Heat/Work/Electricity Applications
- ☑ Map
- ○ Explanation of fusion, its uses and how it compares
- ○ Powerplant Overview
- ○ Explanation of SMRs/Modularity
- ○ Explanation of Shape of Exhibit

Why did you like this the least?

Map has no explanation. Also not enough clarity to usefulness of SMRs in general

Did you have enough background information? Was everything easy to follow and understand?

Organized in a confusing way; unclear how concepts are connected

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

Great job!
Maybe some directionality or a clear starting point would be helpful

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this exhibit? Is so, what?

~~Almost everything~~

A lot! I learned the general overview of a power plant and its structure, the core's appearance, its uses etc.

What did you *most* like about the exhibit?

- [ ] Title
- [ ] Movie
- [ ] Small Modular Reactor Plant Diagram
- [x] Heat/Work/Electricity Applications
- [ ] Map
- [x] Explanation of fusion, its uses and how it compares
- [ ] Powerplant Overview
- [ ] Explanation of SMRs/Modularity
- [ ] Explanation of Shape of Exhibit

Why did you like this the most?

It's really interesting and pressing the buttons and interacting w/ the presentation was fun

What did you *least* like about the exhibit?

- ◯ Title
- ◯ Movie
- ◯ Small Modular Reactor Plant Diagram
- ◯ Heat/Work/Electricity Applications
- ◯ Map
- ◯ Explanation of fusion, its uses and how it compares
- ◯ Powerplant Overview
- ◯ Explanation of SMRs/Modularity
- ◯ Explanation of Shape of Exhibit

Why did you like this the least?

Did you have enough background information? Was everything easy to follow and understand?

Yes.

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this exhibit? Is so, what?

Where SMRs would be useful

What did you *most* like about the exhibit?

- [ ] Title
- [ ] Movie
- [ ] Small Modular Reactor Plant Diagram
- [x] Heat/Work/Electricity Applications
- [ ] Map
- [ ] Explanation of fusion, its uses and how it compares
- [ ] Powerplant Overview
- [ ] Explanation of SMRs/Modularity
- [ ] Explanation of Shape of Exhibit

Why did you like this the most?

Big, central, practical ; they demonstrate why we need energy and make people question where energy comes from (which most of the public doesn't do often)

What did you *least* like about the exhibit?

- [x] Title
- [ ] Movie
- [ ] Small Modular Reactor Plant Diagram
- [ ] Heat/Work/Electricity Applications
- [ ] Map
- [ ] Explanation of fusion, its uses and how it compares
- [ ] Powerplant Overview
- [ ] Explanation of SMRs/Modularity
- [ ] Explanation of Shape of Exhibit

Why did you like this the least?

Sounds like you are saying that SMRs are not making much of an impact in the world, Title could be misunderstood

Did you have enough background information? Was everything easy to follow and understand?

Yes, but I have a background in the material The textboxes could be layed out a bit more orderly with an aesthetic that instantly conveys ~~the~~ where they fit in the "big picture"

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

Much needed lessons for the public!

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- (X) Undergraduate Student
- ( ) Graduate Student
- ( ) Post Doc
- ( ) Faculty/Staff
- ( ) Visitor

Did you learn anything from this exhibit? Is so, what?

What a SMR actually is, its advantages to normal reactors

What did you *most* like about the exhibit?

- ( ) Title
- ( ) Movie
- (X) Small Modular Reactor Plant Diagram
- ( ) Heat/Work/Electricity Applications
- ( ) Map
- ( ) Explanation of fusion, its uses and how it compares
- ( ) Powerplant Overview
- (X) Explanation of SMRs/Modularity
- ( ) Explanation of Shape of Exhibit

Why did you like this the most?

It was new to me and convinced me why this is useful / necessary.

What did you *least* like about the exhibit?

- ( ) Title
- (X) Movie
- ( ) Small Modular Reactor Plant Diagram
- ( ) Heat/Work/Electricity Applications
- ( ) Map
- ( ) Explanation of fusion, its uses and how it compares
- ( ) Powerplant Overview
- ( ) Explanation of SMRs/Modularity
- ( ) Explanation of Shape of Exhibit

Why did you like this the least?

Took too much time, ~~[illegible]~~ too small for me to notice, needed a sign that says "CLICK TO PLAY MOVIE" next to it.

Did you have enough background information? Was everything easy to follow and understand?

Yes I did, it was easy to understand, the material was well-explained/summarized.

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

Needed ~~[illegible]~~ more directions ~~[illegible]~~ on flow of exhibit, maybe arrows that dictates which thing to look at next.

Edit this form

SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this exhibit? Is so, what?

