Nuclear Options

Major Topic: Nuclear Physics

Length of Unit: 8 -90 minute classes

Unit Summary: Students are given the problem of, "How can nuclear energy be made safe and more reliable as a primary energy source?" They will present and write a paper on their views and findings.

Interdisciplinary Connections: Students will develop reading skills using an anticipation guide with a short article about nuclear waste disposal. Students will present a project of their choice. Students will additionally submit a paper required for this unit from one of three topics: *nuclear waste disposal*, *possible nuclear attacks*, of the feasibility of *building new nuclear power plants in the US*.

Understanding Goals: Students should be able to describe nuclear reactions adequately and have an educated opinion about why they do, or do not support the use of nuclear power as a primary energy generation option.

Essential Questions:

- How important is "pure science" today?
- Are the costs of research balanced by the benefits afforded by the research (ie. Inventions based on principles discovered through "pure science")?
- How is the nucleus organized and how can its composition be used by humans?
- Is it a good idea to continue to harness the power of the atom, or should we just use what natural resources we understand now?

Student Objectives:

Students will be able to:

PH.4 The student will investigate and understand how applications of physics affect the world. Key concepts include

a) examples from the real world; and
b) exploration of the roles and contributions of science and technology.

PH.7 The student will investigate and understand that energy can be transferred and transformed to provide usable work. Key concepts include

a) transfer and storage of energy among systems including mechanical, thermal, gravitational, electromagnetic, chemical, and nuclear systems; and
b) efficiency of systems.

Lesson Contributed by: David Flickinger
Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

PH.12 The student will investigate and understand that extremely large and extremely small quantities are not necessarily described by the same laws as those studied in Newtonian physics. Key concepts may include

a) wave/particle duality;
b) wave properties of matter;
c) matter/energy equivalence;
d) quantum mechanics and uncertainty;
e) relativity;
f) nuclear physics;
g) solid state physics;
h) nanotechnology;
i) superconductivity;
j) radioactivity.

Differentiation: Students with special needs should be able to produce a project that works to their strengths. The open nature of the culminating project allows students to focus their ideas in any direction. If a student has difficulty with the spoken word, then their project can be written. If a student excels at explaining their ideas, then an oral presentation can be used. Hard copies of notes are given to all students so that the students with writing disabilities and dysgraphia can keep up with the notes in the lesson.

Blooms Taxonomy	21st Century Skills
Creating Evaluating Analyzing Applying Understanding Remembering	Critical Thinking Problem Solving Communication Creativity & Innovation Collaboration Information & Media Contextual Learning Global/Multicultural Research

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

Performance Tasks:

Students will:

- Fill out am *Anticipation Guide* before reading Nuclear Waste article, then discuss after reading.
- Solve problems balancing nuclear equations indicating alpha and beta decay.
- Solve problems determining the amount of binding energy in a nucleus due to its mass defect.
- Individually complete a two page research/opinion paper on selected nuclear topics.
- Complete a cooperative project related to nuclear physics.
- Complete a quiz.

Evidence of formative assessment:

Discussion: Oral questioning and answering questions during discussion of topics like *Nuclear Power*, *Nuclear Weapons*, and *Nuclear Disasters*.

Class Participation: Teacher will circulate as students complete problems on Nuclear Equations to ensure correct completion of both alpha and beta decay formulas. Questioning techniques will be used to verify understanding of parts of a nuclear reactor and how scientists developed the understanding of the composition of the atom.

Quiz: Comprehensive assessment of the remembering, understanding, applying and analyzing concepts on nuclear physics by the levels of Bloom's Taxonomy.

Evidence of Summative Assessment:

The final project consists of two equally weighted parts: collaborative open-ended project and a two page research/opinion paper

Technology

Hardware	Software
Computers Printer Video Camera Internet Connection Projection System Document Camera	Multimedia Concept Mapping Word Processing Graphic Design Web Browser

Resources from the web:

- Prezi (possible presentation tool for students)

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

- PBS video: Revisiting Chernobyl
- Frontline video: Inside Japan's Nuclear Meltdown
- Element Chart

Supplies:

- Paper for printing projects
- Anticipation Guide and Nuclear Waste Disposal article
- PowerPoint for students (print for notes)
- Nuclear Decay practice worksheet
- Binding Energy worksheet
- Nuclear Physics quiz

Vocabulary: nucleus, electron, proton, neutron, quark, chain reaction, fission, fusion, radioactive, half-life, activity, atomic mass unit, mass number, atomic number, alpha decay, beta decay, gamma decay

Lesson 1: (1 -90 minute class)

- Review Nuclear Physics PowerPoint Notes for chapter 21 and 22 (attached)
  - Development of current concept of the structure of the atom (Plum Pudding, Nucleus, Electron energy levels, presence of neutrons, presence of radioactivity)
- Complete nuclear reaction problem practice in attached PowerPoint (Alpha, Beta, and Gamma Decay)
- Assign Nuclear Decay practice worksheet (attached)
- Discuss: how important was the "pure science" studied by Rutherford and Bohr?

Lesson 2: (1 -90 minute class)

- Check Nuclear Decay worksheet and answer questions.
- Continue Nuclear Physics PowerPoint Notes for chapter 21 and 22
  - Nuclear fission – Chain reaction process, parts and function of a nuclear reactor, history of nuclear fission bombs, Hiroshima and Nagasaki history
- Complete Binding Energy practice problems in attached PowerPoint (mass defect and proton, neutron masses, one amu = 931.49 MeV)
- Assign Binding Energy worksheet
- Did the "pure science" of the nucleus lead to good endings or bad endings?

Lesson 3: (1 -90 minute class)

- Check Binding Energy worksheet and answer questions.

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

- Review operation of a nuclear reactor and have discussion about what students remember about Japanese Tsunami. What about the nuclear accident? International reactions and impacts?
- Watch Japan's Nuclear Meltdown video.
- Is it a good idea to continue to harness the power of the atom, or should we just use what natural resources we understand now?

Lesson 4: (1 -90 minute class)

- Anticipation Guide for Nuclear Waste Disposal
  - Read Nuclear Waste Disposal article and discuss before/after responses
- Hand out final project assignment (paper and project information)
- Let students work with partner(s) to develop project plan and research using computers, the internet and productivity software
- As a closure, ask your students, "How is the nucleus used by the human race?"
- Remind students of due dates and plan for presentations.

Lesson 5: (1 -90 minute class)

- Continue research and group work. Use computers and circulate to answer questions that students have both about concepts and format of the project or paper.

Lesson 6: (1 -90 minute class)

- Collect papers and have some students present their projects.
- Lead discussion of world/country/community impacts brought up by the projects.
- Watch Chernobyl video.
- Ask the students, "Is it a good idea to continue to harness the power of the atom, or should we just use what natural resources we understand now?"

Lesson 7: (1 -90 minute class)

- Have remainder of students' present projects.
- Review problems and concepts necessary for quiz.
- Ask the students, "How important is pure science? How can we harness the power of the nucleus to help us today?"

Lesson 8: (1 -90 minute class)

- Return papers and projects.
- Have students take quiz on Nuclear Physics topics.
- Ask students, "Is nuclear power 'worth it' due to costs and dangers vs. benefits?"

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

Nuclear Physics Project - Test Grade

50% Open-Ended Activity; 50% Paper

How will the world keep nuclear energy safe in the future?

<u>Open Ended Activity:</u> Get a group of two or three students to complete this project.

Choose a style of presentation (television news report, web page, magazine article, or check with the teacher to decide on an original format) that you can use to educate the public about a nuclear topic. Nuclear energy is controversial so you should be persuasive and make sure you also address the opposing viewpoint. Be <u>creative</u> in your project and be as complete as possible in your discussion of how safety can be ensured in the area of nuclear energy discussed. Use the research you did for your paper to guide your presentation. This project is intended to supplement the paper you write, not be completely different. Feel free to focus the presentation on a topic not directly stated in your paper, but in a direction that may be suggested by the topic of your paper.

Project Due on __________________
(5 points extra credit if turned in by ______________)

<u>Paper Topics:</u> One paper per student. ***Choose one (1) of the topics below to write a 2 page, double spaced, typed paper (12 pt font). You must do research (2 source minimum) and cite your sources. Make to show what information in your paper came from each source using parenthetical documentation. There are some opinion paper aspects to this assignment, but make sure you support your position with facts obtained from a <u>reliable</u> source. Wiki articles and personal websites are not reliable sources. Educational institution websites as well as governmental websites (ie the Nuclear Regulatory Commission (www.nrc.gov) are reliable.***

Paper Due on __________________

Topic #1: *Nuclear fuel is highly radioactive and is very useful since only a small mass of fuel is necessary to power a reactor. Once this fuel is spent, it is still highly dangerous to humans.* ***How and where should this spent fuel be deposited?***

Answers must include:

- Location and method of disposal
- Amount that can be stored with this method
- Cost of disposal method

Topic #2: *The threat of nuclear warfare has changed in the past 20 years. The two Superpowers (USSR and USA) were formerly the only two countries on the brink of nuclear war. Many other countries now have nuclear capabilities or nuclear waste that can be fashioned into a "dirty bomb." Where do you think the next nuclear attack will occur?*

Answers must include:

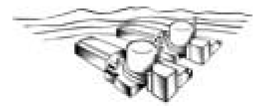
- Who would be involved in the attack
- What type of weapon and what delivery method would be used
- Reasons behind the attack

Topic #3: *With the cost of fossil fuels increasing rapidly and demand for electricity increasing, there is a call for building new nuclear power plants. It is currently against the law to build a new nuclear power plant in the United States since the accident at Three Mile Island (TMI). How could you argue in favor of building new nuclear power plants here in the United States?*

Answers must include:

- Short description of the accident at TMI
- Advantages of nuclear power over conventional (coal, natural gas, etc.) power plants
- Reasons that new nuclear power plants would be safer than those we operate now

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)



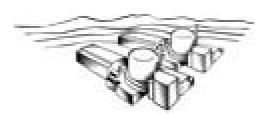
Nuclear Paper
Grade Sheet

Name: ______________________________________

<u>Categories:</u>

Length:	[10 pts]	________
Content:	[21 pts]	________
Overall Effect	[10 pts]	________
Cited Source	[9 pts]	________

TOTAL: [50 pts] ________



Nuclear Project
Grade Sheet

Name: ____

<u>Categories:</u>

Length:	[10 pts]	________
Content:	[21 pts]	________
Overall Effect	[10 pts]	________
Cited Source	[9 pts]	________
Extra Credit?		________

TOTAL: [50 pts] ________

Lesson Contributed by: David Flickinger
Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

"Nuclear Waste" Anticipation Guide

1. We have reliable methods to dispose of nuclear waste.

   Agree:___________ Disagree___________

   Explanation:

2. We currently bury our nuclear waste.

   Agree:___________ Disagree___________

   Explanation:

3. Recorded history goes back to about the 4th millennium BC (about 6000 years ago).

   Agree:___________ Disagree___________

   Explanation:

4. The half- life of Plutonium is approximately two human generations long.

   Agree:___________ Disagree___________

   Explanation:

5. Nuclear energy is safe.

   Agree:___________ Disagree___________

   Explanation:

Lesson Contributed by: David Flickinger
Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

Nuclear Wastes: Where Can We Put Them?

If you knew your garbage wasn't going to get picked up, what would you do? In a sense, this perplexing question recently faced the state of California. And the state decided to take steps to keep the amount of garbage production at the then-current levels.

California took this action not to protect its people from foul-smelling heaps of discarded foods, but from odorless mounds of deadly radioactive substances—the "garbage" of the nuclear industry. No new nuclear reactors would be built, state officials declared, until a permanent dump site for nuclear wastes had been constructed.

In a very real sense, California's problem is not unlike that of the rest of the nation or, for that matter, of any other nation possessing a nuclear industry. The waste products of this industry include the most toxic substances known, the deadliest of which is plutonium 239 (Pu-239). What's more, this poison retains its potency for thousands of years, since the half-life of Pu-239 is 24,100 years.

This means that a nuclear garbage dump must resist the forces of nature and the probings of people for a period into the future longer than the recorded history of humankind. This has led the U.S. Environmental Protection Agency (EPA) to mandate that any place chosen to house the nation's nuclear wastes will be designed to prevent the escape of its contents into the environment for at least 10,000 years.

But how can this be guaranteed? asks critic Kai Erikson, who is a professor of sociology and American studies at Yale. Put the wastes deep underground in a geologically stable area, say some officials of the U.S. Department of Energy (DOE), which is responsible for finding a safe haven for nuclear wastes.

