PRESENTER NOTES FOR LECTURE: "INTRODUCTION TO NUCLEAR POWER: THEORY TO APPLICATION"

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ORIGINALLY AUTHORED FOR NS 191

NAVAL SCIENCE INDEPENDENT STUDY

NAVAL ENGINEERING TOPICS

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1 INSTRUCTIONS FOR USE OF THIS DOCUMENT

1.1 Restrictions on Use

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1.2 Recommended Use

This lecture is directed towards an audience with a technical background, though a passing acquaintence with the mathematical sciences and/or basic engineering is all that is required for immeadiate accessibility to the lecture. No knowledge is assumed, however, and the treatment is a mixture of light science and history. The notes are meant to be used in combination with the lecture; the lecture itself contains very little explanatory information, while the notes provide the presenter with a means to thoroughly engage his or her audience. The body of these notes are separated by slides, though none of these divisions are formal in any sense, and it is recommended that presenter personalize the notes to match his or her style. Additionally, modifications are recommended to personalize the presentation or direct it to a more specific audience.

2 INTRODUCTION TO NUCLEAR POWER: THEORY TO APPLICATION

2.1 SLIDE 1 - TITLE SLIDE

Make sure to substitute the appropriate information into the slide.

2.2 SLIDE 2 - LECTURE PURPOSE AND OUTLINE

This is a brief statement of purpose about the lecture and an outline. The purpose as authored is to provide an introduction to nuclear power (directed, but not specific, to Naval applications) via a historical development of the theory and applications, with brief biographical inserts of key figures. Topics are treated in the following order:

2.3 SLIDE (GROUP) 3 - BASIC POWER THEORY

Questions: What is energy? How do we produce it? How do we make use of it?

2.3.1 ENERGY DEFINITION

Two kinds of energy -

Kinetic energy: the difference between the moving ball versus ball at rest. Proportional to the mass of an object and its velocity squared.

Potential energy: the difference between the ball held at a great height and the ball on the ground. Proportionality varies since there are many varieties of potential energy: gravitational (the ball example), electrostatic (static electricity holding hair to balloon), mechanical (compressed spring), and others.

An excellent reference for simple explanation of energy (and most everything else) can be found at the HowStuffWorks website: http://science.howstuffworks.com/fpte6.htm. This explanation was generated without any specific references.

2.3.2 INTRO TO ENERGY PRODUCTION

Simple notions of Energy Production -

Transforming potential energy into kinetic energy: car burning gasoline converts the energy stored in petroleum into the motion of pistons which in turn drives the vehicle.

Transforming kinetic energy into another form: using the wind to drive a windmill or the flow of water to drive a waterwheel.

2.3.3 THERMODYNAMICS

Specific notion of Energy Production: Thermodynamic Processes -

Thermodynamics refers to the study of the transfer of heat and the generation of work.

Basic Principles of Thermodynamics -

0th Law - If is A is the same temperature as B, and C is the same temperature as B, then A is the same temperature as C.

1st Law - Conservation of Energy - bouncing ball eventually stops, but the energy has not diss-appeared, but is rather converted into sound waves and heat. A car braking hard provides better example: tires make lots of noise and the friction generates a very sensible amount of heat.

2nd Law - Flow of Heat - Heat energy naturally flows from a high temperature to a low temperature. Transfer in the other direction requires that do work (expend mechanical energy); examples: refrigerators and air conditioning require us to expend energy.

General information about Thermodynamics (and physics and science more generally) can be found at the Wolfram Research website: http://scienceworld.wolfram.com/physics/topics/Thermodynamics.html. This is not a citation.

Heat Engines, basic Carnot formulation:

The most common form of energy production is achieved via heat engines, which extract mechanical energy from the transfer of heat energy. Heat is produced typically from the extraction of potential energy (burning of fuel most commonly).

Heat engines operate because of the ideal gas law: PRESSURE OF GAS * VOLUME OF GAS is proportional to AMOUNT OF GAS * TEMPERATURE.

Carnot Cycle:

Gas compresses without heat gain from low temperature to high temperature

Heat is added to increase the volume of the gas while maintaining constant temperature

Temperature is lowered as volume is increased

Heat is removed and volume decreases back to original state

2.3.4 ENERGY USE

Energy Use -

Electricity provides energy for the operation of nearly every aspect of modern life; electricity is produced primarily via heat engines turning AC generators.

The direct production of mechanical energy (the motion of a car for example) is the other primary example of energy use. Like electricity, mechanical energy is produced primarily via heat engines.

2.4 SLIDE (GROUP) 4 - DISCOVERY OF NUCLEAR ENERGY

Questions: How did we discover nuclear energy? How does nuclear energy "work"? What other research was done to move us to the point of applying nuclear energy?

2.4.1 DISCOVERY OF RADIATION & RADIOACTIVITY & MASS-ENERGY EQUIVALENCE

1895 - Wilhelm Roentgen, German physicist and Director of Physics at the University of Wurzburg, discovers X-ray emission from cathode ray tubes. X-rays are a form of light that we cannot see and possess far more energy than visible light.

