[redacted]

"The Story of Safe Nuclear Power"

A short animated film on the current state of nuclear power and the future of power production.

2011-2012

BW and JL

Interactive Qualifying Project

As a requirement for a Bachelor's of Science degree in Mechanical Engineering, we as students at Worcester Polytechnic Institute are required to complete an Interactive Qualifying Project. The concept of this project is to recognize a problem about science and technology in the world around us, and work to address the issue. For our IQP, we chose to analyze the state of nuclear power and produce a short animated film regarding our findings. Through diligent research and experience in film production, the group of Brendan Walsh and Jim Lehner were able to produce a well informed piece on current nuclear power.

The idea for a project on nuclear power was thought up due to the current need for an alternative energy source. As fuel sources dwindle, our energy consumption increases proportionally. As a group we wanted to analyze and learn exactly how a reactor works and assess safety and risk versus the upsides to nuclear energy. Working to make the systems safer seemed like the most obvious issue with nuclear reactors. The majority of nuclear accidents are a direct result of human error. Simpler systems with limited human interaction and more automation are safer.

Introduction

This pre-production binder is organized by the term in which the work was completed. In the first term, we completed serious research about the systems of reactors and about its history. With knowledge about the science of the reactors, how power is generated, and the safety aspects, we would be able to make educated suggestions. We also needed to plan what we were going to do over the three terms of work. This was a big part of the A term, as we stayed on schedule throughout the entire project.

In the second term we worked on completing all pre-production necessities. This included a storyboard, the narration, and final research. Recording the narration and beginning the film was a must to stay on pace with completion. We also took the time to visit the University of Rhode Island nuclear reactor. This experience provided additional knowledge on the subject and a chance to see what we had been learning about.

The third term involved completing the film and putting together this journal. Gathering together all materials from the past two terms was easy due to our prior organization. With over 25 hours of production time and animation, we were able to put together a five minute video that teaches about nuclear energy. Beginning with how a reactor works and then informing people about safe nuclear generation, we are able to convey what everyone should understand about nuclear energy as an alternative fuel source.

Table of Contents:

Term A - 2011

August - October

Safe Nuclear Power

1. Explanation of Nuclear Power
   - Works   - history
   - Safety (briefly)

2. Current Issues w/ N. Power (safety)
   - Japan / Chirnoby/

3. Current US Nuclear set-up and alternatives
   - World Nuclear plants
   - alternatives

4. Understanding of safe nuclear plant operations
   - human error
   - Ways to improve current protocol

5. Popular Opinion on Power

6. Proposition to change opinion due to safer gen [illegible]
   - What we think should be done

Notes

- Interviews (Nihorchuk)

9/7/11

<u>Outcome</u>: solid abstract
- The project objective...
- The research includes...
- The conclusions conclude

Inherently safe reactors and social impact.

↓ necessary safe

↓ still won't believe it

* show project abstract online

<u>New Goals</u>

1. ~~[illegible]~~ "same" -> look at "how it works"

2. How have they not been safe?

3. ~~People's (the world US) view on safety threat (just like our #5)~~

4. How can it be safe?

5. People's (the US) view on current situation and will that change.

Oct 14 - 24

A Intro

Analyze current state... make suggestions better social understanding and improve on designs

B How it works
Current State

- how much is nuclear
- Where they are
- who built them
- who runs them
- costs (general)
- ~~accidents~~
-

- NRC?
- future development
- Waste?
- attack?

C. Disaster
- Japan
- Chernobyle
- Three Mile

D. Current state
2009 - 2011

E. Analysis
(1) Technological advances
(2) . . . Analyze Part D

How It Works

Rankine cycle
- proccess of using heat to do work ~~[illegible]~~ (steam engine)
- basic premise for 90% of energy
-

I Introduction

A. "As global population increases, the demand for energy increases proportionally."

B. Idea that nuclear energy is a better substitute to current situation

C. United States facts on global energy consumption from BP

~~D. [illegible]~~

~~B.~~

D. Thesis:

(1) Our best option for alternative lies in harnessing energy from nuclear fission, and generating clean, abundant energy for millions of people globally.

II. Nuclear Power and how it works

A. History of Nuclear Energy

1. Sheet of research already

B. How harnessing power is achieved.

C. Systems and cooling

1. Mention enormous amount of safety systems.

D. Pictures and Graphs.

(1) System diagram

(2) Picture of standard control room

(3) Fission diagram?

III Impact on Earth

A. Waste

(1) Yucca Mt

"Radium is not to enrich any one. It is an element; it is for all people." (#1)

-Mari Curie

"And Lord, we are especially thankful for nuclear powe[r] the cleanest, safest energy source there is." (#2)

- Homer Simpson

"All the waste in a year from a nuclear power plant can stored under a desk." (#2)

- Ronald Regan

(#3)

- Over 1939-45 most development was for bomb.
- After 1945 attention for naval propulsion and electricity was key.
- Since 1956, focus has been for safe nuclear pl[ants].
- Uranium discovered 1789
- 1895: radiation discovered by Wilhelm Rontgen
- From 1902 - 1935 scientists made progres[s]
- 1938 Otto Hahn and Fritz Strassman showe[d] nuclear fission through waste elements Kr,
- Otto Frisch, Lise Meitner, Neils Bohr discovere[d] what fission was and the calculated 200 mil[lion] volts [of] energ[y]

- Little Boy dropped on Hiros...
6, 1945 → Uranium
→ "Enola Gay"
→ 66,000 killed
→ 69,000 injured
→ 10 kiloton explosion

- Nagasaki "Fat Man"
→ Plutonium
→ leveled nearly 1/2 city
→ 49,000
→ 25,000

- US consumed 20% of world's gas consumption in 2008 (HS)
- US consumed 22.5% oil
- US CO_2 emmissions 20.2%
- Coal 17.1%
- Nuclear 31.0%
→ 104 reactors

URI - 401 789
9391

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senior Communications Advisor
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(1) 235 and 238 are [illegible]
chemically

(2) ratio of conversion from ore
to metal is 500:1

(3) 99.3% of it is useless 238

(4) Only mechanical extraction opt[illegible]

- Oak Ridge, TN — lab/plant
  -> gaseous diffusion and magnetic
  extraction led to better amount

- 1939 - 1945 over $2 billion was spent
  to develop bomb

- Los Alamos

- "The Gadget" July 16 1945
  -> atomic fireball shot up
  at 360 fps
  -> mushroom cloud @ 30,000 ft
  -> only remnants was green
  radioactive glass @ site by heat
  of reaction

confirmed the ideas of Einstein

- Discovered through process neutrons and photo[ns] released as free particles. These would then bre[ak] other nuclei and thus self-sustaining re[action]

- Uranium 235 isotope better than 238
  - ↳ .72% natural uranium
  - ↳ can sustain fission reaction
  - ↳ "fissile" vs. "fertile"

- 5 kg of Uranium could make a very powerful weapon
  - → massive energy
  - → radiation effects
  - → scientists were Peierls and Frisch

- Uranium deposits in – Australia @ $13 US/kg * 1/3 world total
  - → 1,673,000 tons
  - – Kazakhstan
  - – Canada

- Manhattan Project

  #4

  - → J. Robert Oppenheimer
    - – scientific director

- Uranium-235 is hard to extract.

N. American plates

... 30-40 m

Bibliographic Notes

How Nuclear Works

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2. http://thinkexist.com/quotes/with/keyword/nuclear_power/

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4. http://www.bp.com/statisticalreview

http://www.scientificamerican.com/article.cfm?id=how-to-cool-a-nuclear-reactor

3. http://www.world-nuclear.org/info/inf54.html

http://www.world-nuclear.org/info/reactors.html

Impact on the Earth

http://www.indiana.edu/~rcapub/v20n3/4c.html

Nuclear Disasters

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http://www.youtube.com/watch?v=eLPAigMuBk0&list=PL937B0E873F58A3D7&index=1

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http://www.iaea.org/Publications/Factsheets/English/ines.pdf

http://www.whatisnuclear.com/chernobyl/timeline.html

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http://www.pbs.org/wgbh/pages/frontline/shows/reaction/readings/tmi.html

http://www.pbs.org/wgbh/amex/three/sfeature/tmiwhat.html

http://www.youtube.com/watch?v=eLPAigMuBk0&list=PL937B0E873F58A3D7&index=1

http://www.policyalmanac.org/environment/archive/three_mile_island.shtml

http://www.pbs.org/wgbh/amex/three/filmmore/description.html

http://www.oecd-nea.org/press/2011/NEWS-04.html

http://bravenewclimate.com/2011/03/13/fukushima-simple-explanation/

Safe Generation

http://www.youtube.com/watch?v=kV3Zlythcos

http://video.pbs.org/video/1848907161

http://www.inpo.info/

General

4. http://world-nuclear.org/

James Lehner

Brendan Walsh

IQP: Safe Nuclear Energy

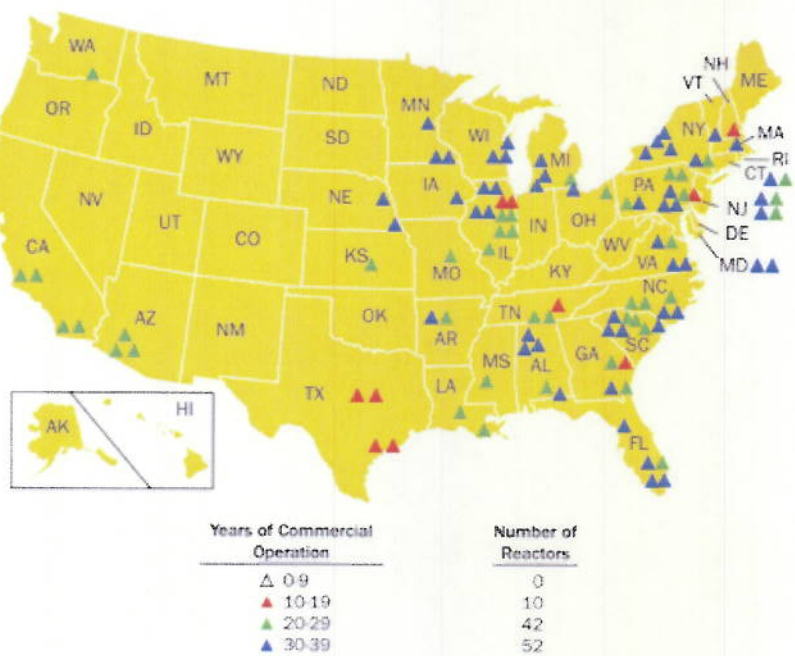
Detailed Video Outline

- The following is a detailed outline of the sections and associated topics that will be included in the Safe Nuclear Energy video for our IQP. The below listed are subject to change.

Introduction

- **Infographic**
    - The infographic will establish the current state of nuclear power in the United States. This will be achieved by presenting facts that as a whole paint the big picture of the role and state of nuclear facilities in the United States
        - There are 104 nuclear power plants in the United States
        - The vast majority of nuclear reactors are located east of the Mississippi river.

U.S. Commercial Nuclear Power Reactors—Years of Operation



Source: U.S. Nuclear Regulatory Commission

- They produce 20% of the countries electricity
- The waste plants produce is stored permanently at Yucca Mountain, Nevada
- The average cost to build a nuclear power plant is about $2000 per installed kilowatt (KW)
- The average cost to operate a nuclear power plant is about 0.2 cents per KW-Hr

        - Nuclear power plants are operated by private companies
        - Etc.
- **Nuclear Power Plant: An animated reactor tour**
    - The reactor tour will explain the processes that occur in a nuclear facility that produce electricity. The process of producing electricity from nuclear fuel can be summarized 7 Steps
        - **1) Fuel**
            - Manufactured in small round pellets, uranium 235 is one of many materials that can be used in a nuclear reactor to produce heat. The pellets are placed end to end in 12 foot long fuel rods of which there are over 200 in a fuel assembly.
        - **2) Reactor**
            - Uranium atoms are split here in a process called fission. This occurs when the uranium atoms collide with neutrons, a unique quality of uranium 235. As the atom splits the pieces are free to collide with other atoms causing a chain reaction which produces heat. The chain reaction is controlled by control rods in the reactor that absorb neutrons. Fission is allowed to occur by removing these rods.
        - **3) Pressurizer**
            - Heat from the reactor is transferred to the primary coolant system. This is the first of three water systems the heat will pass through. The primary coolant is often brought to a temperature of over 600 Fahrenheit and is kept from boiling by keeping the water under pressure (a pressurized water reactor).
        - **4) Steam Generator**
            - The heat from the reactor is transferred to a fluid, most often water, called the primary coolant system. The water is heated and pressurized as it travels through tubes in the steam generator. The tubes are surrounded by a secondary water coolant system. The heat from the primary coolant is transferred to the secondary coolant which turns to steam.
            - Primary and secondary systems are closed. This means that the water contained within the reactor remains separate from the water in other systems.
        - **5) Turbine**
            - Steam is moved from the containment building which holds the reactor and steam generator into the turbine building. The blades of the turbine are now turned by the steam which in turn rotates a shaft connected to an electric generator. (Magnet in generator turns producing electricity)
        - **6) Condenser/Coolant**

            - Now that the turbine blades have been turned the steam is cooled. This is done by running the steam over the third water system, the condenser coolant. Once the steam is cooled enough so that it becomes water again the water is pumped back to the steam generator to be reused.
        - **7) Cooling Towers/Lake**
            - Returning the condenser coolant to a usable temperature is done by pumping the water to the top of cooling towers where it is allowed to poor through the structure. Other facilities lake water is allowed to flow over tubes and then discharged.