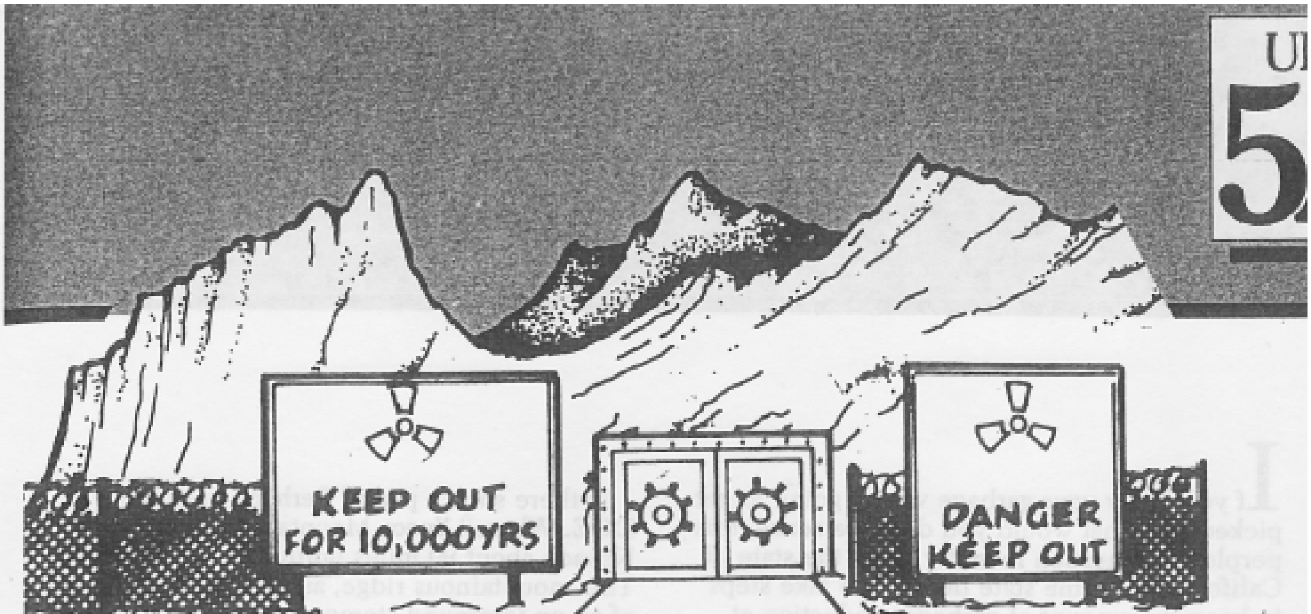
Is there such a place? Perhaps, says the DOE. Where? Yucca Mountain, which lies in Nevada about 90 miles northwest of Las Vegas. This mountainous ridge, assert the supporters of an underground storage site, is far from heavily populated areas, which would reduce the risk of accidents affecting many people; is very dry, which would minimize the corrosion of nuclear waste-containing "garbage cans"; and holds minerals called zeolites, which tend to bind to radioactive materials that might eventually leak from the cans.

Critics, however, point out that earthquakes have rocked the region in the past and four volcanoes have punched holes through its dusty soil. Even more disturbing, U.S. government geologists have recently discovered several faults running through the Yucca Mountain site. True, no dangerous geological activity has occurred in recent times. But who is to say it won't happen again in 100, 1000, or even 10,000 years?

Let's say we are lucky and Yucca Mountain stays in one piece for 10,000 years. What, asks Erikson, makes us confident that people of the future will not deliberately or inadvertently unearth the lethal garbage sometime in the future? As Erikson puts it in an article in *The New York Times Magazine* of March 6, 1994: "It is difficult to predict what human beings will do a year hence, but preposterous to think one can even begin to know what they will do a century or millennium hence."

People might one day hunt for minerals or fuels in or under Yucca Mountain. Or, perhaps, they might change the face of the land in great land-use projects that could alter the way water flows through the mountain. Like the carrier of a plague, the water might pick up and transport

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)



leaking nuclear wastes from inaccessible to accessible places. And pathways provided by fractured rocks filling the faults in Yucca Mountain could increase the rate at which such tainted groundwater moves.

The DOE has a solution for this problem, which is written into a document called the Site Characterization Plan. The solution? Set up "a warning system composed of surface markers and monuments . . . informing future generations of the risks associated with the repository and its contents."

But "surface markers and monuments" are usually eroded and weathered over time. And even if they survive, how can we be sure that people thousands of years from now will be able to figure out what they mean?

So, what is the solution? Rocket the wastes into space? Bury them beneath the ocean floor? Temporarily continue to store them on Earth's surface until we can find a permanent and safe place for them? Or lock them up in Yucca Mountain, with all the safeguards we can develop? What do you think?

Questions

1. The half-life of Pu-239 is
   a. 239 years. c. 24,100 years.
   b. 10,000 years. d. 100,000 years.

2. The EPA has mandated that any nuclear waste site chosen must keep radioactive material from polluting the environment for at least
   a. 10 years. c. 1000 years.
   b. 100 years. d. 10,000 years.

3. In what state is the location of the proposed nuclear waste garbage dump?
   a. California c. Texas
   b. Nevada d. Washington

4. What are the advantages of burying nuclear wastes in Yucca Mountain?

5. On a separate sheet of paper, express your views on why (or why not) nuclear wastes should be deposited in Yucca Mountain.

Lesson Contributed by: David Flickinger
Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

Subatomic Physics

Problem B

NUCLEAR DECAY

PROBLEM

The most stable radioactive nuclide known is tellurium-128. It was discovered in 1924, and its radioactivity was proven in 1968. This isotope undergoes two-step beta decay. Write the equations that correspond to this reaction.

SOLUTION

Given: $^{128}_{52}\mathrm{Te} \rightarrow {}^{0}_{-1}e + \mathrm{X} + \bar{v}$

$\mathrm{X} \rightarrow {}^{0}_{-1}e + \mathrm{Z} + \bar{v}$

Unknown: the daughter elements X and Z

The mass numbers and atomic numbers on both sides of the expression must be the same so that both charge and mass are conserved during the course of this particular decay reaction.

Mass number of X = 128 – 0 = 128

Atomic number of X = 52 – (–1) = 53

The periodic table shows that the nucleus with an atomic number of 53 is iodine, I. Thus, the first step of the process is as follows:

$$^{128}_{52}\mathrm{Te} \rightarrow {}^{0}_{-1}e + {}^{128}_{53}\mathrm{I} + \bar{v}$$

A similar approach for the second beta decay reaction gives the following equation. Again, the emission of an electron does not change the mass number of the nucleus. It does, however, change the atomic number by 1.

Mass number of Z = 128 – 0 = 128

Atomic number of Z = 53 – (–1) = 54

The periodic table shows that the nucleus with an atomic number of 54 is xenon, Xe. Thus the next step of the process is as follows:

$$^{128}_{53}\mathrm{I} \rightarrow {}^{0}_{-1}e + {}^{128}_{53}\mathrm{Xe} + \bar{v}$$

The complete two-step reaction is described by the two balanced equations below.

$$^{128}_{52}\mathrm{Te} \rightarrow {}^{0}_{-1}e + {}^{128}_{53}\mathrm{I} + \bar{v}$$

$$^{128}_{53}\mathrm{I} \rightarrow {}^{0}_{-1}e + {}^{128}_{54}\mathrm{Xe} + \bar{v}$$

ADDITIONAL PRACTICE

1. Standard nuclear fission reactors use $^{235}_{92}\mathrm{U}$ for fuel. However, the supply of this uranium isotope is limited. Its concentration in natural uranium-238 is low, and the cost of enrichment is high. A good alternative is the breeder reactor in which the following reaction sequence occurs: $^{238}_{92}\mathrm{U}$ captures a neutron, and the resulting isotope emits a $^{0}_{-1}e$ particle to form $^{239}_{93}\mathrm{Np}$. This nuclide emits a second $^{0}_{-1}e$ particle to form $^{239}_{94}\mathrm{Pu}$, which is fissionable

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

and can be used as an energy-producing material. Write balanced equations for each of the reactions described.

2. Radon has the highest density of any gas. Under normal conditions radon's density is about 10 kg/m^3. One of radon's isotopes undergoes two alpha decays and then one beta decay (β^-) to form $^{212}_{83}\text{Bi}$. Write the equations that correspond to these reaction steps.
3. Every element in the periodic table has isotopes, and cesium has the most: as of 1995, 37 isotopes of cesium had been identified. One of cesium's most stable isotopes undergoes beta decay (β^-) to form $^{135}_{56}\text{Ba}$. Write the equation describing this beta-decay reaction.
4. Fission is the process by which a heavy nucleus decomposes into two lighter nuclei and releases energy. Uranium-235 undergoes fission when it captures a neutron. Several neutrons are produced in addition to the two light daughter nuclei. Complete the following equations, which describe two types of uranium-235 fission reactions.

$$^{235}_{92}\text{U} + ^{1}_{0}n \rightarrow\ ^{144}_{56}\text{Ba} + ^{89}_{36}\text{Kr} + \underline{\quad}$$
$$^{235}_{92}\text{U} + ^{1}_{0}n \rightarrow\ ^{140}_{54}\text{Xe} + \underline{\quad} + 2^{1}_{0}n$$

5. The maximum safe amount of radioactive thorium-228 in the air is 2.4×10^{-19} kg/m^3, which is equivalent to about half a kilogram distributed over the entire atmosphere. One reason for this substance's high toxicity is that it undergoes alpha decay in which gamma rays are produced as well. Write the equation corresponding to this reaction.
6. The 1930s were notable years for nuclear physics. In 1931, Robert Van de Graaff built an electrostatic generator that was capable of creating the high potential differences needed to accelerate charged particles. In 1932, Ernest O. Lawrence and M. Stanley Livingston built the first cyclotron. In the same year, Ernest Cockcroft and John Walton observed one of the first artificial nuclear reactions. Complete the following equation for the nuclear reaction observed by Cockcroft and Walton.

$$^{1}_{1}p + ^{7}_{3}\text{Li} \rightarrow \underline{\quad} + ^{4}_{2}\text{He}$$

7. Among the naturally occurring elements, astatine is the least abundant, with less than 0.2 g present in Earth's entire crust. The isotope $^{217}_{85}\text{At}$ accounts for only about 5×10^{-9} g of all astatine. However, this highly radioactive isotope contributes nothing to the natural abundance of astatine because when it is created, it immediately undergoes alpha decay. Write the equation for this decay reaction.

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

Subatomic Physics

Practice Problems

NUCLEAR DECAY

PROBLEM

Bromine-80 decays by emitting a positron and a neutino. Write the complete decay formula for this process.

SOLUTION

Given: The decay can be written symbolically as follows:

$${}^{80}_{35}\text{Br} \rightarrow \text{X} + {}^{0}_{1}\text{e} + \nu$$

Unknown: the daughter element (X)

The mass numbers and atomic numbers on the two sides of the expression must be the same so that both charge and nucleon number are conserved during the course of a particular decay.

Mass number of X = 80 – 0 = 80

Atomic number of X = 35 – (1) = 34

$${}^{80}_{35}\text{Br} \rightarrow {}^{80}_{34}\text{X} + {}^{0}_{1}\text{e} + \nu$$

The periodic table (Appendix F) shows that the nucleus with an atomic number of 34 is selenium, Se. Thus, the process is as follows:

$${}^{80}_{35}\text{Br} \rightarrow {}^{80}_{34}\text{Se} + {}^{0}_{1}\text{e} + \nu$$

ADDITIONAL PRACTICE

1. Complete this radioactive-decay formula: ${}^{210}_{84}\text{Po} \rightarrow ? + {}^{4}_{2}\text{He}$
2. Complete this radioactive-decay formula: ${}^{16}_{7}\text{N} \rightarrow ? + {}^{0}_{-1}\text{e} + \overline{\nu}$
3. Complete this radioactive-decay formula: ${}^{147}_{62}\text{Sm} \rightarrow {}^{143}_{60}\text{Nd} + ?$
4. Complete this radioactive-decay formula: ${}^{19}_{10}\text{Ne} \rightarrow ? + {}^{0}_{1}\text{e} + \overline{\nu}$
5. Complete this radioactive-decay formula: $? \rightarrow {}^{131}_{54}\text{Xe} + {}^{0}_{-1}\text{e} + \overline{\nu}$
6. Complete this radioactive-decay formula: $? \rightarrow {}^{90}_{39}\text{Y} + {}^{0}_{-1}\text{e} + \overline{\nu}$
7. Complete this radioactive-decay formula: ${}^{160}_{74}\text{W} \rightarrow {}^{156}_{72}\text{Hf} + ?$
8. Complete this radioactive-decay formula: $? \rightarrow {}^{107}_{52}\text{Te} + {}^{4}_{2}\text{He}$
9. Complete this radioactive-decay formula: ${}^{157}_{72}\text{Hf} \rightarrow {}^{153}_{70}\text{Yb} + ?$
10. Complete this radioactive-decay formula: ${}^{141}_{58}\text{Ce} \rightarrow ? + {}^{0}_{-1}\text{e} + \overline{\nu}$

Lesson Contributed by: David Flickinger
Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

Subatomic Physics

Practice Problems

BINDING ENERGY

Use these values to solve the following problems:

Mass of hydrogen **-** $\boldsymbol{1.007825\ u}$

Mass of neutraon **-** $\boldsymbol{1.008665\ u}$

$\boldsymbol{1\ u = 931.49\ MeV}$

1. The carbon isotope ${}^{12}_{6}C$ has a mass of 12.000000 u.
    a. Calculate its mass defect.

    b. Calculate its binding energy.

2. Deuterium (${}^{2}_{1}H$) has a mass of 2.014102 u.
    a. Calculate its mass defect.

    b. Calculate its binding energy.

3. The nitrogen isotope ${}^{15}_{7}N$ has a mass defect of -0.113986 u.
    a. Calculate the mass of this isotope.

    b. Calculate the binding energy of the nucleus.

Lesson Contributed by: David Flickinger
Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

Nuclear Physics Quiz

Name: ______________________________ Date: ________________________

Part A: *Multiple Choice*. Fill in the blank with the best answer from the four choices listed in each test item. [3 points each]

_____ 1. An atom's atomic number refers to the
- a) number of neutrons in a neutral atom.
- b) number of protons in a neutral atom.
- c) half the atom's atomic mass.
- d) number of isotopes of the atom.