1896 - Henri Becquerel, French physicist, having been to a lecture given on Roentgen's discoveries, investigates material he suspects is also emitting X-rays. This material is uranium and though it is not emitting X-rays, it is emitting a form of radiation.

1896 - The Curies, French physical chemists, investigate the radioactivity (a term coined by Marie Curie) of uranium, discover other elements which are radioactive. Uranium forms the basis of nuclear power today.

1899 - Ernest Rutherford researches radiation phenomena, discovers alpha and beta rays. Later makes initial use of notions of half-life and radioactive decay and transmutation of elements. Transmutation of elements was initially viewed a ridiculous relic of alchemy, however later in life Rutherford would transform nitrogen into oxygen.

1905 - Albert Einstein, German ex-patriot and then Swiss patent clerk, publishes theoretical physics text proposing what is now referred to as special relativity. Later that year he would publish a paper supposing that this relativity would lead to a relation for mass to energy conversion. He proposed a simple experimental test of measurement of mass loss in radioactive materials. Source for this material (and other Einstein biographic information): Einstein by J J O'Connor and E F Robertson (http://www-gap.dcs.st-and.ac.uk/ history/Mathematicians/Einstein.html).

1934 - Enrico Fermi "thermalizes" the first neutrons. Thermal neutrons are those emitted neutrons which have been slowed via equalizing their temperature with surronding material. They equalize by colliding with other particles in a substance. These thermal neutrons have a much greater chance

1938 - Otto Hahn & Fritz Strassman demonstrate nuclear fission. This is the process by which heavy atoms such as Uranium 238 and 235 are split into lighter atoms by neutrons and release both energy and more neutrons.

These ideas and discoveries form the phenomonological basis of nuclear power.

A well organized list of resources on the History of Radiation can be found at Idaho State University's Radiation Information Network site: http://www.physics.isu.edu/radinf/hist.htm. Some of the information was garner from sites linked from that page: The Discovery of Radiation: The Dawn of the Nuclear Age by Fran Slowiczek, Ed.D and Pamela M. Peters, Ph.D (http://www.accessexcellence.org/AE/AEC/CC/radioactivity.html), and Rays and Particles by Michael Fowler (http://www.phys.virginia.edu/classes/252/rays_and_particles.html). Material is also drawn from The Manhattan Project Heritage Association website (index: http://www.childrenofthemanhattanproject.org/HISTORY/ERC-1.htm). Information can be found in a more brief form at Nuclear Innovations (http://inventors.about.com/library/inventors/blnuclear.htm).

2.5 SLIDE (GROUP) 5 - THE MANHATTAN PROJECT

Questions: What did the Manhattan Project add to Nuclear Power?

2.5.1 INCEPTION

The information from this section is from personal knowledge and the aforementioned Manhattan Project Heritage Association site.

1939 - In light of the recent development in physics and fearful of potential Nazi development of an Atomic Bomb, Leo Szilard, Edward Teller, and Eugene Wigner began plans to secure the US the ability to potentially create such a weapon. Szilard convinced Einstein to author a letter with him to FDR via FDR's friend and advisor Alexander Sachs outlining the threat of Germany developing the Atomic Bomb. Later that year FDR would establish a Uranium Committee which would discuss uranium research.

1941 - British MAUD report indicates that uranium can be used to create nuclear weapons; also notes that German researchers in the Wilhelm Institute also know that and have a 3 year lead in research. 7 DEC 1941: Attack at Pearl Harbor. Now involved in the war, impetus is added to the uranium research program.

1942 - Vast amounts of advance in separation techniques is made. GEN Leslie Groves takes over the bomb project. DuPont Chemical accepts contract to build Oak Ridge facilities. Enrico Fermi's team achieves sustained nuclear chain reaction.

2.5.2 LOS ALAMOS

Los Alamos was established in late 1942 with J R Oppenheimer as the Director. Oppenheimer's selection was hotly contested, but the military authority in the matter, GEN Groves, insisted. The laboratory was organized and constructed early in 1943. Over the next 2 years, the lab would test a variety of methods, but finally settled on an implosion type bomb.

2.5.3 TRINITY

16 JUL 1945 - at 0529:45 the test tower at Trinity was annihilated in a 21kiloton nuclear blast. Shortly thereafter, bombs are produced and the cities of Hiroshima and Nagasaki meet the same fate as the Trinity tower.

2.6 SLIDE (GROUP) 6 - ARGONNE LABORATORY

Established in 1946 near the University Chicago, Argonne Laboratory's first project is developing a water cooled nuclear reactor for use in submarines. In 1951, Experimental Breeder Reactor 1 produces for the first time enough electricity to operate anything; initially, 4 light bulbs are lit. Reactor criticallity is first acheived in 1952, and in 1953 the prototype pressurized water reactor for the USS Nautilus achieves criticality. Argonne makes continual progress in reactor research and after declassification of the structures in the late 1950s become an educational center for nuclear science. The laboratory goes on to branch out into a variety of fields.