Nuclear Disasters

- **INES Scale**
    - The INES scale is the international Nuclear and Radiological Event Scale. This scale is used to rate the severity of nuclear accidents around the world. Using the scale as a frame work we will explore the three most severe nuclear accidents of the last 14,000 years of civil reactor operation.
        - **Accidents to be explored**
            - Accidents will be explored from least severe to most severe as we travel up the INES scale. Each accident level will be explored according to the three areas of impact:
                - 1) **Environment and People**
                    - Examines radiation doses to people closest to event
                - 2) **Radiological Barriers and Control**
                    - Only applies to major facilities
                    - Covers events with no direct impact on people
                    - Covers unplanned high radiation levels and spread of large amounts of radioactive material within a facility
                - 3) **Defense-in-Depth**
                    - Covers events with no direct impact on people
                    - Looks at systems in place that should have prevented an accident but did not function properly
            - We will start with 3 mile island which was rated a level 5 accident with wider consequences. Chernobyl and Fukishima are considered level 7 major nuclear accidents and will be explored when we reach the description of level 7 reactor accidents according to the INES Scale.
                - **3 Mile Island**
                - **Chernobyl**
                - **Fukushima**
            - Type of reactor used in each cause will be defined in accident description.

- **Major point to be established from this section is that human influence and error is what has resulted in the previously mentioned major nuclear events.**

Safe Nuclear Energy

- This section will explore the advances in nuclear power production over the last 50 years. The main focus of this section will be **Generation III Reactors.** These systems are the most advanced in terms of removing the opportunity for human error in the operation of a nuclear facility.
- Generation III reactors are reactors derived from designs originally developed for naval use.
- Also to be included here is an exploration of evacuation plans of people within a 50 mile radius of nuclear reactor facilities.
  - **2 reactors operate 35 miles outside NYC**
    - **There are 21 million people within a 50 mile radius of these reactors that would need to be evacuated in the case of a level 7 accident**
    - http://www.cnn.com/2011/US/03/31/nuclear.evacuation.plans/index.html
- **Generation III Reactors make advances from Generation II in:**
  - Standardized design
  - Simpler and more rugged system design
  - Longer life cycle of about 60 years
  - Reduce possibility of core meltdown
  - 72-Hour grace period
    - After shutdown the plant requires no active intervention for a period of 72 hours
  - Resistance to damage caused by an aircraft impact
  - Higher burn up
    - Reduces the amount of fuel needed and subsequently the amount of waste produced
  - Greater use of absorbers to extend fuel life
- **Advanced Water Boiling Reactor (AWBR)**
  - One of twelve new nuclear reactor designs designated as Generation III
  - AWBR is a type of generation III reactor that we will focus on. This is because the production of electricity in most generation II reactors, such as Chernobyl and Fukushima, is done using Generation II water boiling reactors
  - AWBR is a light water reactor system
    - Light water reactors use normal water as a coolant and neutron moderator

Summary

- Recap of the previously discussed issues will lead to an answer of the the question **Is nuclear power Safe?**

Safe Nuclear Energy IQP

Term A, 2011

Jim Lehner, Brendan Walsh

Production Outline

Goal

The goal of this project is to analyze the current state of nuclear power in the United States and provide information that betters social understanding of nuclear power generation and improves on existing nuclear power plant designs. This will be achieved with a combination of animation and video that visually illustrates the aforementioned items.

Treatment

In this documentary style video we will ask the question is there such a thing as safe nuclear power. To achieve this goal, a combination of animation, stock footage, shot footage, and interviews. We will begin by examining the state of power in the United States. By exploring the history and technology of nuclear energy we look to establish in the viewer a foundation from which they can make their own judgments about the safe nature of the system.

The process of creating usable energy from nuclear material is a complicated one. As a product of its inherently scary nature we are looking to show that nuclear energy is not only a safe option for power production but a feasible alternative energy source. To begin we will use a moving info graphic that establishes the current state of nuclear power in the United States. This section will be rely heavily on facts about the nuclear power system and the role it plays in our daily lives. Questions we look to answer are where are nuclear power plants located? Who runs nuclear power plants? And what is the cost to build and operate them? From here an animated tour of a nuclear power plant will be taken. This will explore the major parts and processes involved in the production of power from nuclear material. Fundamental concepts of fission, fusion, and thermal conductivity will be explored.

Nuclear disasters will next be examined. This will be done through a combination of stock footage, stock photographs, and shot footage. Exploring them chronologically we will first examine the Chernobyl nuclear disaster in the Ukraine. This will be followed by the partial core meltdown at Three Mile Island in Pennsylvania. This section will end with the Fukushima nuclear disaster in Japan. In examining all three of these accidents we will establish with the viewer what the fundamental cause of the problem was and how it could have been avoided. Key areas to be examined will be human influence and the related equipment failure. This will lay the groundwork for the third section that looks to explain how nuclear power is safe and the improvements that have been made to nuclear reactor designs over the last few decades.

Finally we will examine how nuclear energy is safe. A major focus of this section will explore the concept of inherently safe nuclear reactor systems. Along with the inherently safe systems we will look at more unique reactor design. Possibilities include pebble bed reactors and Generation III nuclear reactors. Ideally we would like to include 3 designs to be discussed. The video will be closed with a review of the previously discussed areas. In doing so we would like to once again ask the viewer is there such a thing as a safe nuclear power.

Production Plan

Friday September 23, 2011: Production outline Due

- Ongoing research will continue

Friday September 30, 2011: Video Outline Due.

- The video outline will describe the major sections, issues, and topics the video will address.
- Review of this outline will help decide what is missing and what should be omitted.
- Begin writing introductory narration.

Friday October 7, 2011: Detailed outline due

- Detailed outline will have fleshed out the sections decided on in its previous iteration
- At this point major subject material should be decided.
- Narration for the first minute of the video should be outlined.

Friday October 14, 2011: Introductory narration due.

- The first iteration of the paper cut is an ideal description of what, in a perfect world, the video will contain. This includes descriptions of animations, major portions of narration, stock footage we would like to use, and footage we would need to shoot.
- Sections would be outlined as such

Term A Goal: The goal for the end of term A is to have identified the major aspects of safe nuclear power that we will explore. From here we will begin the production process. Shot lists, possible interview subjects and animation layouts will be established in the first few weeks of Term B.

Friday October 28, 2011: Tentative shoot schedule and shot list due

- The shoot schedule will layout when and where we will go to shoot footage (B-roll) that will play under the videos narration
- Shot list is a description of the ideal shots we would like to have to accompany the narration of our video.

Friday November 4, 2011: TBD

Term B Goal: By the end of term B all footage will have been shot and assembly in the form of a rough cut should be complete. The rough cut will include possibly incomplete animations and place holder images for stock footage and photography that still needs to be located.

Term C Goal: Final cut will be produced by the beginning of c term.

Possible Interview Questions

For Professionals

- What is nuclear energy?
- How does nuclear energy produce usable power?
- What does the term safe nuclear power make you think of?
- Is there such a thing as safe nuclear power?
- How much of a concern is nuclear waste?
- What systems are in place in a nuclear power plant that helps make it safe?
- What went wrong at Chernobyl? Three Mile Island? Fukushima?
- How could the previously mentioned disasters been avoided? Could they have been avoided?
- Do you think nuclear power is safe?

For "Public"

- What is nuclear energy?
- Can you explain how nuclear power plants work?
- What is fission? What is fusion?
- Where do you think most of the country's power comes from?
- What kind of qualifications do you think are needed to run a nuclear power plant?
- Have you ever heard of Chernobyl? What happened?
- Have you ever heard of Three Mile Island? What happened?
- Do you think nuclear power is a good alternative to fossil fuels?
- Do you think nuclear power is safe?

Video Layout

Preface to Intro

- Possible narration: "The United States is one of world's leader in energy consumption.

Introduction

- Infographic accompanied by narration of the current state of nuclear power in the United States
    - Section will be filled with facts that address questions such as:
        - Where are nuclear power plants located in the United States?
            - Map of United States, Locations of plants pop up
        - How many of them are there?
            - Same as above visual
        - How much electricity do they produce?
            - Go from map of United States zoom into single plant with electricity leaving through wire
        - How much waste do they produce?
            - Truck drives out of power plant with waste

        - What happens to the waste?
            - Zoom out to map where we see the Truck traveling to waste destination
        - What is the cost to build a nuclear power plant?
            - Zoom into another power plant destination half built

        - Who runs/owns nuclear power plants?
            - Man walks out of building
        - What is the cost to run a nuclear power plant?
            - Truck drives in and drops a dollar on screen

- Nuclear Power Plant: An animated tour
    - Using Adobe After Affects we will show the viewer the essential processes and parts that allow a nuclear reactor to create electricity
    - Parts to include will be:
        - Fission and Fusion process
        - Reactor
        - Steam generator
        - Coolant
    - Tour Outline
        - Start with the fission and fusion processes by zooming into the fuel rods. Here two atoms are smashed releasing energy in the form out heat during fission while fusion is the breaking apart of atoms. In both cases heat is released and transferred to the surrounding water.
            - What does nuclear power run on fission or fusion? If both we talk about both if just one ignore the other
            - Possible Narration: While methods may vary plant systems
            -
    - Zoom out to show the core. Here we will describe the control rods roll in the power production process. Primary roll is to stop the fission process. Zoom out further to show the reactor. The primary coolant in nuclear system is generally water. This is also the material that transfers heat out of the core and reactor to the turbine
    -

Nuclear Disasters

- Chernobyl Nuclear Disaster
    - What happened?
        - Brief visual timeline that includes images of the plant in stages of construction, finished, during, and after the disaster.
            - Timelime:
                - May 1970: Construction begins on the facility.
                - 1982: A partial core meltdown occurs in reactor No. 1. The accident is not made public until 1995.

- April 25,1986: Facility begins test to observe the dynamics of RBMK reactor with limited power flow
- April 26, 1986: Reactor reaches 120 times its power output due to testing. Radioactive fuel disintegrates and Steam builds in system because turbines are shutdown. All pressure tubes are destroyed and entire top shield of reactor is blown off (steam explosion). Hot core of reactor is now exposed to the atmosphere.
  - In attempt to shut down the reactor the control rods are lowered into the core. The rods are made of Boron Carbide and graphite tips. As the rods are lower water is displaced. Inserting the tips all at once causes a dramatic power increase for a few seconds which under normal conditions would not have been a problem. Power surge results
- April 28, 1986: A nuclear facility in Sweden detects high levels of radiation coming from outside the plant. Soviet Union admits an accident has occurred.
- December 15, 2000: Chernobyl plant continues to run for years until 2000 when the last reactor is shutdown.

- Brief overview of the disaster

- References for section:
  - http://blogs.scientificamerican.com/guest-blog/2011/03/15/the-worst-nuclear-plant-accident-in-history-live-from-chernobyl/
  - http://www.whatisnuclear.com/chernobyl/timeline.html
  - http://library.thinkquest.org/3426/data/disaster/timeline.html
- Narration:
  - The Chernobyl Nuclear disaster is the worst in human history.
- What caused it?
  - This will look at the human factor and the associated mechanical failures
- What was the outcome?
  - How was the problem rectified
  - What kind of radiation was released into the surrounding area
- What are the lasting effects?
  - 25 years later what kinds of effects have the radiation had on the surrounding area and people

- Three Mile Island
  - What happened?
    - March 25th 1979
      - Harrisburg, PA
        - Three Mile Island dedicated to providing nuclear energy to PA and Oho area. Located on the Susquehanna River. Was two separate reactors and came online commercially in September 1974.

- What caused it?
    - The accident started at the plant's Unit 2 reactor when a small valve failed to close, causing cooling water to drain from the nuclear core. The main system pumps failed and the reactor began to overheat. . Immediately the control room began to light up with alarms and warning indicators. Eight minutes later, they discovered the emergency systems were not open. Two days prior they had been tested and left closed. Without cooling systems on, the reactor began to overheat. Due to the unbelievable complexity of the system, many of the operators were unable to respond effectively.
- What was the outcome?
    - They tried to evacuate the 500,000 people in the city needed to decide whether or not to evacuate. No official evacuation had been put in place since the first overheating. Eventually 140,000 would leave.
    - Leaking radiation through cracks in the reactor, many of the attendants, answering phone calls and watching for warnings, were forced to wear radiation suits due to the radiation leaking through cracks in the reactor. President Carter visits the reactor and the crisis ends.
    - Twenty years later they were able to lower a camera into Unit 2 and asses the overall damage. Roger Mattson, a senior NRC engineer, describes what was revealed: "We had a meltdown at Three Mile Island. Fifty percent of the core was destroyed or molten and something on the order of twenty tons of uranium found its way to the bottom head of the pressure vessel. That's a core meltdown. No question about it."
- References for section
    - http://www.pbs.org/wgbh/pages/frontline/shows/reaction/readings/tmi.html
    - http://www.pbs.org/wgbh/amex/three/sfeature/tmiwhat.html
    - http://www.youtube.com/watch?v=eLPAigMuBk0&list=PL937B0E873F58A3D7&index=1
    - http://www.policyalmanac.org/environment/archive/three_mile_island.shtml
    - http://www.pbs.org/wgbh/amex/three/filmmore/description.html

- Fukushima Nuclear Disaster
    - What caused it?
        - Chronologically follow how the incident was a product of an earthquake
        - Will also examine how poor planning on the part of designers of the plant led to the tsunami destroying essential backup systems
    - What was the outcome?
        - Will look at the state of the plant and the surrounding region now.
        - Will also examine if this scenario could have been planned for and how designers could have made the facility more "safe"

Safe Nuclear Power

- Will include 3 plant designs:
    - Pebble Bed Reactors

- Generation IV reactors
- Inherently Safe Nuclear Reactors

- Include ideas of government spending and financing briefly. The idea that organized response systems and organizations such as NRC and INPO make safety
- The focus of the previously mentioned designs will be the same as in the introductory section of the video. Parts and systems will include:
  - Fission
  - Fusion
  - Reactor
  - Steam
  - Cooling/ coolant
  - Complexity and engineering aspects are key
    - Think puzzle piece reactors. See Bibliographic Notes
- Will conclude by asking the viewer to now make their own informed decision on whether or not nuclear power can actually be deemed safe. Is safe nuclear power an oxymoron?

Term B - 2011

October - December

Jim Lehner
Brendan Walsh
Safe Nuclear Power IQP
B Term Date Outline

*The following is an outline regarding the week to week progress of our IQP on safe nuclear energy. In some instances dates may be subject to change.