_____ 2. Which of the following types of radioactive decay occurs when a neutron is changed to a proton within the nucleus?
- a) alpha decay
- b) beta decay
- c) gamma decay
- d) both ***a*** and ***b***

_____ 3. The mass number of an atom is equal to
- a) the sum of its protons and electrons.
- b) twice its number of neutrons.
- c) half its atomic number.
- d) the sum of its protons and neutrons.

_____ 4. The number of decays per second in a sample of radioactive material is its
- a) half-life.
- b) activity.
- c) gamma decay.
- d) lepton.

_____ 5. The time required for half the atoms in any given quantity of a radioactive isotope to decay is the __________ of that element.
- a) half-life
- b) activity
- c) ionization rate
- d) weak interaction

_____ 6. What is required to balance the following nuclear equation?

Lesson Contributed by: David Flickinger
Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

$$^{4}_{2}He + ^{9}_{4}Be \rightarrow \_\_\_\_\_\_ + ^{1}_{0}n$$

a) $^{6}_{12}C$
b) $^{12}_{6}C$
c) $^{14}_{6}C$
d) $^{8}_{14}C$

_____ 7. During alpha decay, a(n) __________ is ejected from the nucleus.
a) helium atom
b) hydrogen atom
c) hydrogen nucleus
d) helium nucleus

_____ 8. Which of the following is a type of particle accelerator?
a) Geiger-Mueller tube
b) Wilson cloud chamber
c) synchrotron
d) all of the above

_____ 9. Physicists believe that quarks make up.
a) neutrons and electrons
b) neutrinos and neutrons
c) protons and electrons
d) protons and neutrons

_____ 10. All isotopes of an element have
a) different numbers of protons
b) the same number of neutrons
c) the same number of protons
d) different numbers of electrons

Part B: **Problems and Diagrams.** Solve each of the following problems using the given information. Show your work and place a box around your final answer. If a diagram is given, label each of the parts requested.

11. A radium atom, $^{224}_{88}Ra$, decays to radon, *Rn*, by emitting an alpha particle. Write a nuclear equation for this transmutation. [5 points]

$$^{224}_{88}Ra \rightarrow$$

12. An atom of plutonium, $^{243}_{94}Pu$, emits a beta particle and an antineutrino when its nucleus decays to americium, *Am*. (beta decay) Write a nuclear equation for this transmutation. [5 points]

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

$^{243}_{94}Pu \rightarrow$

13. A uranium atom, $^{238}_{92}U$, decays to thorium, *Th*, by emitting an alpha particle. Write a nuclear equation for this transmutation. [5 points]

$^{238}_{92}U \rightarrow$

14. The Carbon isotope, $^{12}_{6}C$, has a nuclear mass of 12.000000u. [5 points] [$p_{mass} = 1.007825u \quad n_{mass} = 1.008665u \quad 1u = 931.49\,MeV$]

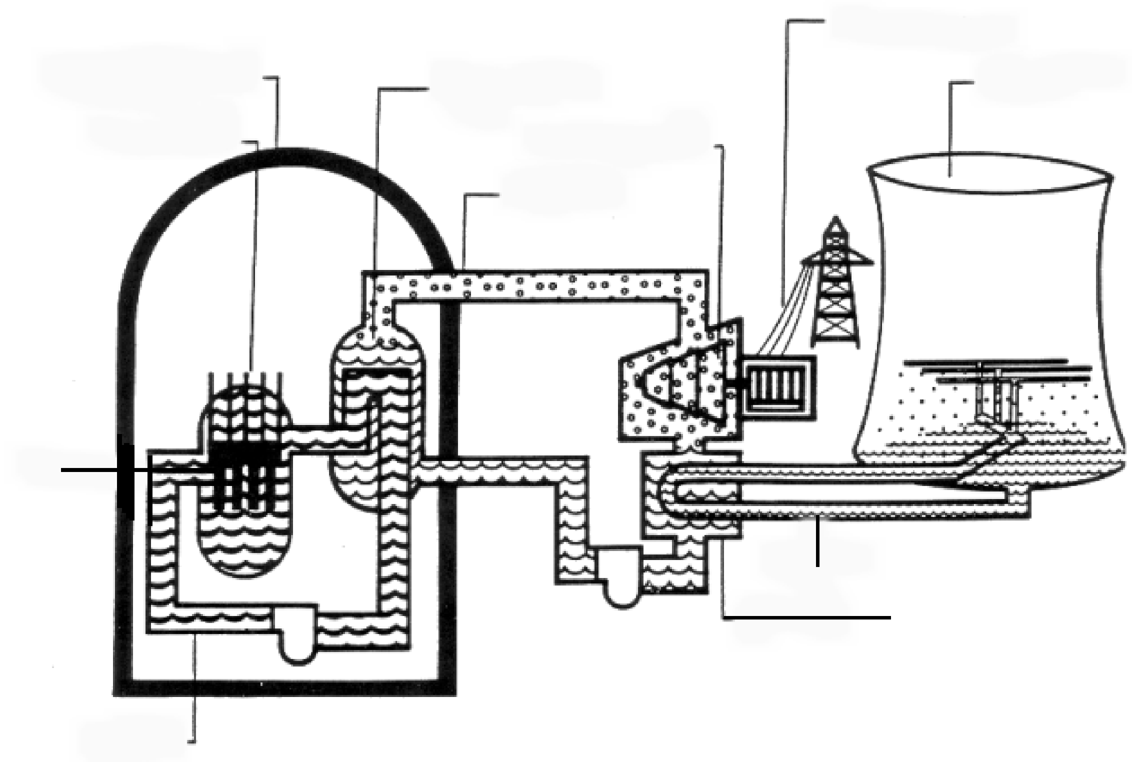
a) What is the mass defect of this isotope?

b) What is the binding energy of its nucleus? (in *MeV*)

15. **Label** the parts of a Nuclear Fission Reactor. Make sure to include the following labels: {containment building, control rods, first loop, second loop, nuclear fuel, steam generator, condenser, transmission lines, turbine-generator, cooling tower, third (cooling) loop} (22 points)

Lesson Contributed by: David Flickinger
Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

PWR Nuclear Power Plant



Pressurized Water Reactor

Part C: ***Questions***. Answer each of the following questions using complete sentences. Limit each answer to two or three sentences.

16. What element do nuclear fuel rods in a nuclear fission reactor contain, and what are their function? [7 points]

____

____

____

17. Describe the operation (how they move) and purpose of the control rods in a nuclear fission reactor. [7 points]

____

Lesson Contributed by: David Flickinger
Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

____

____

18. Describe the importance of a moderator in a nuclear fission reactor and list one of the two substances used for this purpose in reactors. [7 points]

____

____

____

19. Describe the importance of a cooling loop in a nuclear fission reactor and list one of the sources of cool water discussed in class. [7 points]

____

____

____

Extra Credit [5 point bonus]

The half-life of $^{52}_{25}Mn$ is 5.6 days. What was the original mass of $^{52}_{25}Mn$ if after 50.4 days 1.20 g are found?

Funded through 2013 State Council of Higher Education for Virginia (SCHEV) grant, Creativity & Innovation in STEM (CI STEM)

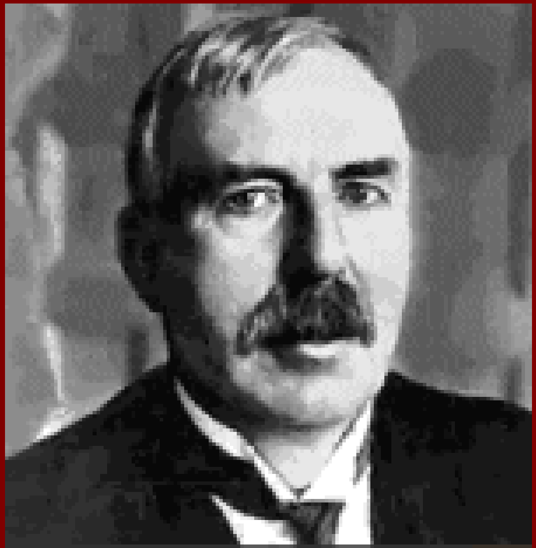
Atomic and Subatomic Physics

Chapter 21 & 22

Lesson 1: Views of the Atom

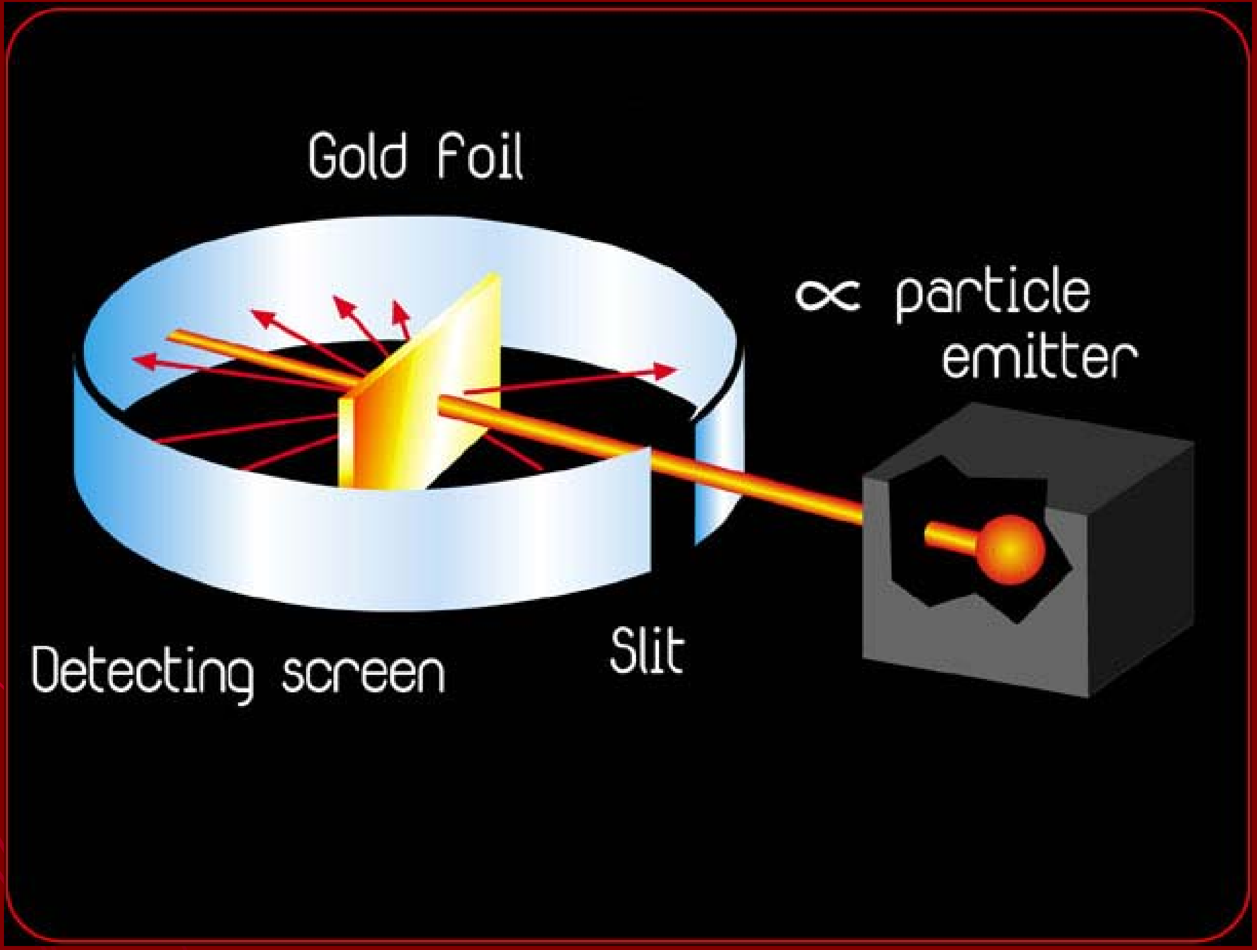
- J. J. Thomson believed that protons and electrons were distributed evenly throughout the atom – The Plum Pudding model (kind of like raisins in a muffin)

- Ernest Rutherford performed a series of experiments that showed the structure was very different.