Some, was part of the team to help with overall project. Cool exhibit

What did you *most* like about the exhibit?

- [ ] Title
- [ ] Movie
- [x] Small Modular Reactor Plant Diagram
- [ ] Heat/Work/Electricity Applications
- [ ] Map
- [ ] Explanation of fusion, its uses and how it compares
- [ ] Powerplant Overview
- [ ] Explanation of SMRs/Modularity
- [ ] Explanation of Shape of Exhibit

Why did you like this the most?

Being able to see a potential layout for SMR

What did you *least* like about the exhibit?

- ◯ Title
- ◯ Movie
- ◯ Small Modular Reactor Plant Diagram
- ◯ Heat/Work/Electricity Applications
- ◯ Map
- ◯ Explanation of fusion, its uses and how it compares
- ☒ Powerplant Overview
- ◯ Explanation of SMRs/Modularity
- ◯ Explanation of Shape of Exhibit

Why did you like this the least?

Just think HP-PCHE should have been at least described as Heat Pipe & PCHE (Printed Circuit heat exchanger), tho it kind of makes you curious what it is

Did you have enough background information? Was everything easy to follow and understand?

Same as above

Any other comments, questions, or concerns you had about the exhibit?
Any feedback would be helpful!

Appendix I: Scanned Executive Summary Surveys

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SMR Exhibit Survey

What is your affiliation to MIT?

- (●) Undergraduate Student
- ( ) Graduate Student
- ( ) Post Doc
- ( ) Faculty/Staff
- ( ) Visitor

Did you learn anything from this executive summary? Is so, what?

Yes. Fusion reactors that generate ~640 MWT power can be considered small.

What did you *most* like about the summary?

- ( ) Overview
- (●) The Core
- ( ) The Interface
- ( ) The Powercycle
- ( ) The Exhibit
- ( ) Total Size and Cost

Why did you like this the most?

It's extremely clear visually what is going on with the structure of the core. Materials are described individually and in great detail.

What did you *least* like about the summary?

- ( ) Overview
- ( ) The Core

- ( ) The Interface
- (●) The Powercycle
- ( ) The Exhibit
- ( ) Total Size and Cost

Why did you like this the least?

Too many numbers at one for me.

Did you have enough background information? Was everything easy to follow and understand?

I do not have any background personally, so the fact that this was written in clear, simple english made it easier to comprehend.

Any other comments, questions, or concerns you had about the summary?
Any feedback would be helpful!

I like the pictures of the design. May be some more pictures / charts for the interface / powercycle?

[Submit] Click.

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SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this executive summary? Is so, what?

learned some details about the design of a SMURF

What did you *most* like about the summary?

- [ ] Overview
- [ ] The Core
- [ ] The Interface
- [ ] The Powercycle
- [x] The Exhibit
- [ ] Total Size and Cost

Why did you like this the most?

could understand it and visualize it

What did you *least* like about the summary?

- [ ] Overview
- [x] The Core

- ◯ The Interface
- ◯ The Powercycle
- ◯ The Exhibit
- ◯ Total Size and Cost

Why did you like this the least?

pretty technical → not 22 so a lot of the words + phrases had little meaning to me

Did you have enough background information? Was everything easy to follow and understand?

some background knowledge but not enough to completely follow the CORE section or the interface section

Any other comments, questions, or concerns you had about the summary?
Any feedback would be helpful!

If not 22 ppl are in the audience, include some more definitions (like what is F_2LiBe?)

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SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this executive summary? Is so, what?

yes
→ the general idea of how this design functions.

What did you *most* like about the summary?

- [ ] Overview
- [ ] The Core
- [ ] The Interface
- [x] The Powercycle
- [ ] The Exhibit
- [ ] Total Size and Cost

Why did you like this the most?

It was very concise and described everything it had to.

What did you *least* like about the summary?

- [ ] Overview
- [x] The Core

- The Interface
- The Powercycle
- The Exhibit
- Total Size and Cost

Why did you like this the least?

There were technical terms. within this that I wasn't sure about

Did you have enough background information? Was everything easy to follow and understand?

Not Everthing was easy to follow & understand. The schematic rep. in the beg gave a good visual. There were alot of technical terms that were a a bit hard to follow &c.

Any other comments, questions, or concerns you had about the summary?
Any feedback would be helpful!

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SMR Exhibit Survey

What is your affiliation to MIT?

- (●) Undergraduate Student
- ( ) Graduate Student
- ( ) Post Doc
- ( ) Faculty/Staff
- ( ) Visitor

Did you learn anything from this executive summary? Is so, what?

Yes, the summary provided an indepth analysis of the medium and visual technicalities in which power production will be enhanced in the future

What did you *most* like about the summary?