Friday October 28, 2011:

- Review of completed video narration to date.
- Discuss possible changes to be made to direction of narration.
- Discuss URI Bay Campus nuclear reactor visit.

Friday November 4, 2011:

- Completed narration due.
- Work on finalizing wording and phrasing of narration which is due following week.

Friday November 11, 2011:

- Final revisions of narration due.
- Begin visualizing script (paper cut).
    - Paper cut is a worded description of the images that will accompany the narrated audio. Idea here is to describe to the viewer what they would see if the video was already created.
- Gather visual aids that will be used to accompany narration.

Friday November 18, 2011:

- Recorded audio of narration due.
- Rough draft of paper cut due.
- Work on finalizing the paper cut for meeting on Tuesday.
- Gather visual aids associated with topics discussed in narration.

Tuesday November 22, 2011 (@ 10am): Possible meeting time before Thanksgiving break

- Final draft of paper cut due.
- Begin work on storyboards based on paper cut.

November 23 to 27 is Thanksgiving Break

- Break will be used to completely flesh out the story board for the video.

Friday December 2, 2011:

- Storyboard of video due.
    - Story board visually illustrates what the viewer will be seeing as the video plays. The images seen are associated to the topics being discussed by the narration.
- Begin art design of video.

   - This will be the start of the video assembly as a rough cut. All narration and associated visuals are finalized here
   - Begin content creation of visuals for safe nuclear energy.

Friday December 9, 2011:

- First round of art concepts due.
- If possible a rough cut of narration will be presented.
- Continue work on rough cut.

Tuesday December 13, 2011 (@10am):

- Rough cut of video due.
   - This rough cut will include all to date progress of the video.
   - It will be very likely that a complete rough cut (something that includes at the least visual place holders) will be see in the first week of C-term.

University of Rhode Island – Nuclear Reactor

10/20/2011

Use of the Reactor

This past Thursday, we visited Rhode Island's only nuclear reactor. Located at the University of Rhode Island's Bay Campus, the Rhode Island Nuclear Science Center serves at the state Atomic Energy Commission. Largely non-profit, the building relies heavily on grants from the state and federal government. According to Zach, on a budget of around 1.5 million dollars annually (with 9 full-time employees), they are allowed to make a profit of about $750,000 dollars per year.

Built in 1960 and critical four years later, this 2 mega-watt reactor serves a major purpose in both the University's and global research. Originally designed as a 5 megawatt reactor, they are only licensed to generate 2 megawatts. In our tour, we were shown that the reactor is equipped with two cooling systems. With only one in use now due to the lower power, they hope to be relicensed to generate a full five over the next few years.

Our tour guide and reactor supervisor Zach told us that many professors and students from surrounding state schools use the reactor in order to perform experiments from carbon dating to indentifying the chemical makeup of specimens. Through grants and external support, the reactor provides much of these benefits at little or no cost. Sometimes private corporations will take advantage of the research reactor, and profit will be made. The process of actually getting samples in or near the core is done through the use of a "rabbit" system. This system is used to transport samples, both large and small, directly to the core or adjacent depending on the experiment. We also saw a large 6 inch lead door that can be opened, revealing a thermal neutron room that lies directly behind the core. The reactor is not designed use the thermal energy for specific use ass it is strictly a research facility.

Tour and Design

Upon entering, we entered the building adjacent to the reactor. Here housed classrooms for teaching, computers for research and a few offices. We spent the first 45 minutes with Zach in one of the classrooms. Here he taught us many things we didn't know. Listed below are a few things we learned.

- Ideally, a reaction starts with a sample nuclear isotope and a neutron. When fission occurs, the isotope is split into three neutrons. The next step is to split into six, then 12, 24, and so on. The time in which it takes for the next split to occur is called the period. Many of the safety system in reactors, and especially this one, are designed around this idea. For this reactor, the period I believe was 4 seconds.
- Despite forgetting the name, the reactor safety systems are based on two things. The first is the actual requirements. This is based on limitations provided both by the manufacturer and the NRC. These are required limitations in terms of shutdown of fission, cooling, maximum power and responses in case of any scenario. The other safety measures are the limitations provided by the operators to ensure that none of these requirements issued are broken. For instance,

the maximum power that is allowed to be generated set by the NRC is 2.4 megawatts of power. This being said however, the operators have set their limitations to 2.3 megawatts in order to guarantee that they will not break the set power limit. This idea is applied to all facets of the reactor. If for some reason the limits set by the operators are reached, the system goes into an automatic shutdown. Below is an update email from Zach about these systems.

From our Tech Specs, which draw from the ANSI standard:

Safety Limits (SL) - "Safety limits are limits on important process variables which are found to be necessary to reasonably protect the integrity of the principal barriers which guard against the uncontrolled release of radioactivity. The principal barrier is the fuel element cladding."

Limiting Safety System Settings (LSSS) -

"Settings for automatic protective devices related to those variables having significant safety functions, and chosen so that automatic protective action will correct an abnormal situation before a safety limit is exceeded"

Limiting Conditions of Operation (LCO) -

"Lowest functional capability of performance levels of equipment required for safe operation of the reactor"

What it means:

SL - The actual point we start breaking stuff

ex: Our safety limit on power is 2.4 MW, beyond this we could begin to damage fuel (taking all conservative estimates into account)

LSSS - The actual point for automatic SCRAMs

ex: Our LSSS on power is 2.3 MW, so that with this and our other LSSS we never hit our SL of 2.4 MW.

LCO - Other things that have to be working that don't directly impact the safety system and fuel integrity

ex: We have LCOs on our effluent monitors, area radiation monitors, and staffing.

Most of our limits are derived from computer models where all conservative assumptions are made, such as what if a control blade gets stuck in the full out position or worst case scenarios for water flow and temperature.

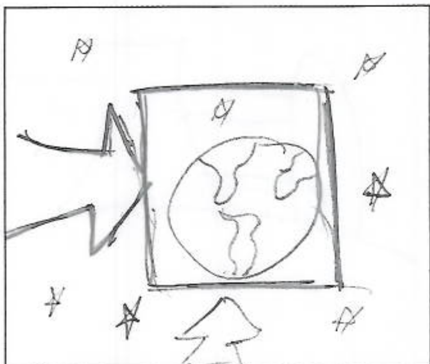
One of the coolest parts of the tour was learning about the design of this reactor. As stated before, as a research reactor the design varies distinctly from a typical reactor. Starting from the outside, the containment building is a large square with the offices connected directly next door. (Shown Below)

Inside is the core. The design of the reactor is a 30,000 gallon pool situated directly above the core (about 25 ft.). This pool will act as a passive safety measure such that if the cooling systems fail, gravity can be used to directly cool the core. With two cooling systems (only one in use), the water is deionized tap and it pumps through a typical reactor system. This water is recycled throughout the day and then dumped at reactor shutdown, which I believe is nightly. This water is filtered and then placed in the storm drain. Inside the core is 14 separate chambers in which different isotopes can be placed depending on the reaction. The most active chamber is directly in the center of the core. Located above the core are 4 control blades. About three feet tall, one foot wide and 2 inches thick, these control the activity inside the core. When only one of the blades is placed inside the core, it quickly becomes subcritical. This means that the sensitivity of each blade is extreme. Shown below is the core, with the Cherenkov radiation (blue glow), and the tall control blades (face front).

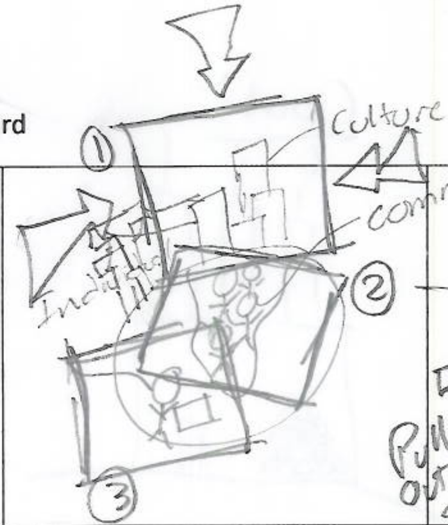
The core contains 14 compartments in which different nuclear isotopes can be stored for experiments. You can also see these in the above picture. The reactor also has a crane that can hoist the core and switch it to the other side of the pool. Going across the pool is a bridge with pulleys and wire, the "rabbit system". As a safety measure, if there is ever a leak in the pool, one side of the pool can be closed off to protect the core.

Another cool part of the tour was the control room. Just updated a few weeks prior, much of the interface was now digital. For a nuclear reactor, the control room was reasonably simple. Upon looking at the computer we were able to tell the power level, location of the control blades and the status of every part of the reactor. Analog interfaces displayed temperatures and other readings. These reading were logged every hour, as to show an increase or decrease throughout the day.

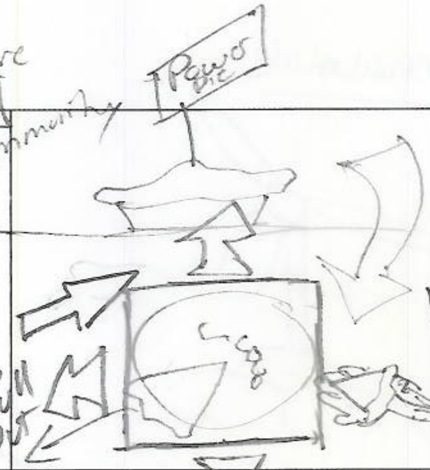
James Lehner, Brendan Walsh
IQP: Safe Nuclear Energy Storyboard



Introduction: The story of safe nuclear power begins with us.

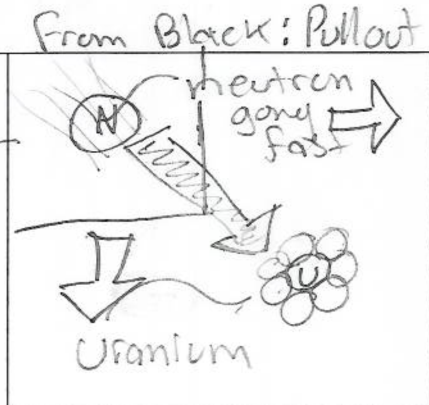


We as a culture, community, and individuals have a need for power that is ever increasing.

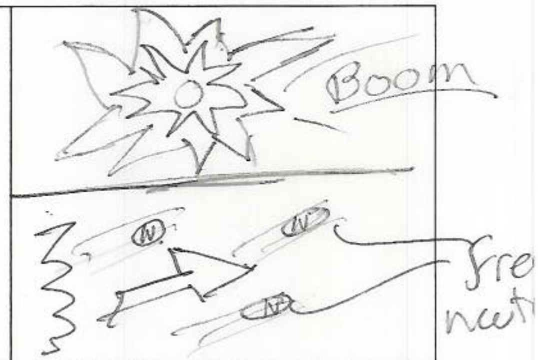


Right now the majority of this power comes from finite fuel sources so what happens when they are all gone? Is nuclear power a feasible option?

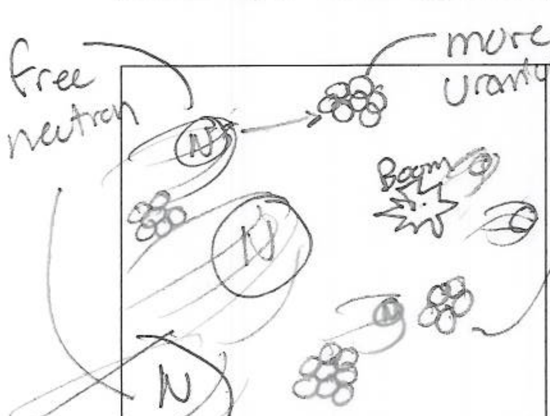
Answering these questions can only be done after first understanding the process takes a nuclear reaction and converts it to energy.



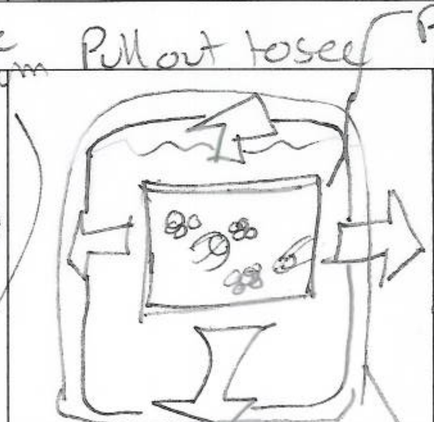
Fission: Generating power starts with nuclear fission. Fission begins when a lone neutron is smashed into an atom of uranium-235.



When the neutron collides with the uranium atom it is splits..



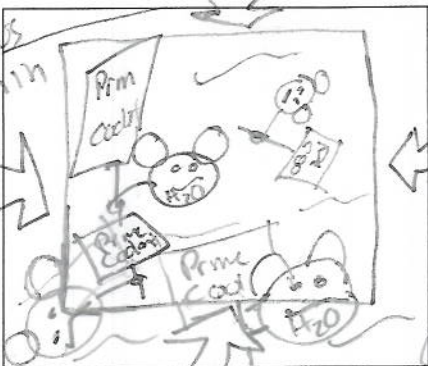
Several free neutrons are also released; these neutrons go on to strike more uranium atoms,



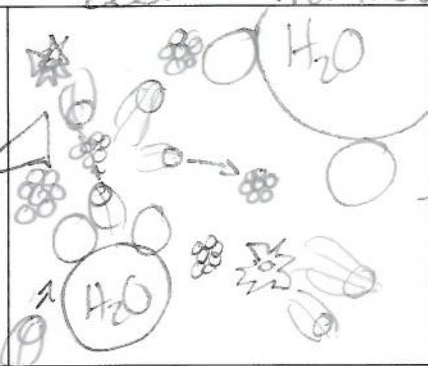
To capture the heat energy from the chain reaction the fission process takes place in water.

Reactor: The fission process takes place within the nuclear reactor.