Rutherford's Gold Foil Experiment

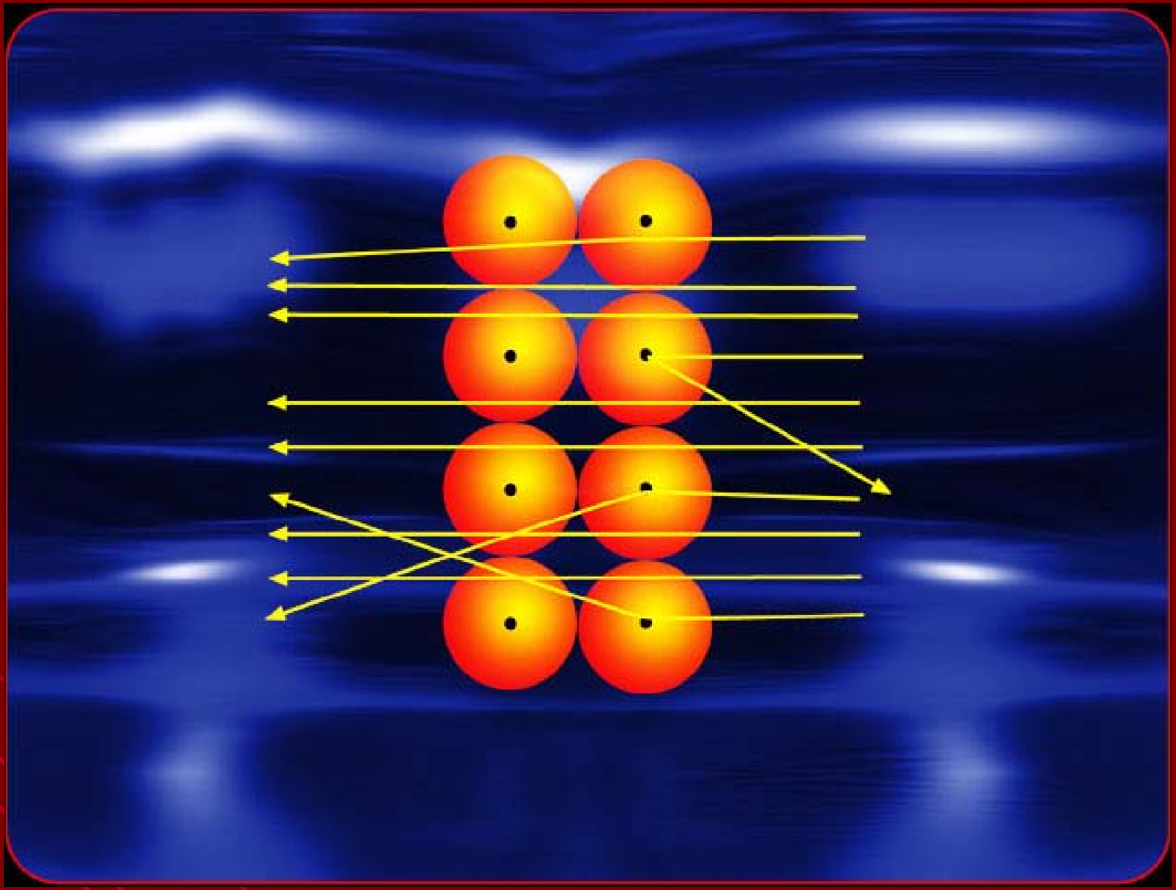
- Massive, positively charged penetrating particles (later named α particles) were supplied by uranium and directed toward a thin gold foil target



http://www.rsc.org/chemsoc/timeline//pages/1911.html

Gold Foil Experiment Details

- The particles made a screen coated with zinc sulfide flash with a little burst of light (called scintillation) each time a particle collided with it.
- Most of the beam of α particles passed right through the gold foil and hit the screen behind it, but some were deflected to the side.
- More unbelievably, some α particles were reflected BACKWARDS!!



- Rutherford was amazed and compared the probability of it happening to firing a 15 inch cannon shell at a piece of paper and having it bounce back!

Gold Foil Experiment continued . . .

- Using Coulomb's Law and Newton's Laws of motion, Rutherford determined that the only way it was possible was if all the positive charge were concentrated in the center of an atom which he called the ***nucleus***.
- The ***nuclear model*** of the atom was born.

Niels Bohr

- Bohr was a Danish physicist who went to England in 1911 to join Rutherford's team in trying to develop an understanding of the structure of the atom.
- He determined that Einstein's photoelectric effect theory applied to atoms and that electrons orbited in discrete energy levels.

The Nucleus

- Rutherford discovered the nucleus in 1911 using the gold foil experiment
- Around 1921 the name "proton" was given to these positively charged subatomic particles.
- In 1932 James Chadwick discovered that there was a neutral particle of about the same mass as the proton in the nucleus.
- This particle was named the neutron and accounted for the missing mass in the nucleus without increasing the charge.

Symbols

- ***u*** represents one *atomic mass unit*
- 1 ***u*** is 1.66 X 10^{-27} kg in mass
- ***Z*** stands for the number of protons in the nucleus or the ***atomic number***
- ***A*** stands for the number of protons and neutrons in the nucleus and is called the ***mass number***

Notation Guidelines

$${}^{A}_{Z}\mathit{Atomic\ Symbol}$$

$${}^{4}_{2}He$$

Helium with 2 protons and 2 neutrons

Strong Nuclear Force

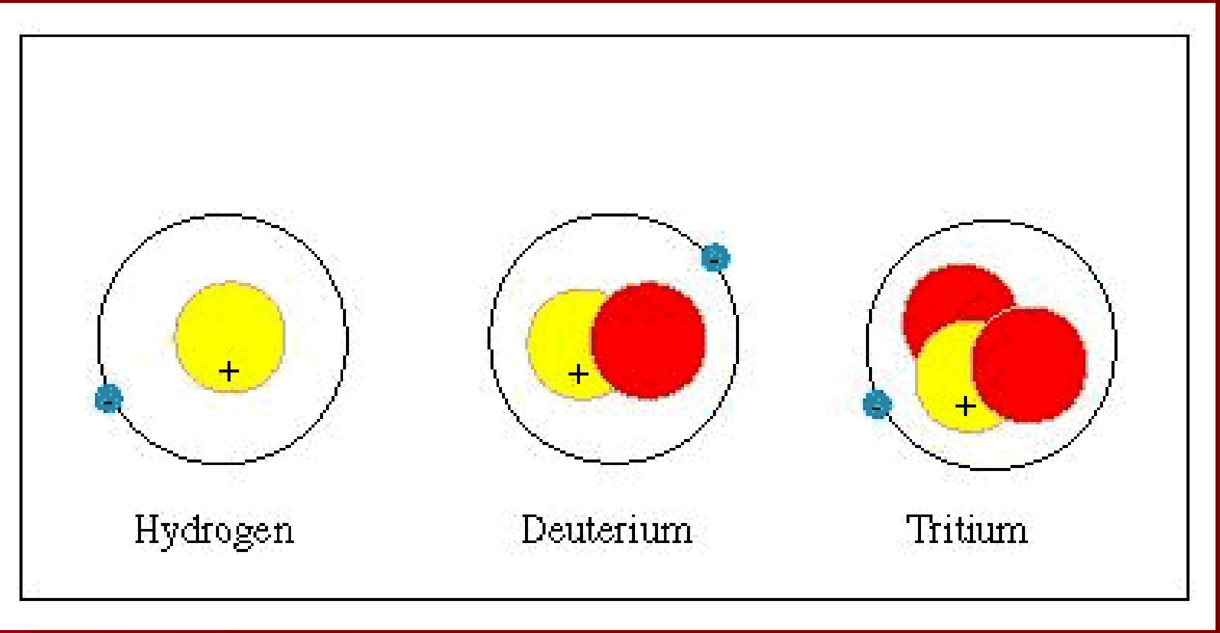
- Protons are naturally positive and should provide a repulsive force
- An attractive ***Strong Nuclear Force*** is exerted by one proton on any other protons or neutrons near it. This force is stronger than the electrostatic force repelling them from one another.
- Therefore the nucleus is held together.

Isotopes

- Isotopes have the same number of protons in the nucleus, but different numbers of neutrons.
- The different nuclei of these isotopes are called ***nuclides***.
- There are special isotopes of hydrogen that have special names.

Isotopes of Hydrogen

- Hydrogen – 1 proton
- Deuterium – 1 proton, 1 neutron
- Tritium – 1 proton, 2 neutron



Radioactive Decay

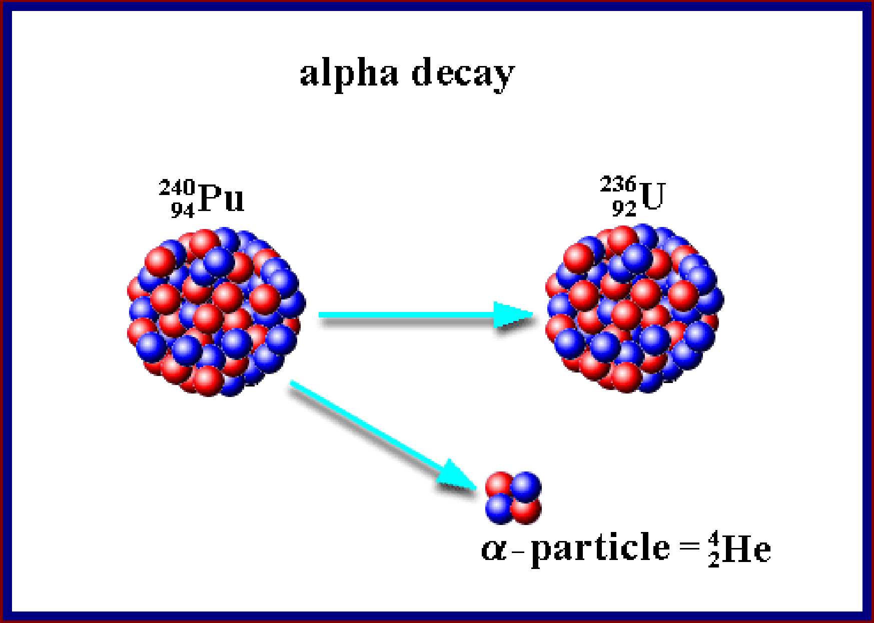
- In 1896 Henri Becquerel was working with uranium compounds and stored samples near covered photographic plates.
- He noticed that they became fogged even though the covers had never been removed.
- This fogging suggested that some kind of ray had passed through the plates and exposed the film.

Radioactive

- Materials that emit this kind of radiation are called ***radioactive***.
- In 1899, Rutherford discovered that uranium compounds produce three (3) different types of radiation.
- He named them according to their penetrating ability
  - α (alpha) – stopped by a thick sheet of paper
  - β (beta) – stopped by 6 mm of aluminum
  - γ (gamma) – stopped by several cm of lead

Alpha Decay – The emission of an Alpha Particle

$$^{240}_{94}Pu \rightarrow ^{236}_{92}U + ^{4}_{2}He$$



- An alpha particle is a helium nucleus with 2 protons and 2 neutrons.
- Alpha particles must come from an atom's nucleus, so the nucleus of the original element will have a new mass and therefore become a new element.
- When an element is changed it is said to have been ***transmuted*** to a new element.

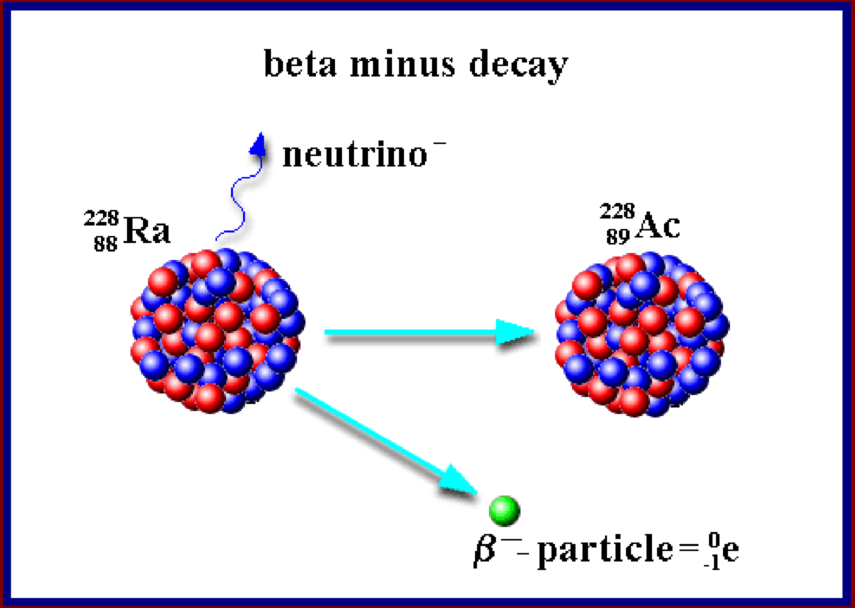
Alpha Decay Problem

- Uranium (U) 238 experiences the alpha decay process and decays to thorium (Th). Show the chemical formula.

$$ {}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He $$

Beta Decay – The emission of a Beta Particle

$$^{228}_{88}Ra \rightarrow {}^{228}_{89}Ac + {}^{0}_{-1}e + {}^{0}_{0}\overline{v}$$



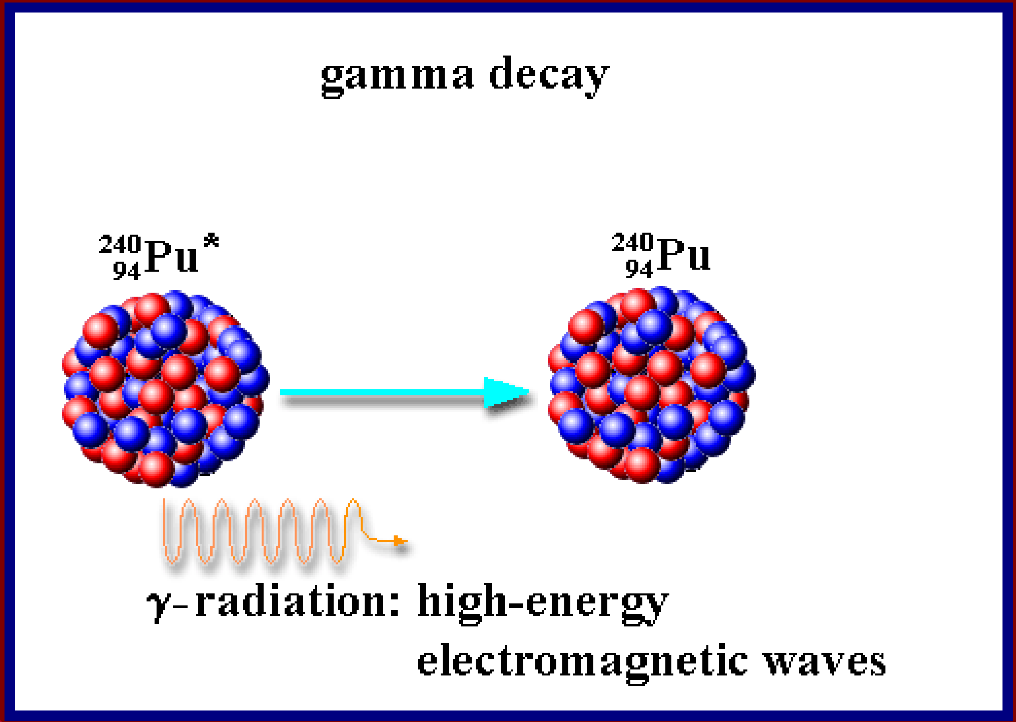
- A beta particle is high energy electron.
- Beta Decay occurs when a *neutron* is changed into a *proton* within the nucleus resulting in a transmutation of the atom.
- A high energy *electron* and an *antineutrino* are ejected from the nucleus during this decay process.