This information, and much more, is available at the Argonne National Laboratory History site (index: http://www.anl.gov/OPA/history/index.html).

2.7 SLIDE (GROUP) 7 - US NAVAL NUCLEAR PROPULSION PROGRAM

The US Nuclear Propulsion Program today, and indeed much of the Navy, is the product of the work of ADM Hyman Rickover. He convinced the Navy and Congress of the feasibilty and necessity of a nuclear fleet. He oversaw all aspects of the development and implementation of the nuclear Navy from his 1949 dual appointment to Reactor Development Division with US Atomic Energy Commission and as Director of Naval Reactors in the Bureau of Ships until his retirement in 1982 after 64 years of service. The current director of the Naval Nuclear Propulsion Program is ADM Frank Lee Bowman.

2.8 THE PRESSURIZED WATER REACTOR (PWR)

Questions: What does a reactor do? How does theory explain this/How does the reactor do this?

2.8.1 BASIC PRINCIPLES & SYSTEMS

The nuclear power that has been discussed historically to this power serves a simple purpose: to provide the heat source in a heat engine. In maritime applications that reactor will operate between the safe upper material limit and the ambient temperature of the surrounding seawater.

The core produces heat via the fission process. The neutrons released by fission thermalize with the moderator (water in the case of the PWR) and then have a higher probability of intersecting with other fuel atoms. The process of thermalizing with the water causes it to be heated.

The water that acts as a moderator also acts as the primary coolant loop. The water is heated well beyond its boiling point at standard pressure, and therefore must be held at an extremely high pressure to avoid boiling in the reactor. Pumps drive the heated coolant water away from the reactor core to the steam generator.

The primary coolant loop transfers the heat to the secondary loop in the steam generator. The primary and secondary loops are not permitted to mix. The secondary loop contains water which is converted to steam in the steam generator.

The steam in secondary loop drives a turbine generator and is sent through a heat sink at the temperature of the surrounding seawater, where it is converted back into water and sent back to the steam generator.

A more complete, since most of the above is derived from it, basic treatment of the topic is available at Nuclear Propulsion (http://www.fas.org/man/dod-101/sys/ship/eng/reactor.html).

2.8.2 USS NAUTILUS - SSN 571

Keel laid down in 1952, the USS NAUTILUS launched in 1954, and CDR Wilkinson signalled the famous "Underway on Nuclear Power" in 1955. She served until her decommissioning 1980, having steamed over half a million miles.

The USS NAUTILUS represented Verne's dream ship for which she was named, and provided the second piece of evidence tangible to the whole world of the coming of the Nuclear Age.

The online museum site for the USS Nautilis is Historic Ship NAUTILUS And Submarine Force Library and Museum (http://www.ussnautilus.org/index.html).

2.8.3 USS NARWHAL - SSN 671 - NATURAL CIRCULATION

The USS NARWHAL - SSN 671 was laid down in 1966 by the Electric Boat Division of General Dynamics Corporation in Groton CT. She is the only ship in her class and operated with great success throughout the Cold War.

The NARWHAL, now decomissioned, is the first submarine to feature a natural circulation plant. Natural circulation plants operate the primary coolant loop via currents in the heated water instead of pumping the water, vastly reducing noise generation. These currents are produced by density changes in the heated vs cooler water, giving rise to a pressure difference, which causes fluid flow.

Information regarding the USS NARWHAL can be found at Mission Report: Shipmates Bid Farewell to USS Narwhal (http://www.chinfo.navy.mil/navpalib/cno/n87/usw/issue_3/mission_report1.htm) and NARWHAL (http://www.subnet.com/fleet/ssn671.htm).

2.8.4 FUTURE POTENTIAL IMPROVEMENTS

Critical to the PWR design is the presence of a moderator; fortunately, the purified water in the reactor can operate as coolant, moderator and reflector. Use of water also has the intrinsic negative feedback effects discussed previously. However, operation of the reactor purely with thermalized neutrons leads to larger nuclear waste production and, by logical extension, less bang for the buck as far fuel goes. Furthermore, fast reactors are capable of operating at a higher thermal efficiency. Fast reactors, however, have certain additional requirements - they require metallic fuel as opposed to the standard ceramic fuel and use liquid sodium instead of water as a coolant. The metallic fuel is not a downside; properties of the metallic fuel increase its passive safety measures (those that do not rely on systems or operators but rather natural law). The use of sodium is a consideration, especially for Naval applications. Sodium reacts violently to exposure to air and water, and despite the fact that it generates less detorioration of core material components, this presents a large potential problem.

Information on the faster reactor comes from The Unofficial IFR site (index: http://www.nuc.berkeley.edu/designs/ifr/).

2.9 SLIDE 8 - CONCLUDING REMARKS

2.10 IMAGE CREDITS

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