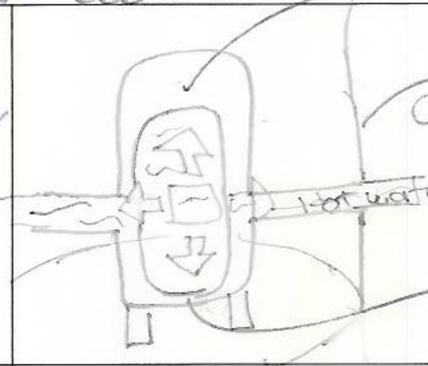
James Lehner, Brendan Walsh
IQP: Safe Nuclear Energy Storyboard



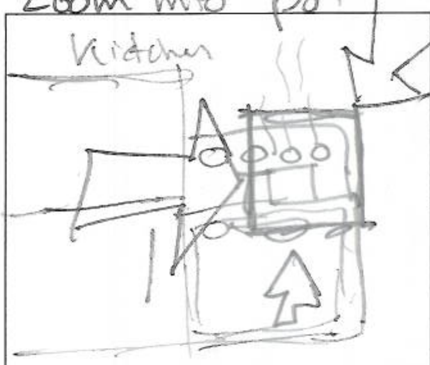
The water within the reactor is called the primary coolant.



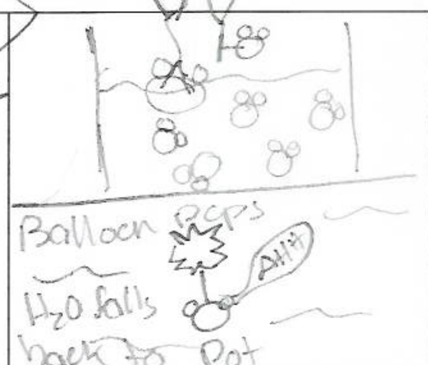
The primary coolant is the fluid that the fission reaction takes place within. It is the first fluid to capture the heat produced by the reaction.



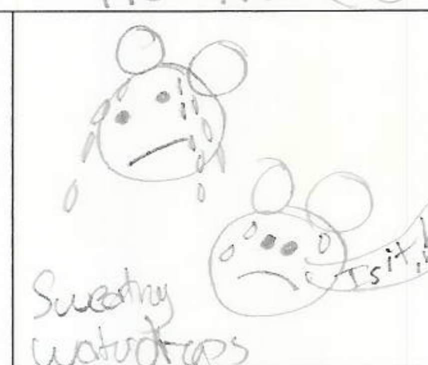
Pressurizer: When water reaches a temperature of 212°F it boils



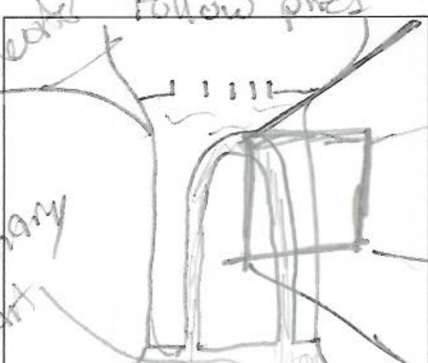
Boiling is the process of a medium changing from a liquid to a gas.



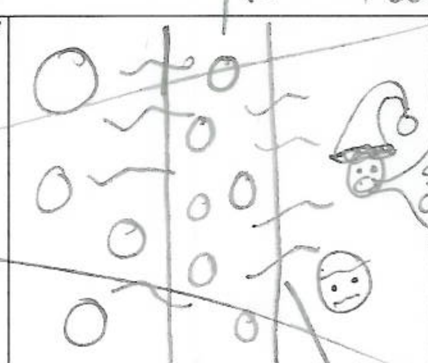
The pressurizer stops this process from occurring because as you increase pressure you increase the boiling point.



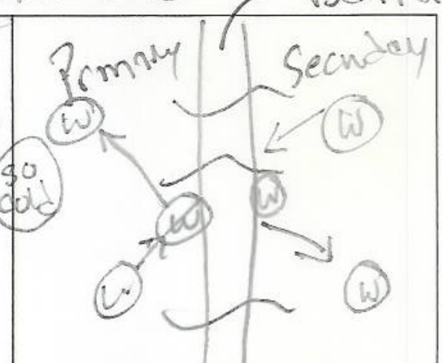
The water can now be kept at extremely high temperatures as it travels through pipes that bring it to the steam generator.



Steam Generator: The water is transferred from the pressurizer to the steam generator.



Here heat is transferred to another cooling system called the secondary coolant.



It is important to note that the primary coolant system and secondary coolant system never directly mix… other by a process called conduction.

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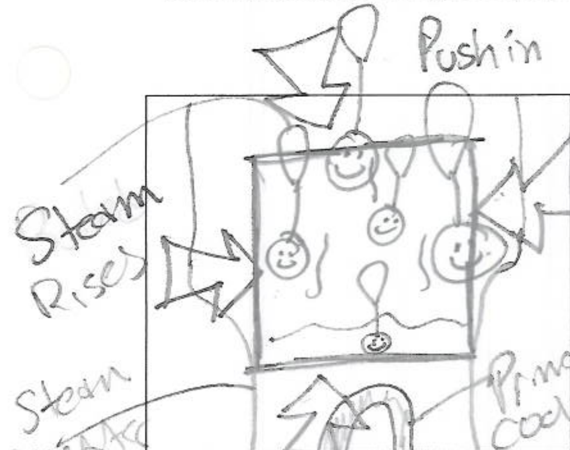
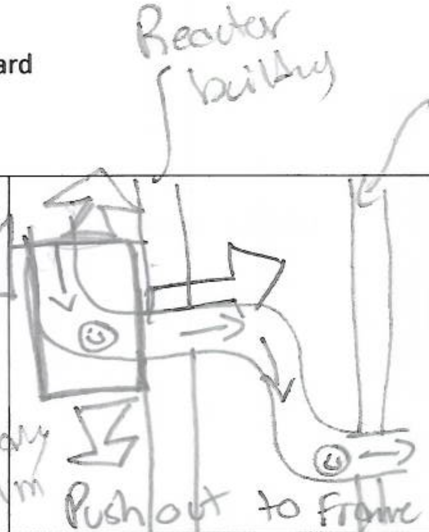
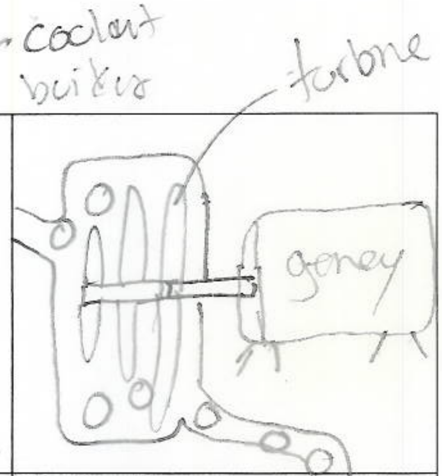
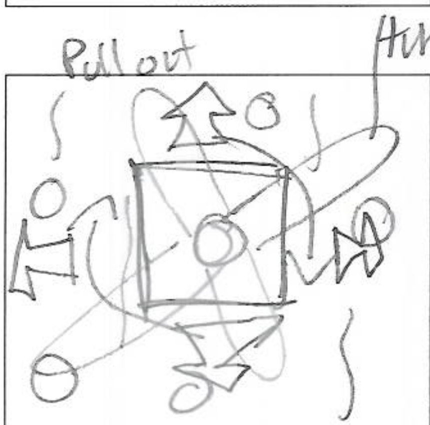
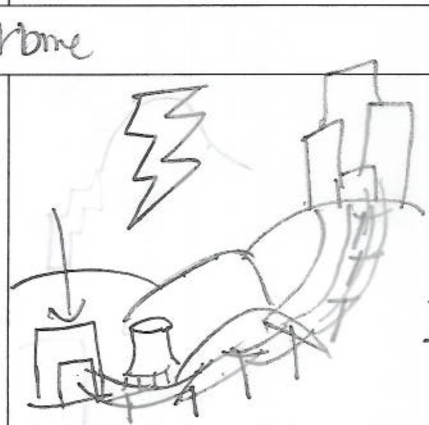
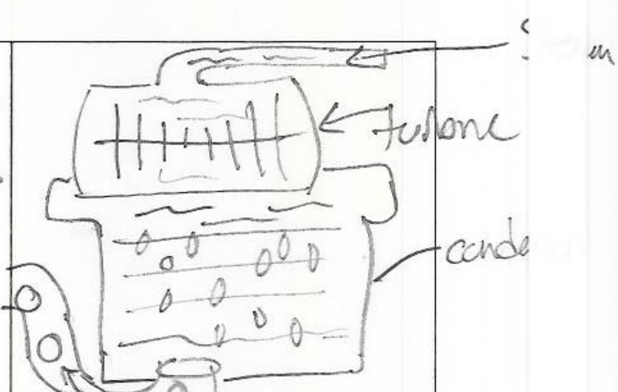
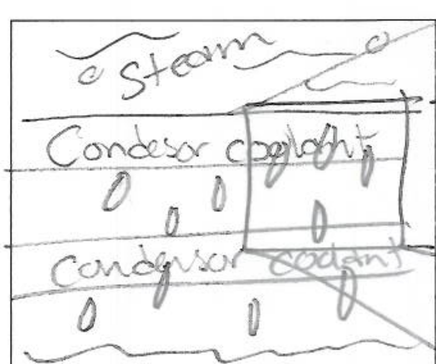
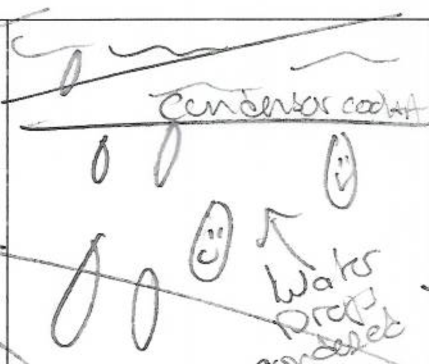
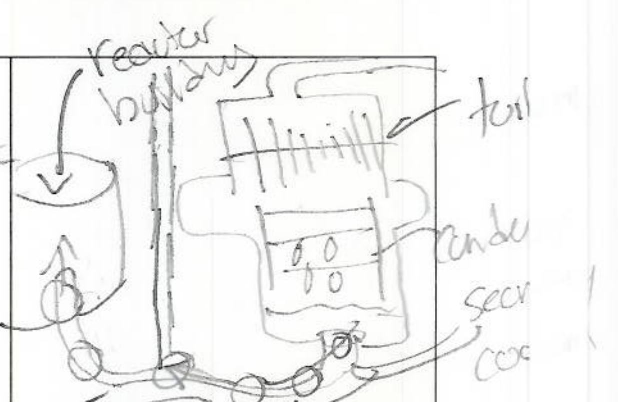
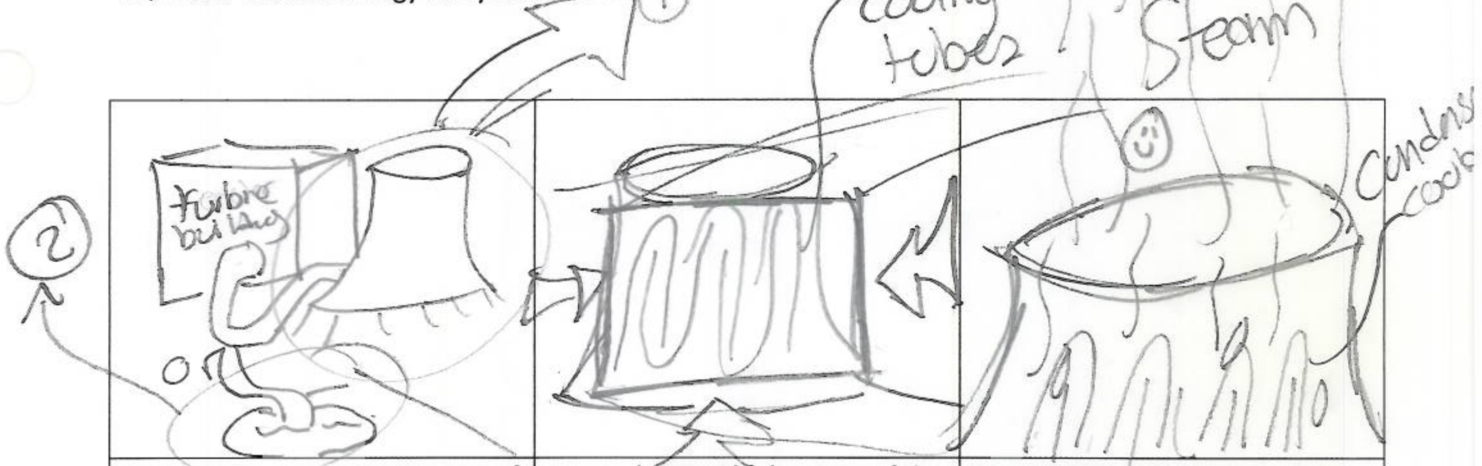
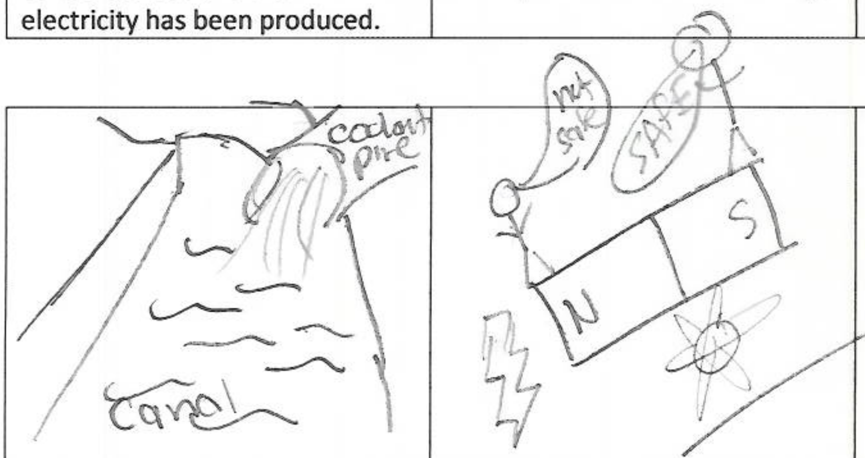
IQP: Safe Nuclear Energy Storyboard

		
Since the secondary coolant is not under pressure the water in the secondary coolant boils.	This produces steam that is captured and transferred to the coolant building where the turbine is located.	**Turbine:** The steam that was produced in the steam generator is transferred out of the reactor building and into the turbine building.
		