Beta Decay Problem

- Thorium (Th) 234 experiences the beta decay process and decays to protactinium (Pa). Show the chemical formula.

$$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e + {}^{0}_{0}\overline{v}$$

Gamma Decay – The emission of a Gamma Particle

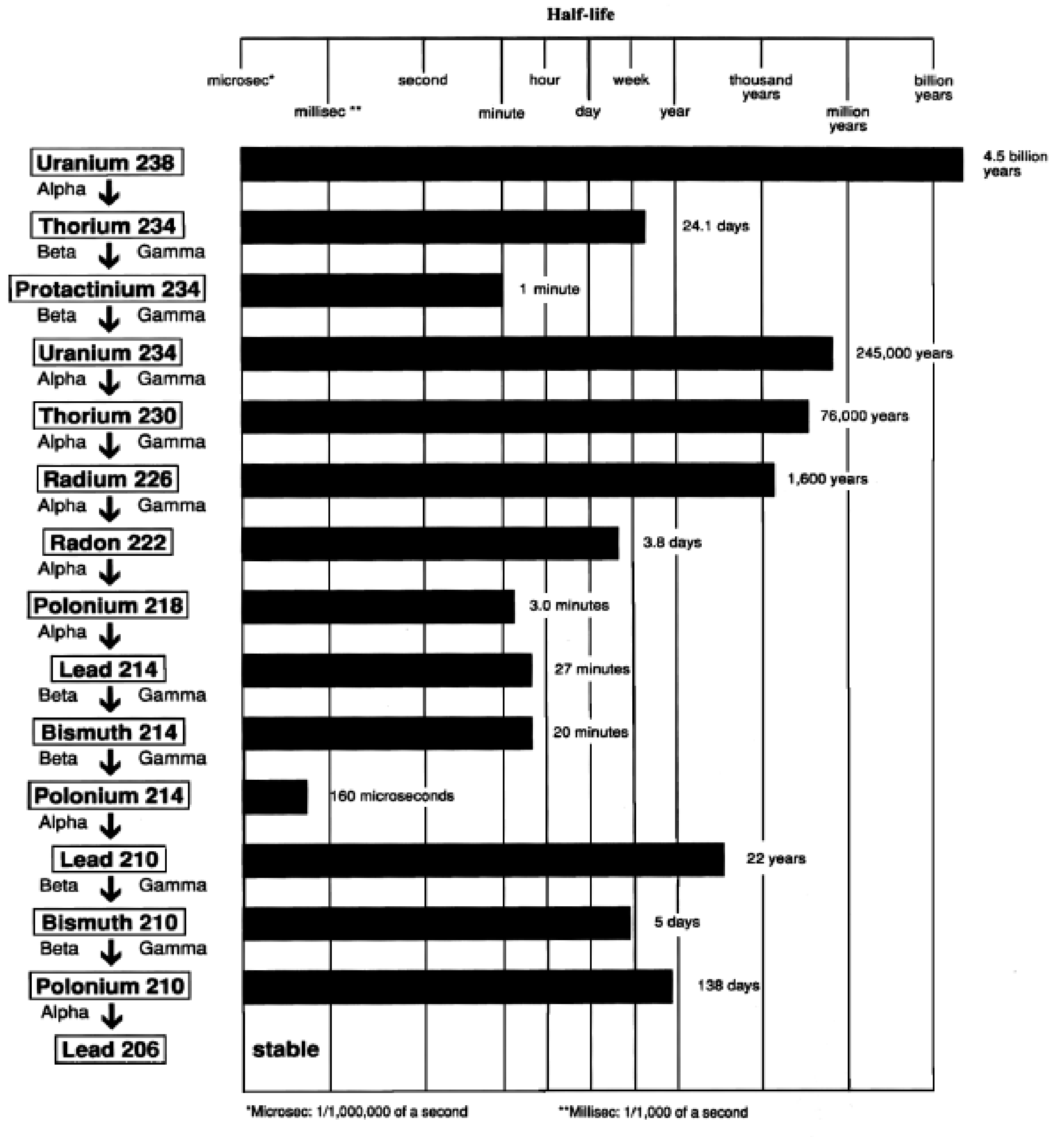


- A gamma particle is a photon.
- The mass and charge of the nucleus do not change, but gamma decay often accompanies α and β decay.

Half-Life

- The time required for half of the atoms in a given quantity of atoms in a radioactive isotope to decay is called the half-life of that element.
- For example, the half-life of radium 226 is 1600 years. That means in 1600 years, half of the given quantity of radium will have decayed into another element.
- After another 1600 years (3200 years total) half of the remaining sample will have decayed leaving only one quarter of the original sample in radium form.

Uranium Decay Series



Half-Life of Selected Isotopes

Element	Isotope	Half-Life	Radiation Produced
Carbon	${}^{14}_{6}C$	5730 years	β
Uranium	${}^{235}_{92}U$	7.1X10^{8} yrs	α, γ
Uranium	${}^{238}_{92}U$	4.51X10^{9} yrs	α, γ
Plutonium	${}^{236}_{94}Pu$	2.85 years	α
Plutonium	${}^{242}_{94}Pu$	3.79X10^{5} yrs	α, γ

Activity

- The decay rate, or the number of decays per second, of a radioactive substance is called its activity.
- After one half-life, the activity is reduced by one half since there are only one half the atoms available to decay.

Assignment

- Nuclear Decay practice worksheet
  - Be sure to reference an Element Chart to assist you.

Nuclear Bombardment

- Rutherford bombarded many atoms with alpha particles. When he hit nitrogen nuclei with α particles he found a proton was emitted. What was the nitrogen changed into?

$$ {}^{4}_{2}He + {}^{14}_{7}N \rightarrow {}^{1}_{1}H + {}^{A}_{Z}X $$

$$ {}^{4}_{2}He + {}^{14}_{7}N \rightarrow {}^{1}_{1}H + {}^{17}_{8}O $$

- Oxygen was created by introducing an α particle into the nitrogen nucleus!

Nuclear Bombardment

- James Chadwick in 1932 bombarded beryllium with an alpha particle and noticed that the particle emitted from that nucleus was uncharged. What was the beryllium changed into?

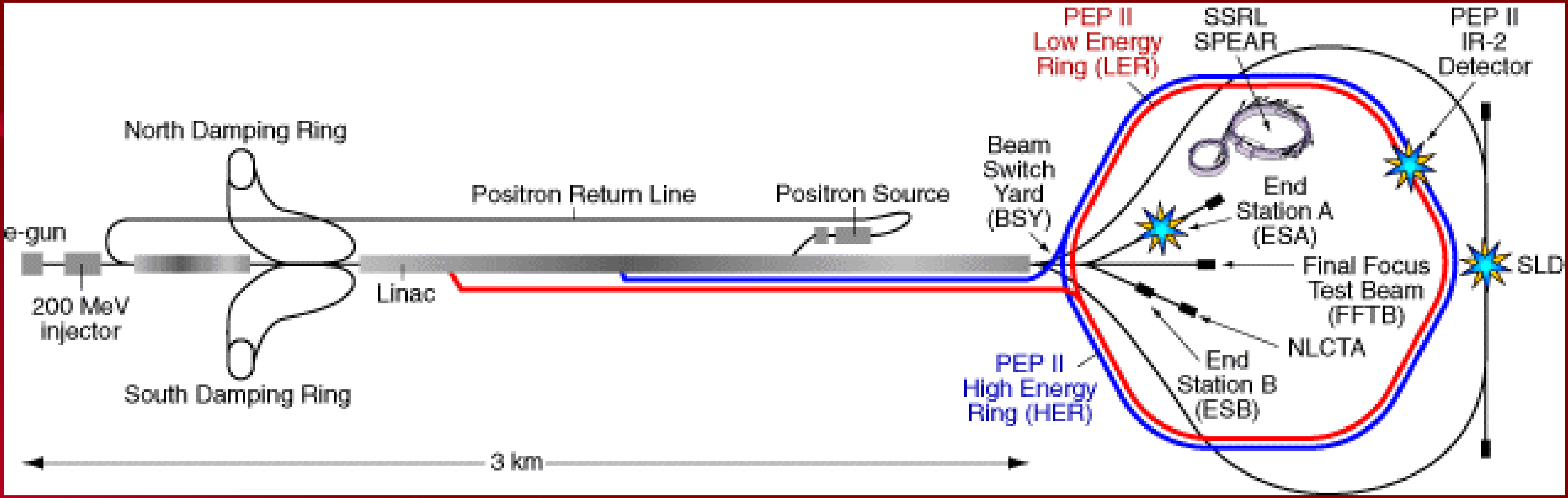
$$ {}^{4}_{2}He + {}^{9}_{4}Be \rightarrow {}^{1}_{0}n + {}^{A}_{Z}X $$

$$ {}^{4}_{2}He + {}^{9}_{4}Be \rightarrow {}^{1}_{0}n + {}^{12}_{6}C $$

- Carbon was created by introducing an α particle into the beryllium nucleus!

Linear Accelerators

- Stanford has a 3.3 km linear accelerator operated by SLAC (Stanford Linear Accelerator Center) and the US Dept. of Energy.



http://www.slac.stanford.edu/

SLAC Construction

The concrete floor, walls, and roof to the accelerator tunnel progressed along the two mile cut, in an ongoing concrete pouring process.

Construction began in 1962 and research began in 1966.

http://www.slac.stanford.edu/history/highlights.shtml

The Synchrotron

- Taking linear accelerator ideas and curving the magnets into a circular shape allows continuous acceleration of charged particles.
- The patterns found in a bubble chamber follow patterns that can help determine what type of particle is ejected from the struck nucleus.

Elementary Particles

- In the 1930s the elementary particles were the proton, neutron, electron and gamma ray.
- Physicists now believe all elementary particles can be grouped into families labeled:
  - Quarks
  - Leptons
  - & Force Carriers

Quarks

- Make up protons, neutrons and mesons.
- There are 6 types of quarks
  - Up
  - Down
  - Top
  - Bottom
  - Charm
  - Strange

Quarks

- Up quark
  - +2/3 charge
- Down quark
  - -1/3 charge
- Proton
  - uud
- Neutron
  - udd

Weak Nuclear Force

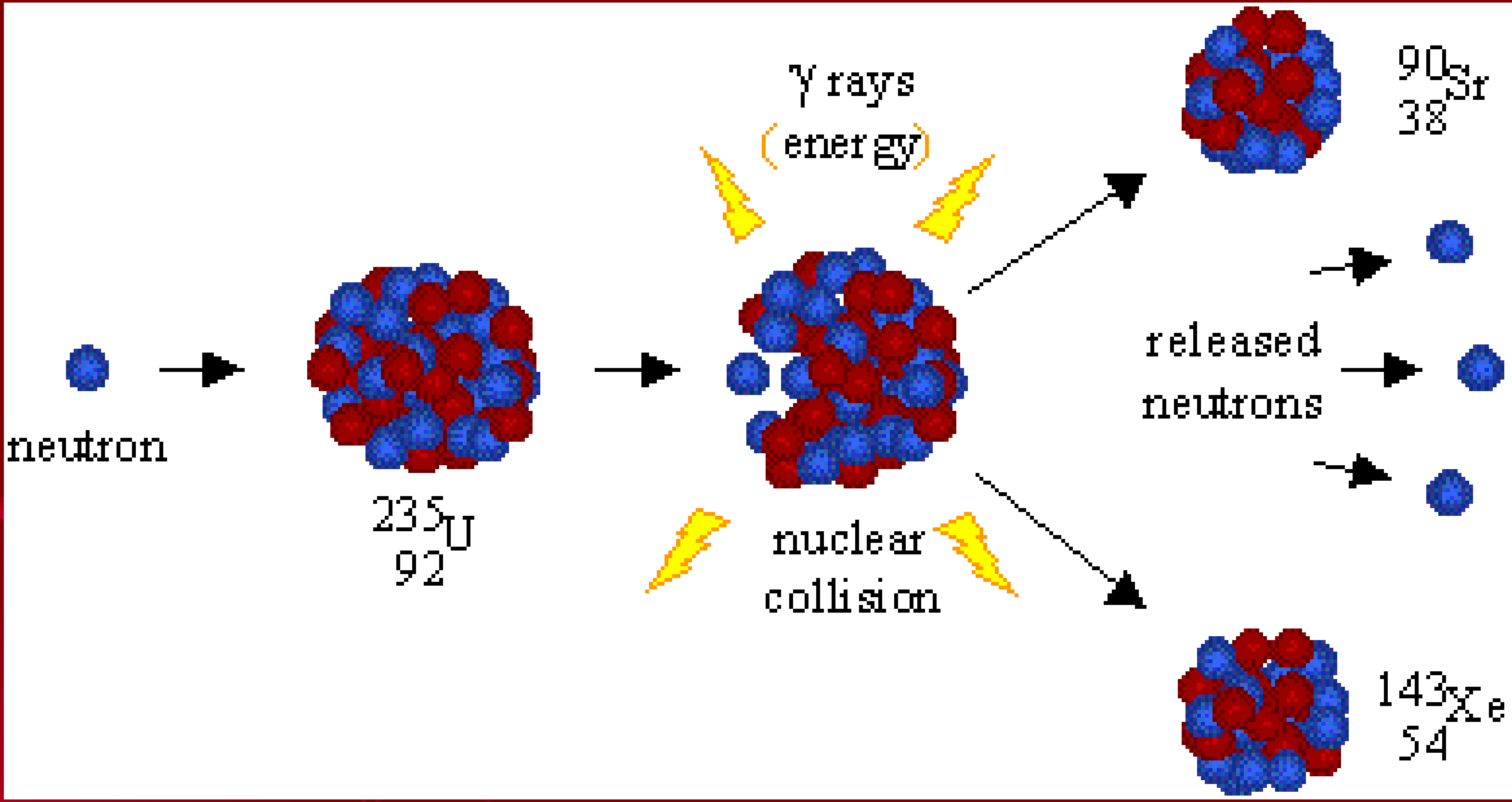
- Causes the neutron to decay into a proton and an electron while also emitting an antineutrino.