- ( ) Overview
- ( ) The Core
- ( ) The Interface
- ( ) The Powercycle
- (●) The Exhibit
- ( ) Total Size and Cost

Why did you like this the most?

I am a visual learner, so real-life representations and specific details help me store information, as well as enhance my understanding. I was instantly captivated.

What did you *least* like about the summary?

- ( ) Overview
- ( ) The Core

- (x) The Interface
- ( ) The Powercycle
- ( ) The Exhibit
- ( ) Total Size and Cost

Why did you like this the least?

Its simply my least favorite because it includes no visuals, has complex jargon, and was full of acronyms

Did you have enough background information? Was everything easy to follow and understand?

Yes, the writing was done very methodically and I found it easy to follow and internalize. Visual representations were excellent supplements

Any other comments, questions, or concerns you had about the summary?
Any feedback would be helpful!

Great job, I see no major issues.

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SMR Exhibit Survey

What is your affiliation to MIT?

- (●) Undergraduate Student
- ( ) Graduate Student
- ( ) Post Doc
- ( ) Faculty/Staff
- ( ) Visitor

Did you learn anything from this executive summary? Is so, what?

Power plants, regardless of size, are expensive!

What did you *most* like about the summary?

- ( ) Overview
- ( ) The Core
- ( ) The Interface
- ( ) The Powercycle
- (●) The Exhibit
- ( ) Total Size and Cost

Why did you like this the most?

It painted a vivid picture of what the exhibit would be like and how people would interact with it

What did you *least* like about the summary?

- ( ) Overview
- (●) The Core

- ◯ The Interface
- ◯ The Powercycle
- ◯ The Exhibit
- ◯ Total Size and Cost

Why did you like this the least?

It was pretty technical, and so I didn't really understand it.

Did you have enough background information? Was everything easy to follow and understand?

I didn't have much background, but it was still straightforward and easy to follow.

Any other comments, questions, or concerns you had about the summary?
Any feedback would be helpful!

It'd be nice/helpful to see goals explicitly stated/listed.

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SMR Exhibit Survey

What is your affiliation to MIT?

- ○ Undergraduate Student
- ● Graduate Student
- ○ Post Doc
- ○ Faculty/Staff
- ○ Visitor

Did you learn anything from this executive summary? Is so, what?

Learned about the different pieces that make up the entire system.

What did you *most* like about the summary?

- ● Overview
- ○ The Core
- ○ The Interface
- ○ The Powercycle
- ○ The Exhibit
- ○ Total Size and Cost

Why did you like this the most?

It's quick to see that I don't have sufficient background to fully understand this but the overview does a great job showing the entire premise.

What did you *least* like about the summary?

- ○ Overview
- ● The Core

○ The Interface

○ The Powercycle

○ The Exhibit

○ Total Size and Cost

Why did you like this the least?

overly verbose and hard to understand if you don't have the sufficient background for it.

Did you have enough background information? Was everything easy to follow and understand?

Some parts ~~were~~ were easy to understand, the technical parts were efficient enough where you get an idea but not full understanding

Any other comments, questions, or concerns you had about the summary?
Any feedback would be helpful!

The overview should encompass the different parts a little better and lead the reader up to those parts

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SMR Exhibit Survey

What is your affiliation to MIT?

- [x] Undergraduate Student
- [ ] Graduate Student
- [ ] Post Doc
- [ ] Faculty/Staff
- [ ] Visitor

Did you learn anything from this executive summary? Is so, what?

- understanding of material ~~processes~~ properties and the reasonings behind their incorporation in the SMURF
- overall layout & function of different sections of the SMURF

What did you *most* like about the summary?

- [ ] Overview
- [ ] The Core
- [ ] The Interface
- [ ] The Powercycle
- [x] The Exhibit → (1)
- [x] Total Size and Cost → (2)

Why did you like this the most?

(1) After reading the complex parts, it was very interesting to see the plan to make this more accessible to the general public - it seems awesome!

(2) This brought the project into a realistic context & then gives a good justification of all the technology we just read about

What did you *least* like about the summary?

- [ ] Overview
- [ ] The Core

- The Interface
- The Powercycle
- The Exhibit
- Total Size and Cost

Why did you like this the least?

Wasn't a particular part... if the audience is scientists, "the core" & "the interface" are fine: If for others maybe make it more accessible with simpler explanations

Did you have enough background information? Was everything easy to follow and understand?

more or less. maybe some definitions for things that are common in NSE like FLiBe. you figure it out as you read, but might be nice to have them spelled out at the beginning

Any other comments, questions, or concerns you had about the summary?
Any feedback would be helpful!

the exhibit's plasma discharge tube is so cool.

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