The turbine's blades are rotated as steam passes through them producing electricity.	This electricity is used by the surrounding community for use in homes and industry.	**Condenser:** Now that electricity has been produced the heat contained within the secondary coolant needs to be removed.
		
This process starts by passing the steam of the secondary…fluid called the condenser coolant.	As the steam passes over the condenser coolant its…returning it to a liquid state	It is then pumped back reactor building used again. The heat in the…must now be removed.

James Lehner, Brendan Walsh
IQP: Safe Nuclear Energy Storyboard



Cooling: Cooling is the process of lowering the temperature of the condenser coolant after electricity has been produced.	Depending on the location of the nuclear power plant this is usually done in one of two ways	The condenser coolant can be pumped to the top of a cooling tower where it pours through the structure releasing its heat.



The second has the condenser coolant pumped into a large canal where its heated is released into the environment.	**Safe Nuclear Energy:** The polarizing and controversial nature of nuclear power leaves it vulnerable to misunderstanding.	Although the process of creating electricity from nuclear sources is well understood, there are many opportunities for things to go wrong.

- what is a nuclear reactor tour?
- point is to make people feel like they understand how plants work.

nuclear reactors = electricity production

The story of safe nuclear energy

- need more to use same word as reference

[Draft 1] 11/5

Introduction

The story of safe nuclear power begins with us. We as a culture, community, and individuals have a need for power that is ever increasing. Right now the majority of this power comes from finite fuel sources so what happens when they are all gone? Is nuclear power a feasible option? Is it actually safe? We will find answers to these questions by exploring the current role nuclear plays in our world, how we harness its power, exploring the reasons we are afraid of it, and what the future has in store to make the next generation of nuclear facilities the safest the world has ever seen.

Infographic

The current state of nuclear power – hot mess

Don't need?

In the United States there are 104 nuclear power plants ~~with the majority of these facilities residing east of the Mississippi river. This is because~~ Nuclear power plants need vast amounts of water which is ? used in their cooling systems. The 104 reactors produce around 20% of the countries electricity. This 20% is dwarfed by the major producer of energy in the U.S., fossil fuels. Coal fired plants produce around 48% of the countries power with over 600 facilities. Other producers of power include natural gas, petroleum, and renewable sources like hydroelectric facilities. [move to top of ¶: A major concern with nuclear power is waste.] Waste produced by nuclear facilities falls into three categories: low-level waste, intermediate-level waste and high-level waste. In a given year a single nuclear reactor produces between 200-350 m^3 of low to intermediate volume waste.

find a normal equivalent

After reprocessing only 28 m^3 of this will be placed in a disposal canister and shipped to a storage facility like Yucca Mountain in Nevada. The volume of waste produced is low when compared to coal which in a single year produces an average of 400,000 tons of ash from a plant of similar capacity.

Nuclear power plants are built and operated by private companies. The average cost to build a nuclear power plant is around $2000 per installed KW. Once built the plants operate with a cost of 0.2 cents per KW-Hr. To put this into perspective your standard home light bulb of 60 watts running for one thousand hours consumes 60 KW-Hr of electricity. With 14000 years of civil operations under their belt and only three notable accidents the nuclear option has one of the best safety records of any power production system.

Nuclear reactor: A guided Tour

Steps to producing power

1) **Fuel**

Power production for a nuclear reactor starts on the smallest of scales using a process called nuclear fission. Nuclear fission is like any other recipe and it starts with a few simple components beginning with a neutron. Neutrons, protons and electrons are the three ~~subatomic particles~~ that when put together make an atom. Protons and neutrons compose the nucleus with electrons orbiting. By themselves neutrons are unstable and want nothing more than to become part of the nucleus of an atom. Enter the second component to our fission recipe, an atom of Uranium-235. Uranium-235 is an isotope of the more dominant Uranium-238. Isotopes are atoms of elements with the same number of protons but different number of neutrons. Uranium-235 is considered a fissile atom. This means that the because of the odd number of neutrons in the nucleus (235-92=143) it is capable of sustaining a chain reaction of nuclear fusion. When the free neutron impacts the Uranium-235 atom it creates another atom called Uranium-236. Uranium-236 is extremely unstable and splits into smaller products of barium (Ba) and Krypton (Kr). A by product of the splitting of Uranium-236 is more free neutrons and the release of energy. The newly freed neutrons go on to strike more uranium-235 atoms causing a chain reaction. The process occurs in water which captures the energy that is released when Uranium-236 splits. This heats the surrounding fluid. The chain reaction is controlled by the fuel rods which absorb the free neutrons preventing the reaction from getting out of control.

2) Reactor

The chain reaction that occurs between uranium-235 and free a neutron takes place in the part of a nuclear facility called the reactor. The reactor contains the fission reaction whose by product is energy in the form of heat. This heat is transferred to the water, the primary coolant system, within which the fission process is taking place. Since the process occurs in water the energy that is released during fission heats the surrounding liquid. The heat from the fission process transfers into the primary coolant system by conduction.

3) Pressurizer

The primary coolant system is one of three water systems in a nuclear facility that heat will pass through. The water within the pressurizer is brought to temperatures of over 600 degrees Fahrenheit without boiling. This is achieved by keeping the system under constant pressure sufficient enough to keep the water in its liquid phase. It is kept under this pressure as it travels through a series of tubes leading to the facilities steam generator.

4) Steam Generator

The steam generator is where heat is transferred from the primary coolant system to the secondary coolant system. The secondary coolant is not kept under pressure like the primary coolant. This allows the water from the secondary coolant to boil. As the water boils steam is produced. The steam is captured and transferred out of the containment building to the turbine building. The primary and secondary coolants are closed systems. This means that fluid in the primary coolant never comes in direct contact with the secondary coolant. Heat is transferred between these two systems by a process called conduction.

5) **Turbine**

Steam that was produced by the steam generator has now been transferred to the turbine building. Within the turbine building a series of steam turbines are kept. The steam produced by the secondary coolant is fed into the steam turbines. The blades within the turbines are turned by the steam which in turn rotates a shaft connected to an electrical generator.

6) **Condenser/coolant**

Having produced electricity in a usable form the steam from the secondary coolant must now be cooled. This is done by passing the steam over a series of tubes called the third coolant system called the condenser coolant. As the steam cools it condenses and reforms into water where it is pumped back to the steam generator to be reused. The condenser coolant, which took the heat from the secondary coolant, must now also be cooled.

7) **Cooling tower/ lake**

This is done by pumping the condenser coolant to the top of a cooling tower. Here the water is allowed to poor through the structure where it cools by evaporation.

Why we don't trust nuclear power: Accidents and Disasters

The story of nuclear power has been defined by its history. Mishaps, misunderstandings, and missed opportunities have all contributed to a public opinion deeming nuclear not safe. What is the real story behind this history? Was it the systems that failed or the people that operate them? To understand we first explore how nuclear accidents are rated and how the public comes to understand them using the International Nuclear and Radiological Event Scale or INES Scale.

The INES scale is a worldwide measure of the severity of nuclear facility related accidents. Its primary purpose is to bridge the gap of understanding between nuclear technology and the public when accidents occur. The scale is broken into eight distinct levels ranging from 0, a deviation, to 7, a major accident. The level at which an accident is rated is evaluated according to three criteria: Environment and People, Radiological Barriers and Control, and Defense-in-Depth. Environment and people is a measure of radiation dose to the people and area closest to the event. Radiological barriers and control applies only to major facilities and examines the spread of radioactive material within the walls of an afflicted facility. Finally, Defense-in-Depth looks at what happened to the systems that should have prevented an accident from occurring. Depending on how extensive damage is within each of these criteria a nuclear accident is then given an INES rating.

The Three Mile Island Accident, which occurred in 1979, is considered **Level 5: Accident with wider Consequences** on the INES scale. What went wrong here? What was the cause of the reactor failing? Upon investigation a few things become clear. The problem started with the failure of a mechanical valve. At this time the system was undergoing what is known as a **loss-of-coolant accident.** This is a problem that can easily be rectified by returning coolant to any of the three reactor cooling systems. In this case the secondary cooling system was affected. An emergency system within the reactor called the

why we don't trust nuclear power notes:
- don't need specific examples
- compartmentalize issues/reasons/solutions
- what makes these relevant → what have we learned?

Emergency Core Cooling System (ECCS) automatically starts running to restore coolant to the secondary cooling system. An operator manually overrode the ECCS system and thus coolant from the secondary cooling system was unable to remove heat from the primary. The subsequent partial core meltdown is a direct result of too much heat gathering in the primary coolant. The major cause of this accident can be attributed to human error. Poor control room design made it hard for operators to interpret if a relief valve had returned to its closed position. Compounding this problem was inadequately trained personnel running the facility at the time. After a month of high tension, operators are able to achieve a state called cold shutdown. This is when the natural movement of water, not pumped, cools the reactor's core at standard atmospheric pressure.

April 1986 introduced the world to the now infamous Chernobyl nuclear accident. Chernobyl is considered a **Level 7: Major Accident** on the INES scale. 25 years later the local populous is still dealing with the accidents aftermath. The accident developed after operators pushed the RBMK reactor to levels which It was not designed to operate under. A subsequent power surge and steam explosion destroyed the reactors shield exposing the hot core to the atmosphere. Massive amounts of radiation and core material are released into the surrounding environment. Vast numbers of people are evacuated and the nearby city of Pripyat is abandoned. The accident, like Three Mile Island, is a result of human error. Systems within the reactor, designed to shut it down under its pre-accident conditions were overlooked. Emergency notifications were ignored and as a result the subsequent accident occurred. Initially the reactor did as it was designed. It shut itself down when it recognized system conditions were entering unsafe levels. Operators returned power to area where the reactor had stopped itself from functioning. Like Three Mile Island the accident at Chernobyl is a product of human error. Had the reactor been left to function as it was designed system integrity would have never been pushed to levels that produced the accident.

Until March 2011 Chernobyl was the largest nuclear disaster on record. No other accident had affected more people and done more damage to the surrounding environment. The fukushima Diachi accident changed all this

Until recently Chernobyl had been the accident that defined nuclear accidents. This title has since been revoked by the Fukushima Diachi nuclear accident, a **level 7** accident more complicated was revoked on March 11 2011 after the Tohoku earthquake and tsunami

A **level 0** accident is labeled a deviation. This means there is no significant effect to safety in any of the three previously mentioned impact areas.

Level 1 on the scale is called "Anomaly". The Anomaly rating is accrued when there is a small system failure that may have lead to a radiation exposure slightly over annual limits.

Level 2 is considered Incident. In such a case **Environment and People** rating sees a worker exposed to radiation levels above annual limits. **Radiological barriers and control** see a significant amount of contamination occur within areas of the facility that were not designed for exposure. Finally, **Defense-in-depth** sees failures in safety systems that result in no major consequences.

Level 3 is considered a serious incident. The impact on **Environment and people** is significant in that workers may be exposed to 10 times that of annual doses. **Radiological barriers and control** sees severe contamination to areas that were not part of containment design. Furthermore, **Defense-in-Depth** sees all safety systems fail but results produce no significant impact.

Level 4 accidents are described as Accidents with local consequences. The impact on **Environment and people** see minor release of radioactive material to local surroundings. **Radiological barriers and control** sees damage to fuel in some manner that causes contamination through out a facilities infrastructure.

Level 5 accidents are described as Accidents with Wider Consequences. An example of such an incident is the 1979 partial core meltdown at the Three Mile Island facility near Harrisburg, Pennsylvania. The effects of the accident on the **Environment and people** saw major controlled releases of radiation which led to significant impact on local animal populations. More importantly, **Radiological barriers and control** saw major damage to the facilities unit 2 core, a product of a partial fission meltdown.

Safe Nuclear Power

All three of the previously mentioned nuclear reactor accidents occurred in systems constructed in the early 1970s.

Contrary to popular belief nuclear power is very safe. With over 14,000 years of nuclear power plant operation there have only been the 3 previously discussed accidents. Nuclear power and safety starts with the systems. Within every nuclear power facility there is a system called the

Conclusion Ideas:

- What's providing energy in your town?
- ☆ New designs = safe nuclear power
- Explore nuclear power & other forms of electricity production in your community.

Narration 2

BW

Introduction

The story of safe nuclear power begins with us. We as a culture, community, and individuals have a need for power that is ever increasing. Right now the majority of this power comes from finite fuel sources so what happens when they are all gone? Is nuclear power a feasible option? Is it actually safe? Answering these questions can only be done after first understanding the process takes a nuclear reaction and converts it to energy.

How do nuclear power plants generate power?

1) Fission

Generating power starts with nuclear fission. Fission begins when a lone neutron is smashed into an atom of uranium-235. ~~When the neutron collides with the uranium atom it is split into atoms of krypton and barium.~~ any isotopes can be produced. Several free neutrons are also released; these neutrons go on to strike more uranium atoms, ~~in~~ starting a chain reaction. The chain reaction produces heat energy. ~~To capture~~ In order to capture the heat energy from the chain reaction the fission process takes place in water. The heated water ~~will be~~ is used elsewhere in the nuclear power plant.

2) Reactor

The fission process takes place within the nuclear reactor. The nuclear reactor contains and controls the fission reaction that heats the surrounding water. The water within the reactor is called the primary coolant. The primary coolant is the fluid that the fission reaction takes place ~~within~~ w/in. It is the first fluid to capture the heat produced by the reaction. ~~In a reactor, this water~~

3) Pressurizer

When water reaches a temperature of 212°F it boils. Boiling is the process of a medium changing from a liquid to a gas. ~~The pressurizer~~ stops this process from occurring because as you increase pressure you increase the boiling point. The water can now be kept at extremely high temperatures as it travels through pipes that bring it to the steam generator.