Lesson 2: Nuclear Fission

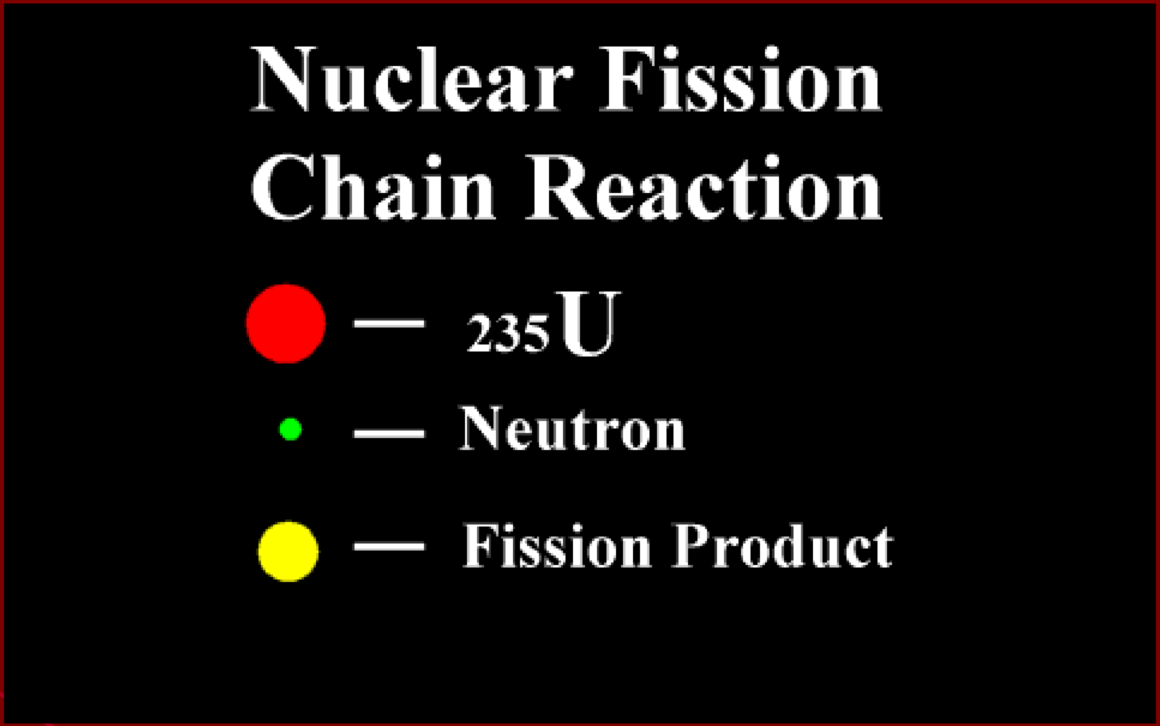
- Uranium 235 is unstable. It can be induced to split by introducing a free neutron.
- To fission means to split.
- U235 fissions into

- 235U + 1 neutron ➔ 2 neutrons + 92Kr + 142Ba + ENERGY
- 235U + 1 neutron ➔ 3 neutrons + 90Sr + 143Xe + ENERGY

Fission Diagram



Chain Reaction



- Nuclear Fission is a sustainable reaction only if you have enough U235 available to continue the process.
- U235 must be enriched since there is not sufficient concentrations of U235 available in nature.
  - Natural concentration is about 0.7 % U235, 99.3% U238
  - Reactors require 2-3% U235
  - Weapons grade is 95-97% U235

Practice Problem

- Tritium = 3.016049 u
- Proton = 1.007825 u
- Neutron = 1.008665 u

Mass Defect =

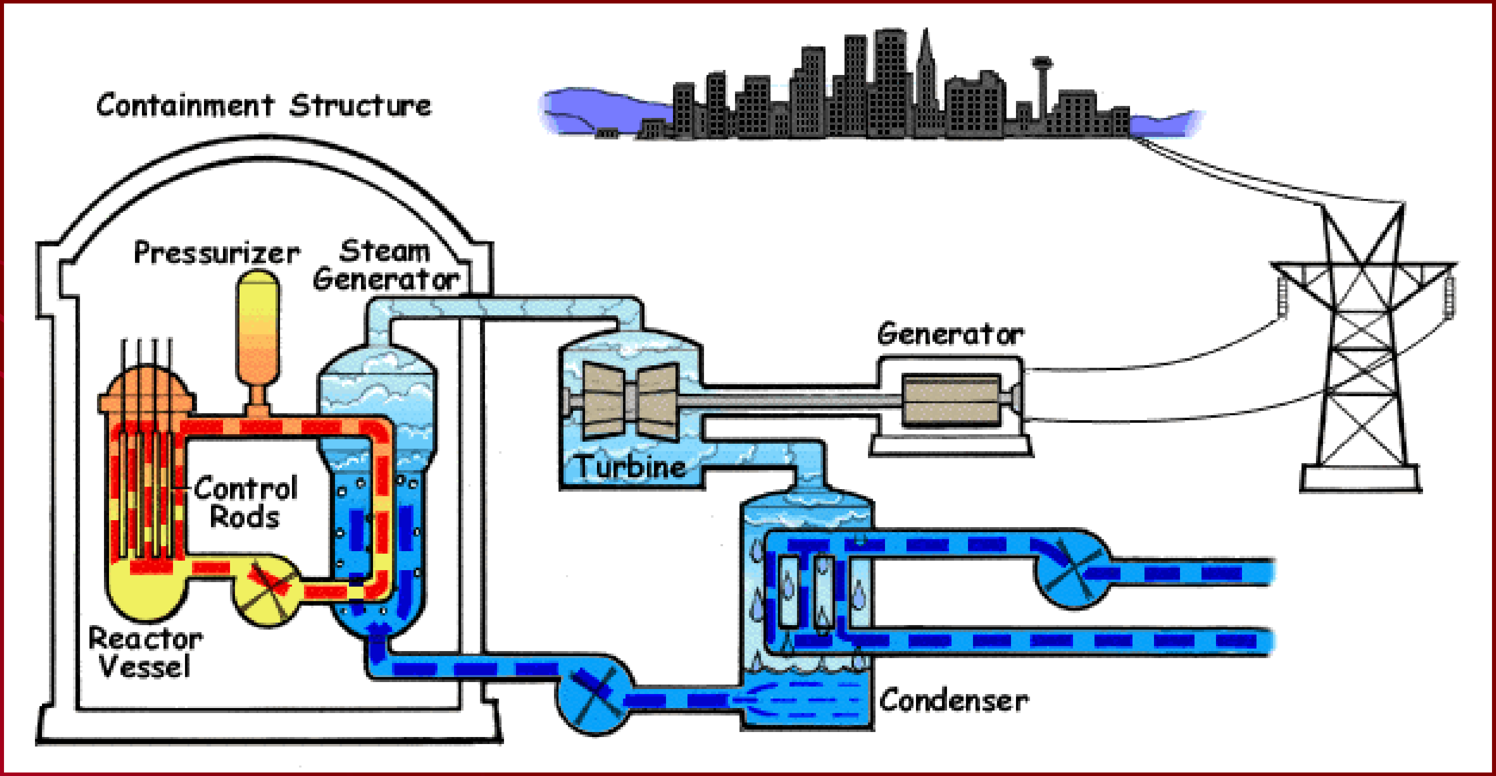
Binding Energy =

Assignment

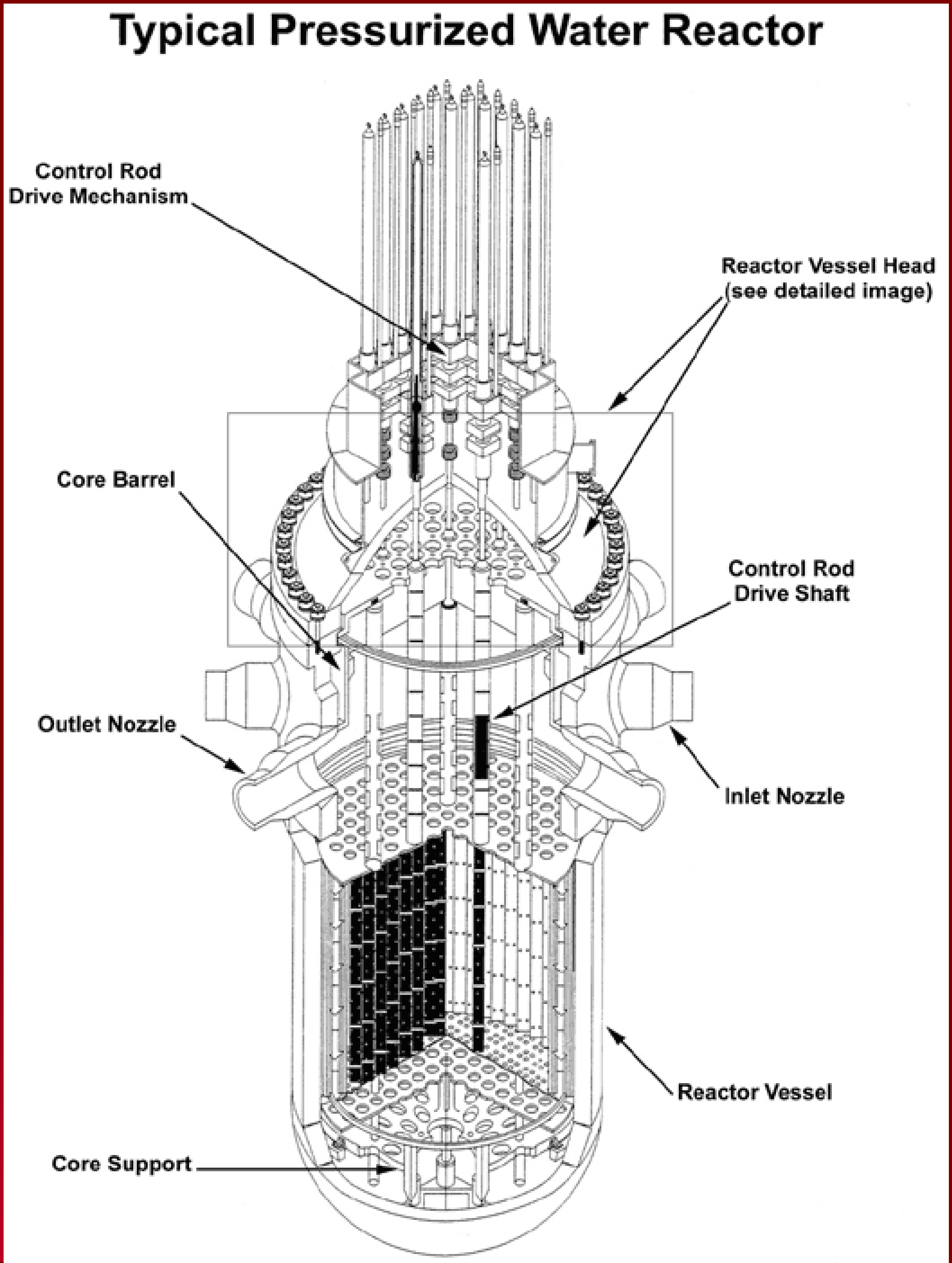
- Binding Energy worksheet

Lesson 3: Pressurized Water Reactor (PWR)

- 3 distinct loops of water keep water that is directly in contact with radioactivity inside the containment structure.



Inside the Reactor Vessel



- Fuel Rods – contain uranium fuel pellets
- Control Rods – cadmium rods to absorb free neutrons

Power Plant Parts

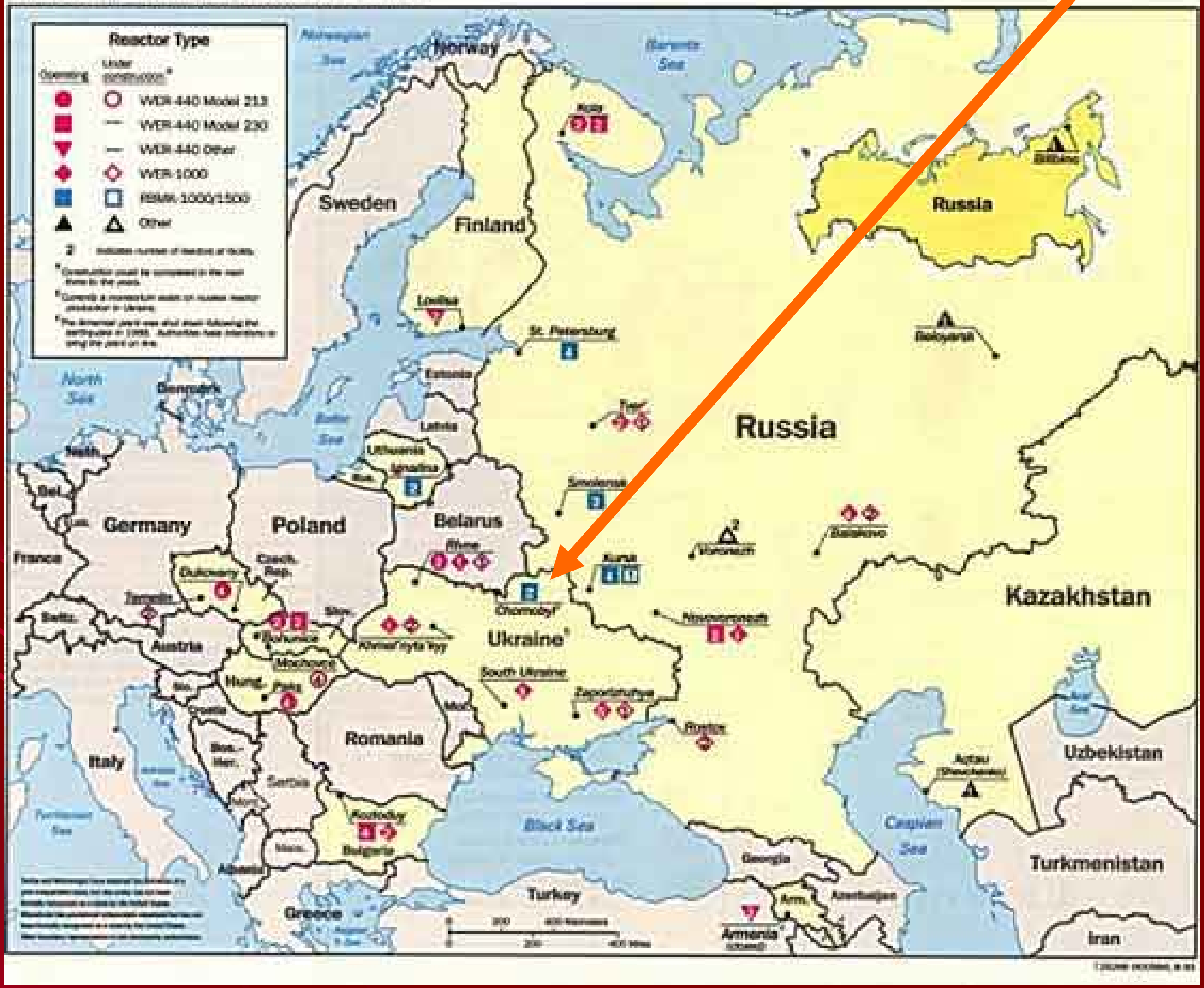
- ***Moderator*** – water or graphite to slow down free neutrons to encourage fission
- ***Reactor*** – contains fuel and control rods
- ***Fuel Rods*** – Metal tubes containing pellets of enriched Uranium 235
- ***Control Rods*** – Cadmium rods lowered into the core to absorb free neutrons and slow the chain reaction
- ***Containment Building*** – 3-5 feet of solid concrete to safely contain radioactive material

Power Plant Parts

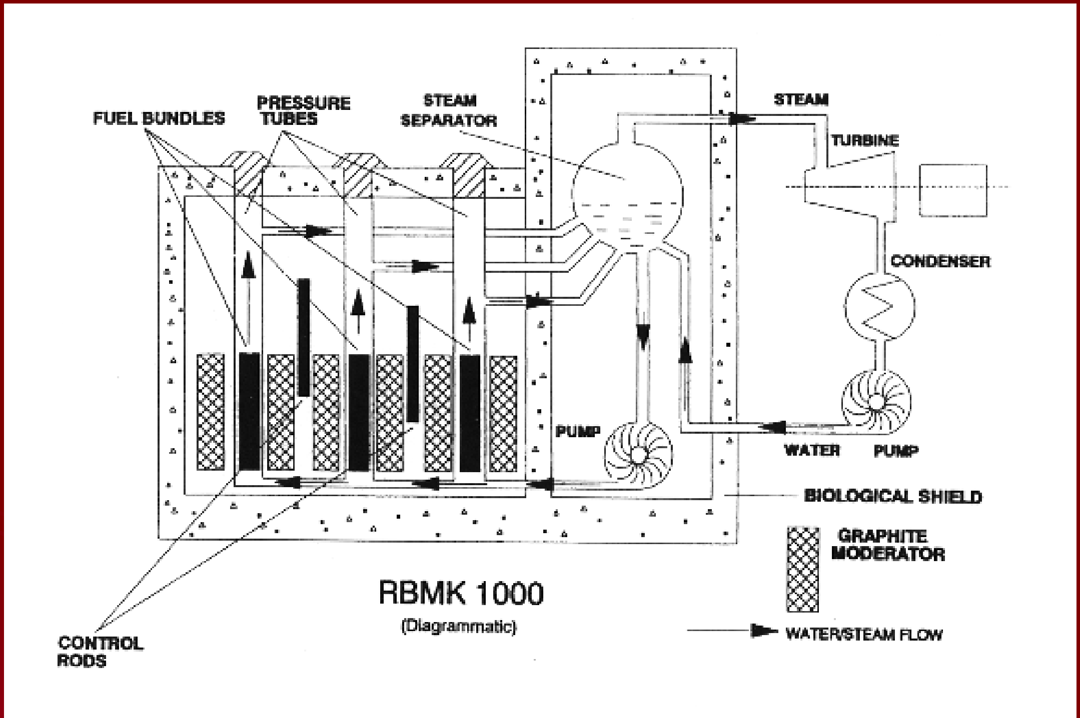
- ***Steam Generator*** – pressurized water flows through pipes at high temperature and makes steam in the 2nd loop
- ***Turbine Generator*** – turns to generate electricity for use by power company
- ***Condenser*** – steam condenses on cool pipes to return to water state to be used again in the steam generator
- ***Cooling Tower or River*** – Source of cool water for the condenser.

Chernobyl Location

Figure 31 Soviet-Designed Nuclear Power Plants



Chernobyl Accident

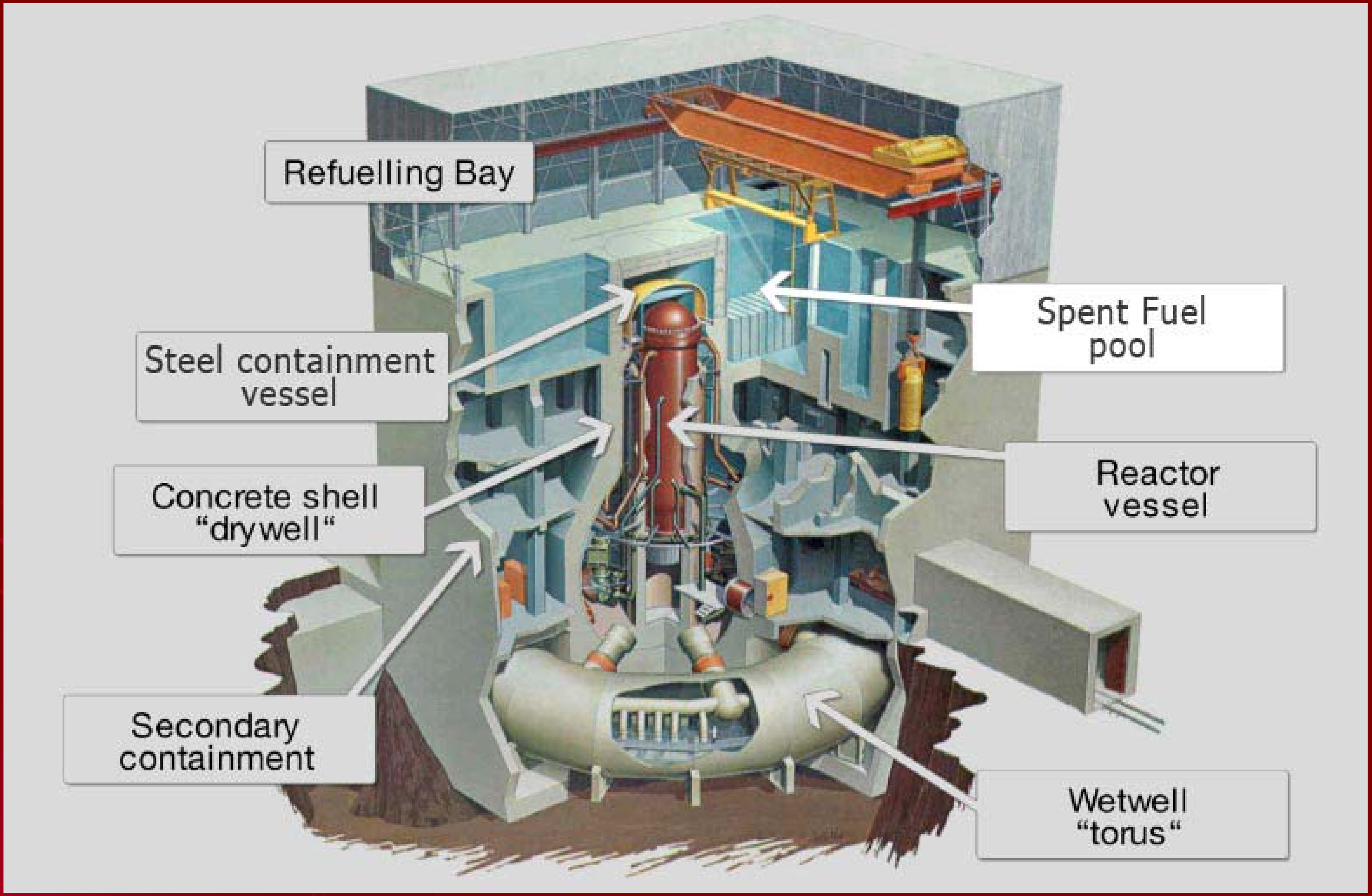


http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fschernobyl.html

Fukushima Daiichi

Units #
1, 2, 3,
& 4

Unit Diagram



Check This Out!

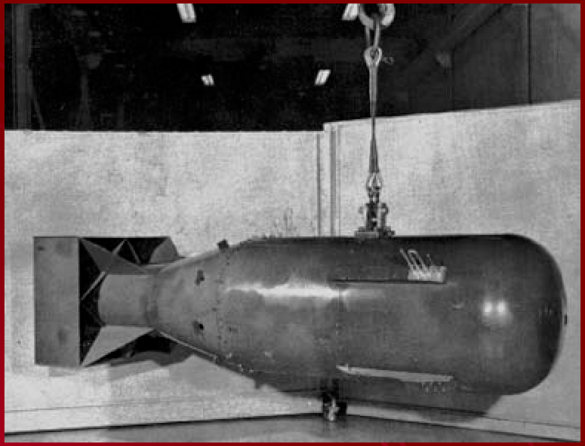
- http://www.pbs.org/wgbh/pages/frontline/japans-nuclear-meltdown/

Fission Bombs

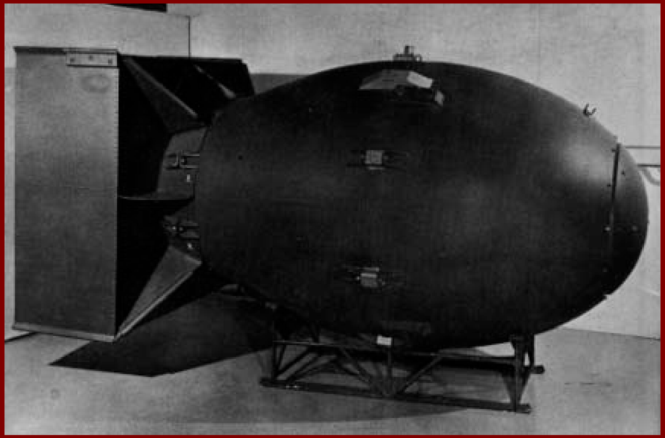
- These bombs were dropped on Japan to end World War II.

Click for more info . . .