4) Steam Generator

The water is transferred from the pressurizer to the steam generator. Here heat is transferred to another cooling system called the secondary coolant. The secondary coolant ~~is also a fluid~~ typically water, that removes the heat from the primary coolant. It is important to note that the primary coolant system and secondary coolant system never directly mix. The heat within one is transferred to the other by a process called conduction. Since the secondary coolant is not under pressure the water in the secondary coolant boils. This produces steam that is captured and transferred to the coolant building where the turbine is located.

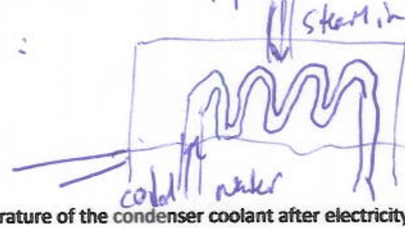
5) Turbine

The steam that was produced in the steam generator is transferred out of the reactor building and into the turbine building. The turbine's blades are rotated as steam passes through them producing electricity. This electricity is used by the surrounding community for use in homes and industry.

6) Condenser

Now that electricity has been produced the heat contained within the secondary coolant needs to be removed. This process starts by passing the steam of the secondary coolant over pipes filled with another fluid called the condenser coolant. As the steam passes over the condenser coolant its temperature is lowered, returning it to a liquid state. Typically, ~~It is then pumped back to the reactor building to be used again. The heat in the condenser coolant must now be removed.~~ ~~Depending on the~~ Best way to say it? Ex. Salisbury

Show section of reactor in paper. In diagram condenser looks like this:



7) Cooling

Cooling is the process of lowering the temperature of the condenser coolant after electricity has been produced. Depending on the location of the nuclear power plant this is usually done in one of two ways. The condenser coolant can be pumped to the top of a cooling tower where it pours through the structure releasing its heat. The second has the condenser coolant pumped into a large canal where its heated is released into the environment.

Safe Nuclear Energy/Conclusion

We need a better transition into this section. → maybe an overall plant analysis into react section

The polarizing and controversial nature of nuclear power leaves it vulnerable to misunderstanding. Although the process of creating electricity from nuclear sources is well understood, there are many opportunities for things to go wrong. This brings up the question is there such a thing as safe nuclear energy? According to the world nuclear association there has been over 14,000 years of nuclear power plant operation. Within that collective time there have been three accidents of any notoriety: Three Mile Island, Chernobyl, and most recently Fukushima Diachi. Some might argue that three accidents are three too many. This is a stance that is hard to disagree with since the effects of nuclear accidents on the magnitude of Chernobyl or Fukushima have long lasting environmental and social implications. So what is being done to make the future of nuclear energy safer? Quote from article: "Car accidents, don't stop driving. Work to make them safer."

Making nuclear power safer starts with understanding what is not safe about it in the first place. The reoccurring themes and problems of any nuclear accident can be attributed to a single cause, human error. Nuclear power plants are designed to anticipate every possible route that could lead to failure. Possible failures range from anything from loss of coolant within the reactor to an earthquake. In any case the reactor is designed with the anticipation of something going wrong. Never the less all the possibilities of failure never seem to be accounted for. The Fukushima Diachi reactor was exposed to a 49 foot tsunami following the April 2011 earthquake. The plant had been designed to withstand a tsunami but not one of such ~~large size~~ magnitude. While designers had anticipated the possibility of a tsunami no one had anticipated such a catastrophic event. The poor design is a product of human error. The Chernobyl nuclear accident has similar links to human error. ~~The core meltdown was a result of an unauthorized experiment conducted by the facilities operators~~ routine system check by operators. When the experiment got out of control operators made decisions that led to the facilities breakdown. Human error in some way, shape, or form has always played a major factor in the failure of nuclear power plants.

If we feel that way fine ...?

What is the poor design? Choose some ...

Should we discuss the design of the reactor or poor design

Learning from history is essential to making nuclear power plants safe. Fundamental to the idea of safety is keeping the reactors within the plants cool. Future designs will allow grace periods where reactors, even with lose of power, can cool themselves for up to 72 hours with no human intervention. The nuclear fusion process hopes to revolutionize nuclear energy by combining atoms rather than separating them. The conditions to achieve such a process make it inherently safer because it can only occur under very particular circumstances. If the conditions are not met, fusion can not occur and the process shuts down. Simpler more rugged designs will make the plants easier to operate and less vulnerable to operational errors. All these changes make an effort to simplify the systems. In doing so understanding and operating them becomes easier in case of an emergency.

reiterate importance of cooling

establish this as a passive ...

As traditional fuel sources become more scarce nuclear power as a replacement ~~will~~ has become a more popular option. It is up to us as communities and a culture to decide if this is the right choice. Fundamental to making this choice is understanding the role nuclear currently plays and how that will change in the future. Is there a nuclear power plant in your area? How much of your electricity is from nuclear power? Finding the answers to these questions allows us to make informed decisions about how we get our energy and the way we choose to use it.

more summary then call to action

establish position ... nuclear

- If we mention the three events, should we explain ?
- Idea of passive cooling systems like gravity and fluid mechanics.
- Ending is nice but we can flow with it with a storyboard idea.

Jim Lehner, Brendan Walsh

Narration 3

IQP: Safe Nuclear Energy

Safe Nuclear Power

Introduction

The story of safe nuclear power begins with us. We as a culture, community, and individuals have a need for power that is ever increasing. Right now the majority of this power comes from finite fuel sources so what happens when they are all gone? Is nuclear power a feasible option? Is it actually safe? We will find answers to these questions by exploring the current role nuclear plays in our world, how we harness its power, exploring the reasons we are afraid of it, and what the future has in store to make the next generation of nuclear facilities the safest the world has ever seen.

How do nuclear power plants generate power?

1) Fission

Generating power starts with nuclear fission. ~~The fission process begins with a neutron. Neutrons, protons, and electrons are the three parts that make an atom. At the center of the atom is the nucleus made of protons and neutrons. Orbiting the nucleus in the electron cloud are electrons~~. Fission begins when a lone neutron is smashed into an atom of uranium-235. After the neutron collides with the uranium-235 atom the uranium-235 is broken down into atoms of Krypton and barium. Several free neutrons are also released. These neutrons go on to strike more uranium-235 atoms. ~~This~~ process ~~repeats itself in~~ a chain reaction. ~~The chain reaction produces~~ energy ~~in the form of heat~~. To capture the heat from the chain reaction the ~~entire~~ process takes place in a ~~fluid~~ like water. The ~~now~~ heated water ~~can~~ be used elsewhere in the nuclear power plant.

2) Reactor

The ~~chain reaction called~~ fission takes place in the ~~part of a nuclear power plant called the~~ nuclear reactor. The reactor contains and controls the fission reaction that heats the surrounding water. The water within the reactor is called the primary coolant. The primary coolant is the fluid that the fission reaction takes place within. It is the first fluid to capture the heat produced by the reaction.

3) Pressurizer

When water ~~is heated to~~ a temperature of 212°F it boils. Boiling is the process of a ~~material~~ changing from a liquid to gas~~eous state~~. The pressurizer stops this process from occurring~~. This is possible~~ because as you increase pressure you increase boiling point. ~~The water in the pressurizer is said to then be super heated when it is brought to a temperature higher than its boiling point.~~ The water is kept ~~super heated~~ as it travels through pipes and tubes that bring it to the steam generator.

4) Steam Generator

Once the water has been transferred from the pressurizer to the steam generator its heat is transferred to another cooling system called the secondary coolant. ~~The secondary coolant is also a fluid that removes the heat from the primary coolant.~~ Since the secondary coolant is not under pressure the water in the secondary coolant boils. This produces steam that is captured and transferred to the coolant building where the turbine is located. It is important to note that the primary coolant system and secondary coolant system never directly mix. The heat within one is transferred to the other by a process called conduction.

5) Turbine

The steam that was produced in the steam generator is transferred out of the reactor building and into the turbine building. ~~This is where usable electricity is produced as the steam is forced through one of several turbines.~~ The turbine's blades are rotated as ~~the~~ steam passes through them producing electricity.

6) Condenser

~~Having produced~~ electricity ~~the focus becomes getting rid of all~~ the heat contained within the secondary coolant. This process starts by passing the steam of the secondary coolant over ~~tubes~~ filled with another fluid called the ~~third~~ coolant. ~~The third coolant is at a lower temperature than~~ the ~~secondary coolant~~ ~~and because of this the~~ temperature ~~of the secondary coolant~~ is lowered. ~~This condenses the steam of the secondary coolant back to its liquid state~~. It is then pumped back to the reactor building to be used again. The ~~third coolant, aka as the~~ condenser coolant, must now also be brought to a lower temperature.

7) Cooling

Cooling is the process of lowering the temperature of the condenser coolant ~~after it has cooled the secondary coolant~~. Depending on the location of the nuclear power plant this is usually done in one of two ways. The condenser coolant can be pumped to the top of a cooling tower where it pours through the structure releasing its heat. The second has the condenser coolant pumped into a large canal where its heated is released into the environment.

Safe Nuclear Energy/Conclusion

~~The process of creating electricity from nuclear power plants is fundamentally very simple. The plants harness the power of the atom to create heat energy that eventually becomes electricity. While the overall process is simple there are many opportunities for things to go wrong. This brings up the question is there such a thing as safe nuclear energy?~~ According to the World Nuclear Association there has been over 14,000 years of nuclear power plant operation. Within that collective time there have been three accidents of any notoriety. Some might argue that in terms of nuclear energy three accidents are three too many which is hard to disagree with. The effects of nuclear accidents on the magnitude of

Chernobyl or Fukushima have long lasting environmental and social implications. So what is being done to make the future of nuclear energy safer?

Making nuclear power safer starts with understanding what is not safe about it in the first place. The reoccurring themes and problems of any nuclear accident can be attributed to a single cause, human error. Nuclear power plants are designed to anticipate every possible route that could lead to failure. Possible failures range from loss of coolant within the reactor, to earthquake, to militant attack. In any case the reactor is designed with the anticipation of something going wrong in some way. Never the less all the possibilities of failure never seem to be accounted for. The Fukushima Diachi reactor was not designed for such a major natural disaster a fact that Japanese authorities have admitted to. The poor design is a product of human error. The Chernobyl nuclear accident was a result of an unauthorized experiment conducted by the facilities operators. Human error in some way shape or form always has always played a major factor in the failure of any nuclear power plant.

Learning from history is essential to making nuclear power plants safe. Fundamental to the idea of safety is keeping power plants cool. Future designs will allow grace periods where reactors, even with loss of power, can cool themselves. In some cases the systems could lose power and never need it restored with no fear of nuclear meltdown. The nuclear fusion process hopes to revolutionize nuclear energy by combining atoms rather than separating them. The conditions to achieve such a process make it inherently safer because it can only occur under very particular circumstances. If the conditions are not met, fusion can not occur and the process shuts down.

Nuclear power is something everyone should be concerned about. As fossil fuels become more scarce the energy needs of the world are going to need to be met by some other source. Nuclear power may be the easy fix to fuel the demand but at what cost?

Nuclear power is a very controversial issue. Although the process of creating electricity from nuclear power is well understood, there are ~~many~~ opportunities for things to go wrong.

Jim Lehner, Brendan Walsh

Narration 4

IQP: Safe Nuclear Energy

Safe Nuclear Power

Introduction

The story of safe nuclear power begins with us. We as a culture, community, and individuals have a need for power that is ever increasing. Right now the majority of this power comes from finite fuel sources so what happens when they are all gone? Is nuclear power a feasible option? Is it actually safe? Answering these questions can only be done after first understanding the process takes a nuclear reaction and converts it to energy.

How do nuclear power plants generate power?

1) Fission

Generating power starts with nuclear fission. Fission begins when a lone neutron is smashed into an atom of uranium-235. When the neutron collides with the uranium atom it is split into atoms of Krypton and barium. Several free neutrons are also released; these neutrons go on to strike more uranium atoms, in a chain reaction. The chain reaction produces heat energy. To capture the heat energy from the chain reaction the fission process takes place in water. The heated water will be used elsewhere in the nuclear power plant.

2) Reactor

The fission process takes place within the nuclear reactor. The nuclear reactor contains and controls the fission reaction that heats the surrounding water. The water within the reactor is called the primary coolant. The primary coolant is the fluid that the fission reaction takes place within. It is the first fluid to capture the heat produced by the reaction.

3) Pressurizer

When water reaches a temperature of 212°F it boils. Boiling is the process of a medium changing from a liquid to a gas. The pressurizer stops this process from occurring because as you increase pressure you increase the boiling point. The water can now be kept at extremely high temperatures as it travels through pipes that bring it to the steam generator.

4) Steam Generator

The water is transferred from the pressurizer to the steam generator. Here heat is transferred to another cooling system called the secondary coolant. The secondary coolant is also a fluid that removes the heat from the primary coolant. It is important to note that the primary coolant system and secondary coolant system never directly mix. The heat within one is transferred to the other by a process called conduction. Since the secondary coolant is not under pressure the water in the secondary coolant boils. This produces steam that is captured and transferred to the coolant building where the turbine is located.

5) Turbine

The steam that was produced in the steam generator is transferred out of the reactor building and into the turbine building. The turbine's blades are rotated as steam passes through them producing electricity. This electricity is used by the surrounding community for use in homes and industry.

6) Condenser

Now that electricity has been produced the heat contained within the secondary coolant needs to be removed. This process starts by passing the steam of the secondary coolant over pipes filled with another fluid called the condenser coolant. As the steam passes over the condenser coolant its temperature is lowered, returning it to a liquid state. It is then pumped back to the reactor building to be used again. The heat in the condenser coolant must now be removed.

7) Cooling

Cooling is the process of lowering the temperature of the condenser coolant after electricity has been produced. Depending on the location of the nuclear power plant this is usually done in one of two ways. The condenser coolant can be pumped to the top of a cooling tower where it pours through the structure releasing its heat. The second has the condenser coolant pumped into a large canal where its heated is released into the environment.

Safe Nuclear Energy/Conclusion

The polarizing and controversial nature of nuclear power leaves it vulnerable to misunderstanding. Although the process of creating electricity from nuclear sources is well understood, there are many opportunities for things to go wrong. This brings up the question is there such a thing as safe nuclear energy? According to the world nuclear association there has been over 14,000 years of nuclear power plant operation. Within that collective time there have been three accidents of any notoriety: Three Mile Island, Chernobyl, and most recently Fukushima Diachi. Some might argue that three accidents are three too many. This is a stance that is hard to disagree with since the effects of nuclear accidents on the magnitude of Chernobyl or Fukushima have long lasting environmental and social implications. So what is being done to make the future of nuclear energy safer?

Making nuclear power safer starts with understanding what is not safe about it in the first place. The reoccurring themes and problems of any nuclear accident can be attributed to a single cause, human error. Nuclear power plants are designed to anticipate every possible route that could lead to failure. Possible failures range from anything from loss of coolant within the reactor to an earthquake. In any case the reactor is designed with the anticipation of something going wrong. Never the less all the possibilities of failure never seem to be accounted for. The Fukushima Diachi reactor was exposed to a 49 foot tsunami following the April 2011 earthquake. The plant had been designed to withstand a tsunami but not one of such large size. While designers had anticipated the possibility of a tsunami no one anticipated such a catastrophic event. The poor design is a product of human error. The Chernobyl nuclear accident has similar links to human error. The core meltdown was a result of an unauthorized experiment conducted by the facilities operators. When the experiment got out of control operators made decisions that led to the facilities breakdown. Human error in some way, shape, or form has always played a major factor in the failure of nuclear power plants.

Learning from history is essential to making nuclear power plants safe. Fundamental to the idea of safety is keeping the reactors within the plants cool. Future designs will allow grace periods where reactors, even with lose of power, can cool themselves for up to 72 hours with no human intervention. The nuclear fusion process hopes to revolutionize nuclear energy by combining atoms rather than separating them. The conditions to achieve such a process make it inherently safer because it can only occur under very particular circumstances. If the conditions are not met, fusion can not occur and the process shuts down. Simpler more rugged designs will make the plants easier to operate and less vulnerable to operational errors. All these changes make an effort to simplify the systems. In doing so understanding and operating them becomes easier in case of an emergency.

As traditional fuel sources become more scarce nuclear power as a replacement will become a more popular option. It is up to us as communities ~~and a culture~~ to decide if this is the right choice. Fundamental to making this choice is understanding the role nuclear currently plays and how that will change in the future. ~~Is there a nuclear power plant in your area? How much of your electricity is from nuclear power? Finding the answers to these questions allows us to make informed decisions~~ about how we get our energy and the way we choose to use it.

~~However [illegible] with recent incidents such as the great Fukushima Diachi accident the [illegible] people Questions have arisen regarding nuclear systems and there safety.~~ Fundamentally these systems are safe. ~~Nuclear power~~ they are a great option for efficient and clean energy ~~That being said to~~

These systems are safe but with currently outdated technology still in use a lot must be done to ~~improve~~

~~These sy~~ The systems are safe but need to be updated. Improving and Updating the current infrastructure ~~will~~ can will provide peace of mind ~~while providing eff~~

Term C - 2012

January - March

Brendan Walsh

Safe Nuclear Energy Section

<u>Focus :</u> Future generations of nuclear reactors are being built now. These reactors are inherently safer due to simpler designs and systems.

About 85% of the reactors in the United States are outdated and are being superseded by newer designs. These designs, known as Generation 3+ reactors, have been built in Japan and other are currently in construction phase.

Third-generation reactors have:

- a standardized design for each type to expedite licensing, reduce capital cost and reduce construction time,
- a simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets,
- higher availability and longer operating life - typically 60 years,
- further reduced possibility of core melt accidents,*
- 72-hour grace period, so that following shutdown the plant requires no active intervention for 72 hours,
- resistance to serious damage that would allow radiological release from an aircraft impact,
- higher burn-up to reduce fuel use and the amount of waste,
- greater use of burnable absorbers ("poisons") to extend fuel life.

Two of the most relevant designs are the EPR and the Westinghouse AP1000. I took both above and below from http://www.world-nuclear.org/info/inf08.html. I figured it easier to just copy and paste rather than rephrase everything.

EPR

Areva NP (formerly Framatome ANP) has developed a large (4590 MWt, typically 1750 MWe gross and 1630 MWe net) European pressurised water reactor (**EPR**), which was confirmed in mid 1995 as the new standard design for France and received French design approval in 2004. It is a 4-loop design derived from the German Konvoi types with features from the French N4, and is expected to provide power about 10% cheaper than the N4. It will operate flexibly to follow loads, have fuel burn-up of 65 GWd/t and a high thermal efficiency, of 37%, and net efficiency of 36%. It is capable of using a full core load of MOX. Availability is expected to be 92% over a 60-year service life.

It has double containment with four separate, redundant active safety systems, and boasts a core catcher under the pressure vessel. The safety systems are physically separated through four ancillary buildings on the same concrete raft, and two of them are aircraft crash protected. The primary diesel generators have fuel for 72 hours, the secondary back-up ones for 24 hours, and tertiary battery back-up lasts 12 hours. It is designed to withstand seismic ground acceleration of 600 Gal without safety impairment.

The first EPR unit is being built at Olkiluoto in Finland, the second at Flamanville in France, the third European one will be at Penly in France, and two further units are under construction at Taishan in China.

A US version, the **US-EPR** quoted as 1710 MWe gross and about 1580 MWe net, was submitted for US design certification in December 2007, and this is expected to be granted early 2013. The first unit (with 80% US content) was expected to be grid connected by 2020. It is now known as the Evolutionary PWR (EPR). Much of the one million man-hours of work involved in developing this US EPR is making the necessary changes to output electricity at 60 Hz instead of the original design's 50 Hz. The main development of the type is to be through UniStar Nuclear Energy, but other US proposals also involve it.

AP1000

The Westinghouse AP1000 is a 2-loop PWR which has evolved from the smaller AP600, one of the first Generation III reactor designs certified by the US NRC, in 2005. Simplification was a major design objective of the AP1000, in overall safety systems, normal operating systems, the control room, construction techniques, and instrumentation and control systems provide cost savings with improved safety margins. It has a core cooling system including passive residual heat removal by convection, improved containment isolation, passive containment cooling system to the atmosphere and in-vessel retention of core damage (corium) with water cooling around it. No safety-related pumps or ventilation systems are needed. It is being built in China, and the Vogtle site is being prepared for initial units in USA. The first four units are on schedule, being assembled from modules. It is quoted as 1200 MWe gross and 1117 MWe net (3400 MWt), though 1250 MWe gross in China. Westinghouse earlier claimed a 36 month construction time to fuel loading. The first ones being built in China are on a 51-month timeline to fuel loading, or 57-month schedule to grid connection, but ate likely to do better than this.

Overall: EPR has four redundant cooling systems and a containment built to withstand a plane crash. It's safety systems are designed to run for 3 days without human interaction. The AP1000 is the only US certified Generation 3 reactor. It is very feasible to see such a reactor in the United States by the year 2030. The AP1000, as written above, is much simpler in design. Passive safety systems require no pumps, using gravity and flow to cool the systems for up three days as well. Think simplification of these reactors, as this makes operating, understanding, and reacting much easier in the case of emergency.

Jim Lehner, Brendan Walsh

Narration 6 – Final Product

IQP: Safe Nuclear Energy

Safe Nuclear Power

Introduction

The story of safe nuclear power begins with us. We as a culture, community, and individuals have a need for power that is ever increasing. Right now the majority of this power comes from finite fuel sources so what happens when they are all gone? Even though nuclear power has become a popular option for its ability to produce large amounts of energy at low costs it still has its downfalls. Do the benefits outweigh its hazards? Is nuclear energy actually safe? Understanding how these systems work and what is being done to improve them is fundamental to determining if nuclear power is the right choice.

How do nuclear power plants generate power?

1) Fission

Generating power starts with nuclear fission. Fission begins when a lone neutron is smashed into an atom of uranium. When the neutron collides with the uranium atom it is split into smaller byproducts. One of these byproducts are several free neutrons; these neutrons go on to strike more uranium atoms, in a chain reaction. The chain reaction produces heat energy. To capture the heat energy from the chain reaction the fission process takes place in water. The heated water will be used elsewhere in the nuclear power plant.

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Safe Nuclear Energy/Conclusion

The polarizing and controversial nature of nuclear power leaves it vulnerable to misunderstanding. Although the process of creating electricity from nuclear sources is well understood, there are many opportunities for things to go wrong. This brings up the question is there such a thing as safe nuclear energy? According to the world nuclear association there has been over 14,000 years of nuclear power plant operation. Within that collective time there have been three accidents of any notoriety: Three Mile Island, Chernobyl, and most recently Fukushima Daiichi. Some might argue that three accidents are three too many. This is a stance that is hard to disagree with since the effects of nuclear accidents on the magnitude of Chernobyl or Fukushima have long lasting environmental and social implications. So what is being done to make the future of nuclear energy safer?

Making nuclear power safer starts with understanding what is not safe about it in the first place. The reoccurring themes and problems of any nuclear accident can be attributed to a single cause, human error. The Fukushima Daiichi reactor was exposed to a 49 foot tsunami following the April 2011 earthquake. The plant had been designed to withstand a tsunami but not one of such large size. While designers had anticipated the possibility of a tsunami no one anticipated such a catastrophic event. The poor design is a product of human error. The Chernobyl nuclear accident has similar links to human error. The core meltdown was a result of an unauthorized experiment conducted by the facility's operators. When the experiment got out of control operators made decisions that led to the facilities breakdown. Human error in some way, shape, or form has always played a major factor in the failure of nuclear power plants.

Learning from history is essential to making nuclear power plants safe. As traditional fuel sources become scarcer nuclear power as a replacement will become a more popular option. It will be up to communities to decide if nuclear is the right option by weighing both the benefits and hazards. Fundamental to this choice is understanding the role nuclear currently plays and how that will change in the future.

First Draft:

Safe Nuclear Power as An Alternative Energy Source

Report By:

Brendan Walsh

and

Jim Lehner

Introduction/Abstract

With serious growth in population over the past decade, there has been a directly proportional increase in the demand for energy. Today people have more computers, televisions and home appliances that require a greater amount of electricity.

In the United States, that electricity comes primarily through the use of fossil fuels. In 2008 the US consumed 22.5% of the total world's production of oil. With an equal share in CO_2 emissions the United States is one of the benefactors in depleting the world around us. (BP World Energy Review – 2008)

Another issue with such high consumption of fossil fuels is their non-renewability. General estimates put the extinction of crude oil at about the year 2090. This being said, in less than 80 years we will need another source for our energy.

Currently there are many viable options. Over the past ten years, many advances in solar energy have been made. Seemingly a viable option, news broke recently that the US's number one solar cell manufacturing company Solyndra has declared bankruptcy. Stock in solar energy has since declined. Solar energy continues to be an efficient means of generating power, with a sufficient kilowatt per dollar spent ratio. However, solar power will not suffice the massive amount of energy consumed on a daily basis. A more grand scale plant is far more sufficient.

Another low emission option is wind energy. A renewable source, wind turbine farms can provide electricity for a small town. This option however is very small scale. The amount of wind turbine generators to provide power for the majority of the country is unfeasible. It is much too small scale.

Although the United States is a leader in the consumption of naturally occurring fossil fuels, we are also the world leader in nuclear power. With 104 nuclear plants currently generating power, we account for 31% of the world's total nuclear energy production. (BP Energy Review) As a carbon neutral system, nuclear energy has very little long-term effect on the environment.

Currently nuclear power represents only 19.6% of total electricity consumed in this country. However with over thirty newly proposed nuclear plants in 2011, this percentage will increase dramatically over the next twenty years. (World Nuclear Association – Uranium Requirements)

The other beneficial part of nuclear energy is the fuel. Used in very small doses, only several kilograms can sustain a plant for days. This radioactive fuel is naturally occurring and is also found abundantly. Unlike fossil fuels, we have barely scratched the surface of our supply. (Nuclear Power Education – www.nuclearinfo.net)

This addition of these plants will take a burden off our reliance for foreign and domestic oil, and reduce our carbon footprint dramatically. Nuclear energy is a safe, cost-competitive and reliable source of electricity. It is the future of energy in this country.

Background

On an atomic level, the process for nuclear generation is quite simple. The process, known as fission, is completed by speeding several atomic particles. These particles are travelling at such speeds that when they crash into each other, they split into even smaller subatomic particles. This splitting of atoms releases an enormous amount of energy.

This process was first acknowledged by scientist Albert Einstein in 1905. After about 30 years of cumulative research Otto Hirsch, Leis Meitner and Neils Bohr were able to confirm Einstein's idea. They concluded that when the atoms crashed neutrons and photons were released as free particles. These free particles would then break apart other atoms, thus resulting in a self sustaining reaction. This fact makes nuclear energy possible. With a self-sustaining reaction they were able to estimate an energy output of over 200 million volts per day.

With these unbelievable new developments, scientists began to think about how to harness this energy and put it to use. The years 1939-1945 were mostly research to develop an atomic weapon. This was the United States first use for nuclear energy.

Known as the "Manhattan Project", with Robert Oppenheimer as the director, many scientists began developing this new atomic weapon. After a few years, two bombs were developed. "Little Boy" was a uranium-235 based bomb. The Enola Gay took off on August 6, 1945 and dropped the 8,900 pound payload above Hiroshima, Japan. The 10 kiloton explosion killed over 66,000 and injured 69,000. Three days later, plutonium based "Fat Man" was dropped over the city of Nagasaki, Japan. This bomb leveled nearly half of the city, killing 49,000. This demonstration of such power was something never seen before. The unbelievable amount of energy that nuclear fission reactions could produce was useful in ways that would benefit humankind too, not just destroy it. (World Nuclear Association)

How Nuclear Energy Works

As with every other electrical plant, the object is to produce steam to turn the generators turbines. This can be accomplished in one of several ways. One option is to burn fuel. Oil, gas or coal make very good fuels as they can be continuously burned for a long period of time. The heat generated from burning is used to produce steam as nearby water reaches boiling. This steam, when pressurized, is used to turn the massive generator turbines. In a nuclear plant, despite many different designs and systems, the general concept is the same.

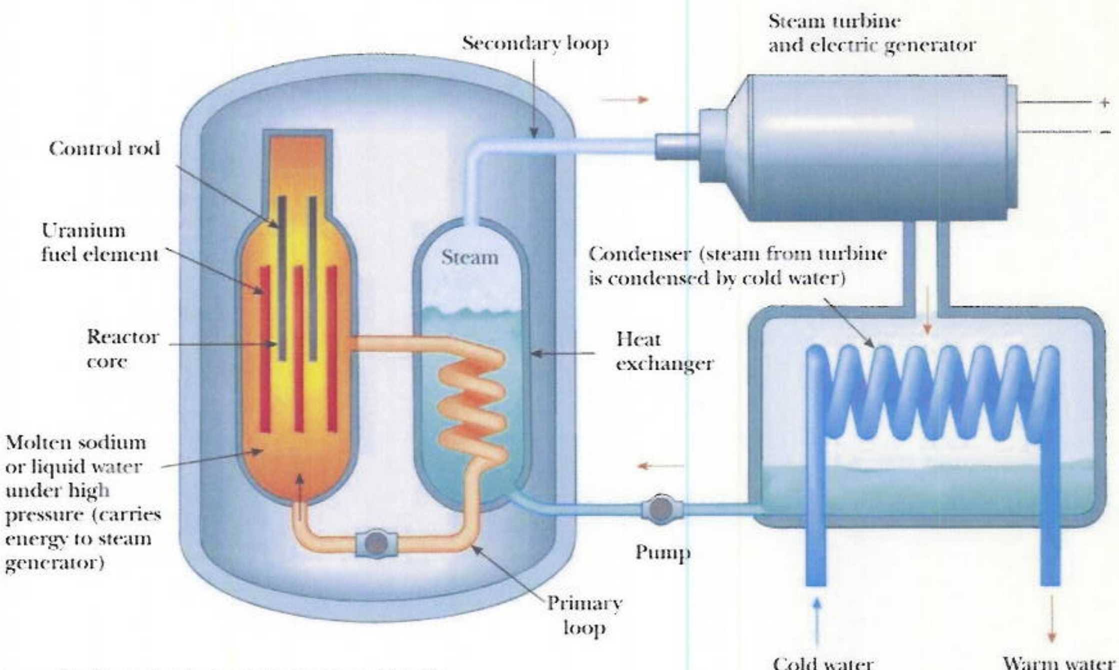

Figure 1: Schematic for a typical nuclear power plant

(http://cnx.org/content/m31328/latest/?collection=col11260/latest)

In a nuclear plant, the reactor core is where the fuel is stored. Inside the core, a continuous fissile reaction is taking place in long cylindrical rods called the fuel rods. This enormous amount of energy is released in terms of heat. This heat is so enormous that without some sort of cooling agent, the entire core would melt. In order to keep this from happening there is constant circulation of water (the typical cooling agent). A pump pushes water towards the core in order to remove the heat. In addition to keeping the system cool this water boils off as steam thus turning the steam turbine and stimulating the generator. Generating steam is the entire idea of a nuclear reactor. Without water as the primary coolant, there would be no steam to turn the generators. After the water passes through the generator it typically goes through a condenser and either returns to the closed system or enters back out into the ocean or nearby source.

Most nuclear reactors are built on or around water due to the amount needed to cool the system. Because there are very little byproducts of nuclear generation, many times the plant will have a pump coming in from the ocean and a pump going back out.

Another key aspect to plant operation is the controls rods. Situated above the fuel rods, the control rods are dropped in to the reactor core in order to stop the fission process. Control rods are typically made up of boron or hafnium and are designed to absorb neutrons. Through absorbing these particles, we are able to remove the pieces that will split further atoms. If there is ever a reason to stop a reactor, lowering the control rods is the first step. Despite ceasing the fission of atoms heat is still being generated inside the core. In order to remove this heat, the cooling system must remain running for several weeks to keep the core at bay. If this is not possible, a nuclear disaster is quite a possibility.

Nuclear Disasters

Since 1952, there have been 33 serious nuclear incidents in plants worldwide. All of these incidents are rated on the International Nuclear Event Scale, or INES. Rated on a scale from one to seven, lowest to highest accordingly, it rates the severity of reported accidents. A rated one is an example of a slight exposure to a rated level seven, Chernobyl. (IAEA – www.iaea.org) In total there have only been two registered events on a scale of seven. The first was of course Chernobyl, the worst nuclear disaster in history. The second tragedy was Fukushima, which is still being contained to this day. Although it seems that the public is quite concerned about nuclear meltdowns, they are quite avoidable.

Chernobyl

As a level seven, Chernobyl was one of the worst meltdowns in the history of nuclear power. On April 26, 1986, outside the city of Prypiat, Reactor No. 4 at the Chernobyl nuclear power plant exploded. It tore the entire 1,000 ton steel-cement roof off the top of the reactor. Without the biological shield attached to the roof the entire core remained exposed to the atmosphere. (What Is Nuclear – www.whatisnuclear.com) Radioactivity that was released in just a matter of seconds was blown thousands of miles all over the countries of Ukraine and Belarus. It is estimated that 5% of the radioactive core escaped from the building.

By May 14, 116,000 people within 30 km of the accident were evacuated. Soon thereafter 220,000 people were relocated to less contaminated homes. Overall, radiation poisoning in the general public was minimal. Today, the surrounding area remains uninhabited.

Figure 2: A photo of the area surrounding the Chernobyl plant

(http://www.oddee.com/item_96462.aspx)

When the reactor exploded two workers were killed instantly, and 28 were killed within weeks from radiation poisoning. Subsequently within years, 19 more workers were killed by the radiation suffered that fateful day.

It all began when the attendants were preparing for a routine system check. Combined with system failure and operator error the power output in the core dropped dramatically. Because of this, extra xenon remained in the reactor. Xenon, very much the control rods, began absorbing neutrons thus slowing and nearly stopping the fission process. This bewildered the operators who didn't know how to act next. When the alarms began going off, one of the operators dropped the control rods into the core. Ironically, this is what caused the explosions. When the rods were dropped, they caused a spike in energy and heat that created the explosion. (World Nuclear Association – Chernobyl Appendix 1)

Fukushima

At 12:46 PM EST on March 11, 2011, the thrust on or near the subduction zone of the Pacific and North American plates caused an earthquake of magnitude 9.0. In perspective, gap between plates ruptured 30-40 meter in height over a span of 300 kilometers. This massive earthquake rocked just offshore Honshu, Japan and sent shockwaves throughout mainland. It demolished buildings, homes and damaged thousands of roads. As a result of such a shift in plate structure, a resulting tsunami followed. This 38 meter wave crashed on the town of Miyoko, Japan. In reality this wave was also 300 kilometers long, so it wiped out a majority of the coastline of Japan.

Total deaths as result of the earthquake and tsunami are estimated at 15703, with 4647 still missing. In total, the damage was estimated around 309 billion dollars. It was one of the most tragic natural disasters of the past decade. To add to the chaos, the Fukushima Daichii nuclear power plant cooling systems were not working.

When the earthquake hit the Fukushima plant, everything went as expected in reactors 1-4. The control rods fell into place and fission ceased. Cooling systems were now responsible to provide cooling for only 7% of max power. Shortly afterward however, power to the plant was lost. A loss of an external power supply is a tough situation for a nuclear plant. This system relied on its diesel generators to run the cooling pumps, with a battery backup. The generators kicked on, but then the tsunami hit. The generators were contained in the shell of the plant, guarded by a large seawall, but no engineer had planned for a wave of this size. Water ran into the plant, knocking out the generators. The batteries kicked in, but eight hours they were left without pumps, and heat was building up in the core. Obviously with the core so delicate, there were many individual systems in place for a scenario like this. However either operator error or failure ended these options very quickly. Water needed to be pumped into the core fast. Over the next three days, while crews worked frantically, the core grew hotter. Eventually hydrogen pockets built after due to the saturation of radioactive byproducts. Three of the four reactors exploded due to this flammable build up. The reactor core itself remained intact for the most part but all were leaking radiation. The plant automatically went into emergency mode, only having 50 people onsite. These people, typically older without children or potential for children, became media dubbed the "Fukushima 50".

The radiation from exploded units 1, 2 and 3came primarily from water dumped into the site in an attempt to cool the reactors. The Japanese government, since July, still has over 90,000 m^3 of contaminated water still awaiting treatment. Overall, general containment of the radiation has been effective as there have been no immediate deaths or sickness from the radiation. (World Nuclear Association – Fukushima Disaster 2011)

Avoiding Disasters Like These

Through new technology and better understanding, the potential for such a disaster in the United States is very minimal. Standards in our country for safe generation are extremely high with the public's safety as priority number one.

Out of the 32 countries with nuclear power plants, and thousands of nuclear generators there have only been three serious nuclear accidents, with only one in the US. This is contrary to public opinion however. In general, the fear of nuclear power is great. Informing the public on how events like these can be avoided is very necessary.

Chernobyl is in the country of the Ukraine and is one of six nuclear reactors in the country. When the general public thinks of nuclear meltdown, they think Chernobyl. However a catastrophe like this is not possible in

America. Compared to 1986 regulations and standards for nuclear plants in Ukraine, America is above and beyond. The engineering standards in place today help protect and prevent outcomes like Chernobyl. A meltdown of this magnitude is highly unlikely (World Nuclear Association – Chernobyl Disaster)

Another interesting point in the Chernobyl accident is the ineptness of the operators. In the process of trying to right the system, every effort seemed to deplete it even more than the last. From shutting off the emergency cooling supply, to dropping the rods causing the explosion, they seemed to have very little idea of exactly what they needed to do. This is a very avoidable system. Today, all of the reactors rely on less human interaction and are based on computational execution. This takes the reactor out of the hands of the operator, which seems to be fatal.

In Fukushima, no engineer could have prepared for a wave of such magnitude. However, there are many things that both the engineers and the system operators could have done. When the tsunami flooded the reactor, all of the water flowed towards the ground floor. Unfortunately this is where the backup emergency diesel generators were located. Almost immediately they were flooded and destroyed. This location of the generators was a very simple mistake, but was the tragic flaw in the incident.

A way that nuclear designers and engineers are learning to make plants safer is through recent disasters. Being able to plan for the most dramatic, unpredictable scenario is a must. New plant designs take into account all of the situations that have arisen in the past and attempt to provide a safety plan in case something goes haywire. (World Nuclear Association – Nuclear Radiation and Safety)

Future Designs

In the United States, over 85% of out reactors are considered outdated. Many of these systems were designed and built in the seventies and eighties, and are still using much of the old technology originally designed. These systems are over complicated, difficult to use, and specifically much less safe than those being built and developed in countries like Japan and China.

These newer facilities are called Generation 3 reactors. Generation 3 reactors are inherently safer due to simpler designs and systems. These reactors are planned and built using a standardized method in an effort to speed up the process of requesting a license, reduce cost and improve construction of the plants. With a simpler and less vulnerable design, accidents stemming from both user and computer failure have been reduced.

Three key points to these new reactors include a grace period in case of cooling shutdown, stronger containment structure, and more efficient systems. The grace period of 72 hours would allow for zero interaction with the systems for 72 hours without threat of meltdown. These passive safety systems, like in the new Westinghouse AP1000, use gravity and require no pumps to actively cool the core for days. Also, a stronger containment structure would protect from radiation leakage in case of earthquake, tsunami and even a direct plane crash. This is very important to citizen's protection from terrorist threat and acts of Mother Nature. The final aspect that the new Generation 3 reactors provide is a higher burn up rate, expending the majority of its fuel. This means that there is less waste and less need to replace the fuel as often.

Being built and tested around the world these new generation reactors provide simpler, safer designs that are the future of nuclear generation. Designs like the AP1000 provide assurance that nuclear energy is a feasible alternative energy source. (World Nuclear Association – Advanced Nuclear Power Reactors) Working to make these systems safer is the concern now, for the future ahead. As Dr. Yaron Danon, professor of nuclear engineering at Rensselaer Polytechnic Institute said, "When someone dies in a car accident we don't stop using cars. We work to make them safer." (Popular Science)

Conclusion

Overall, nuclear power is a safe alternative that on a grand scale can provide sufficient power for hundreds of years. With most nuclear contracts averaging a lifespan of fifty years, these plants can provide carbon clean electricity to millions of homes country wide. (IAEA – Nuclear Reactor Ages)

The time is now to remove ourselves from the dependence of fossil fuels. Foreign oil dependency has killed far more people in the world than nuclear energy ever could. It is expensive, harmful to the environment and it is limited. Nuclear energy is abundant and cost competitive. Nuclear energy is the future of electricity generation worldwide.

Safety of the public is a number one concern at nuclear plants. Every safety check, every system and every response agenda is in place to protect people. There is no possibility of a Chernobyl taking place again as both engineering standards and systems have been improved upon one hundred fold. With new generation 3 and 4 reactors being built worldwide over the next 20 years, we will begin to see the acceptance of nuclear power as safe and effective.

All together nuclear power is our most viable option for renewable energy source. With one large plant, like Palo Verde in Arizona, the four reactors are capable of generating nearly 4,000 megawatts when operating at full power, (McClellan, Colin) This enormous amount of energy could heat about one million homes. Nuclear power is an excellent alternative energy source, generating enormous amounts of energy for people every day.

"And Lord, we especially thank you for nuclear power,

the cleanest, safest energy source there is."

-Homer Simpson

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