Little Boy



Fat Man



http://science.howstuffworks.com/nuclear-bomb3.htm

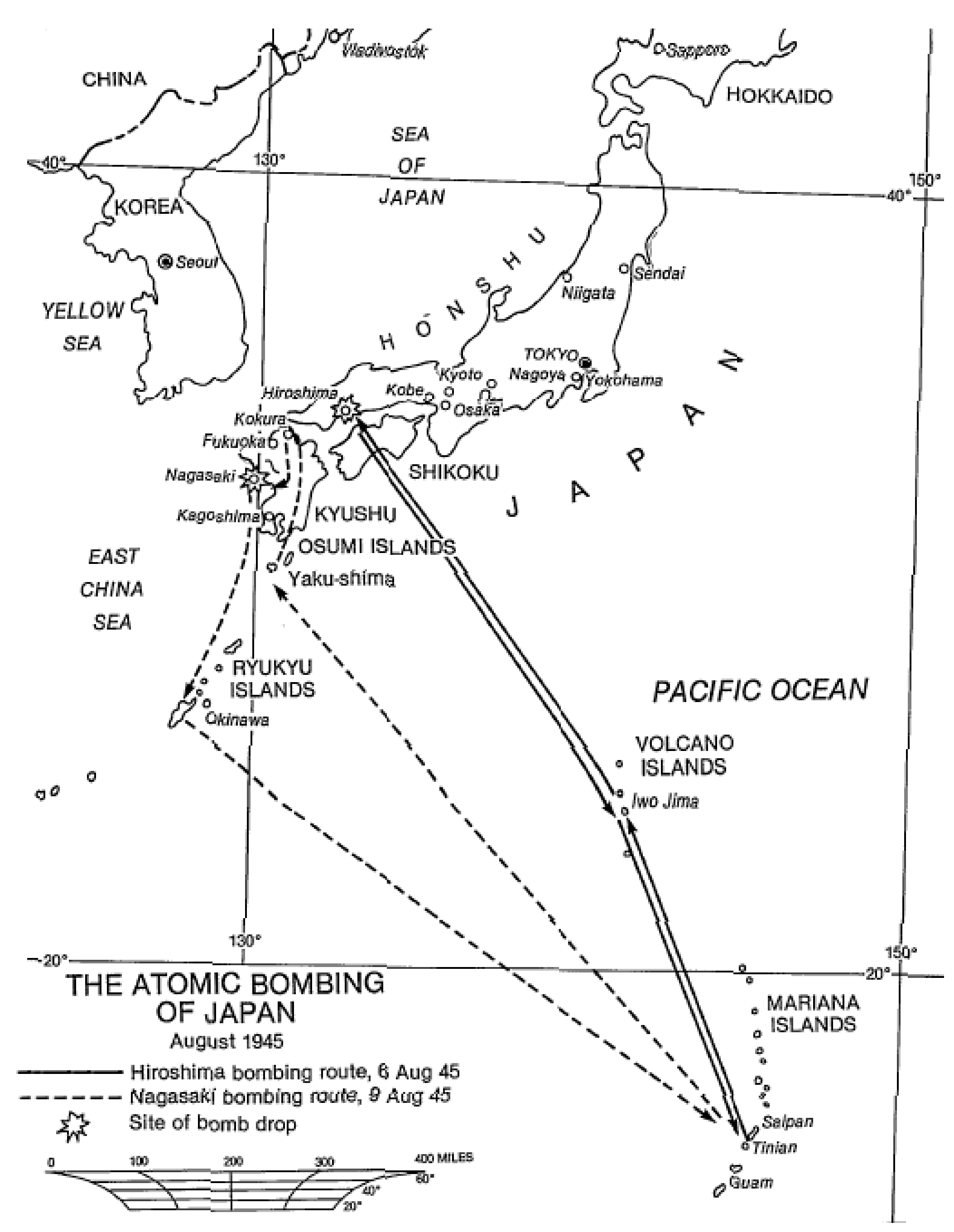
The *Enola Gay*

- Lt. Col. Paul Tibbets commanded the mission to drop *Little Boy* on Hiroshima.
- The bombadier, Thomas Ferebee, took control of plane and dropped the bomb on 6 August 1945 at about 0915 local time.
- *Little Boy* had a15-16 kiloton yield (this means the explosion is the equivalent of 15,000-16,000 tons of TNT).

The *Enola Gay* returning from the bombing mission against Hiroshima.

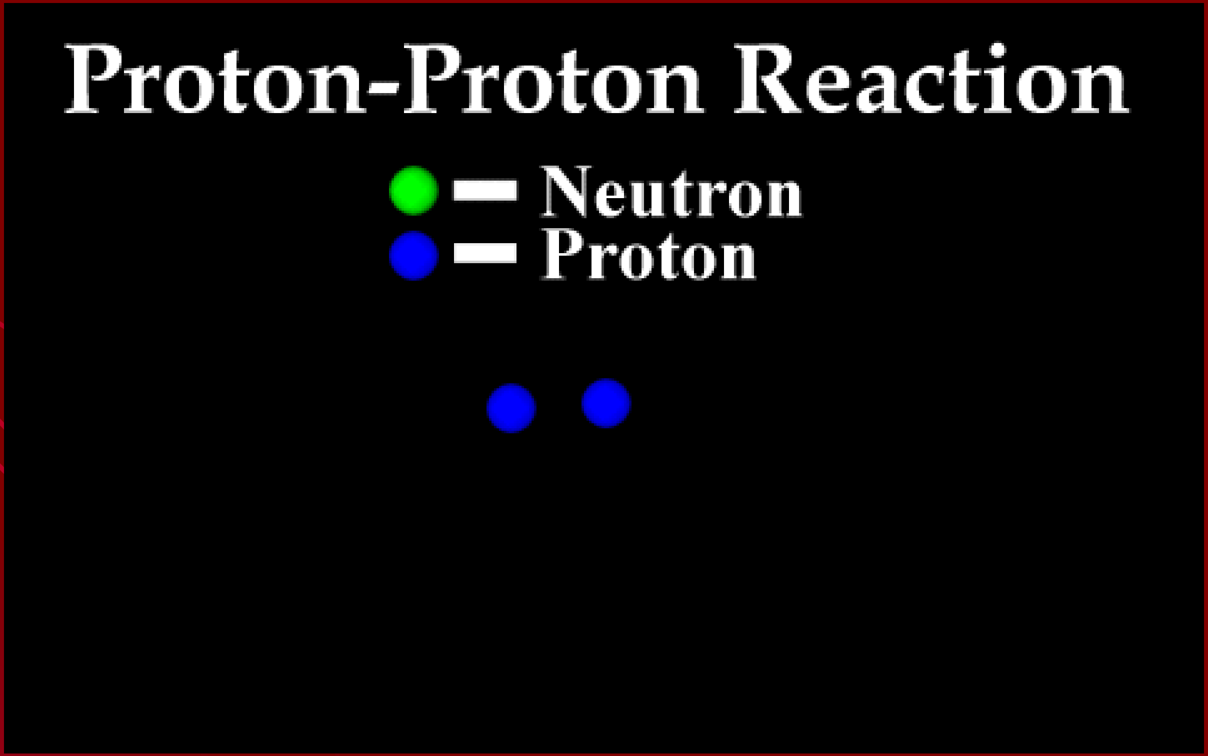
The *Bock's Car*

- Maj. Charles W. Sweeney commanded the mission to drop *Fat Man* on Kokura .
- Weather obstructed the view of the target city of Kokura and a decision was made to drop the bomb on the secondary target at Nagasaki.
- *Fat Man* had approximately a 23 kiloton yield (this means the explosion is the equivalent of 23,000 tons of TNT).
- The day after the attack on Nagasaki, the emperor of Japan overruled the military leaders of Japan and forced them to offer to surrender

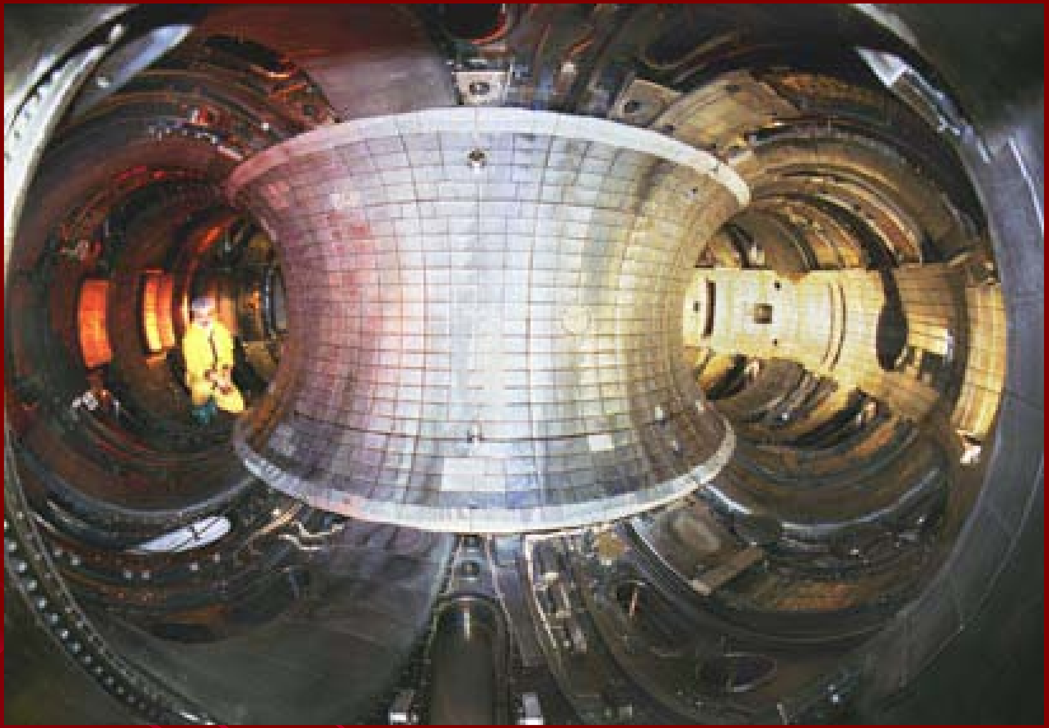


Fusion

- Nuclear fusion means to put nuclei together.
- Small nuclei are necessary to achieve fusion.



Tokomak Reactor



- One is located at Princeton University and operated by the university and the Dept. of Energy.
- Superheated plasma is suspended in the donut shaped region and hydrogen is introduced and fusion is attempted.

Inertial Confinement Fusion

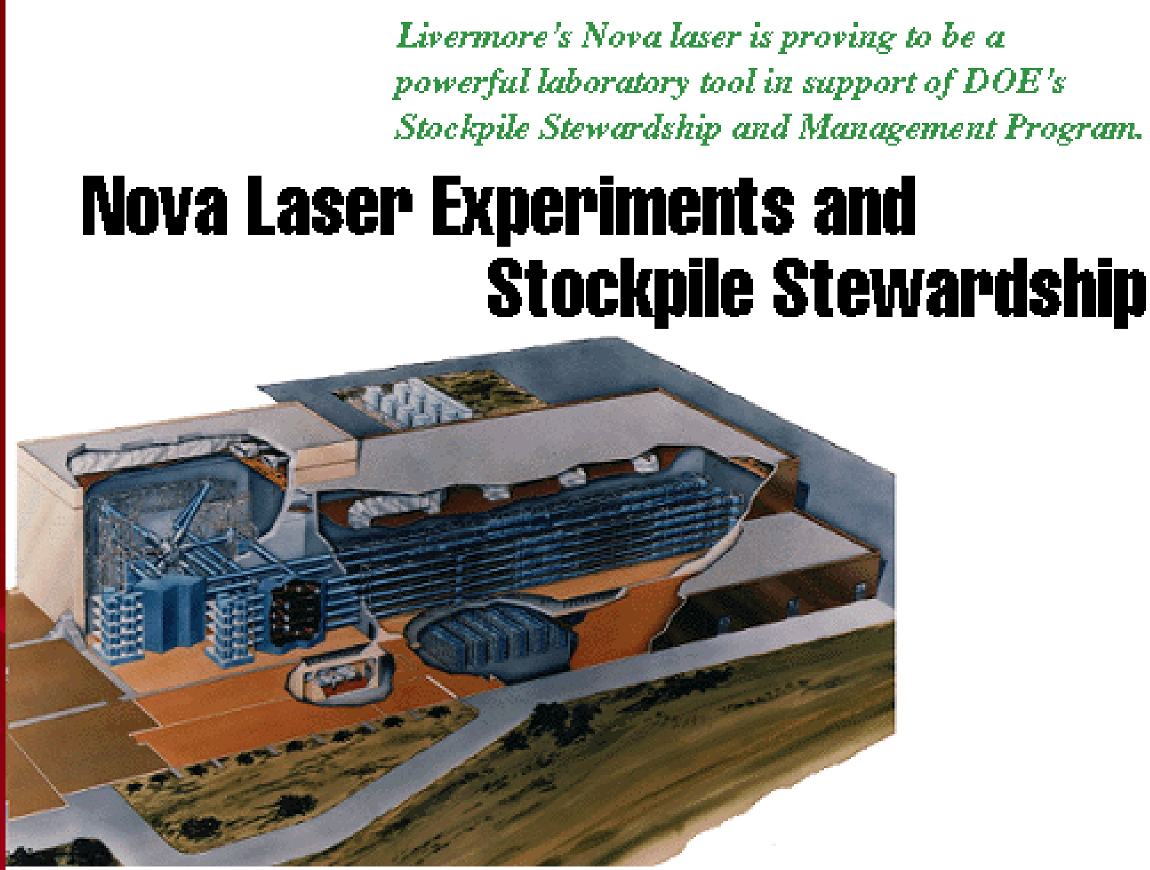


Figure 1. Cutaway view of Nova laser facility when it opened in 1985. The space frame (right) supprts the ten-laser amplifier chains. A system of high-reflectivity mirrors ensures that the ten laser beams arrive simultaneously at the target, centered in the spherical chamber (left).

- Located at Lawrence Livermore Labs in California
- Hydrogen is bombarded on all sides by high energy lasers to create high temperature.

Inertial Confinement

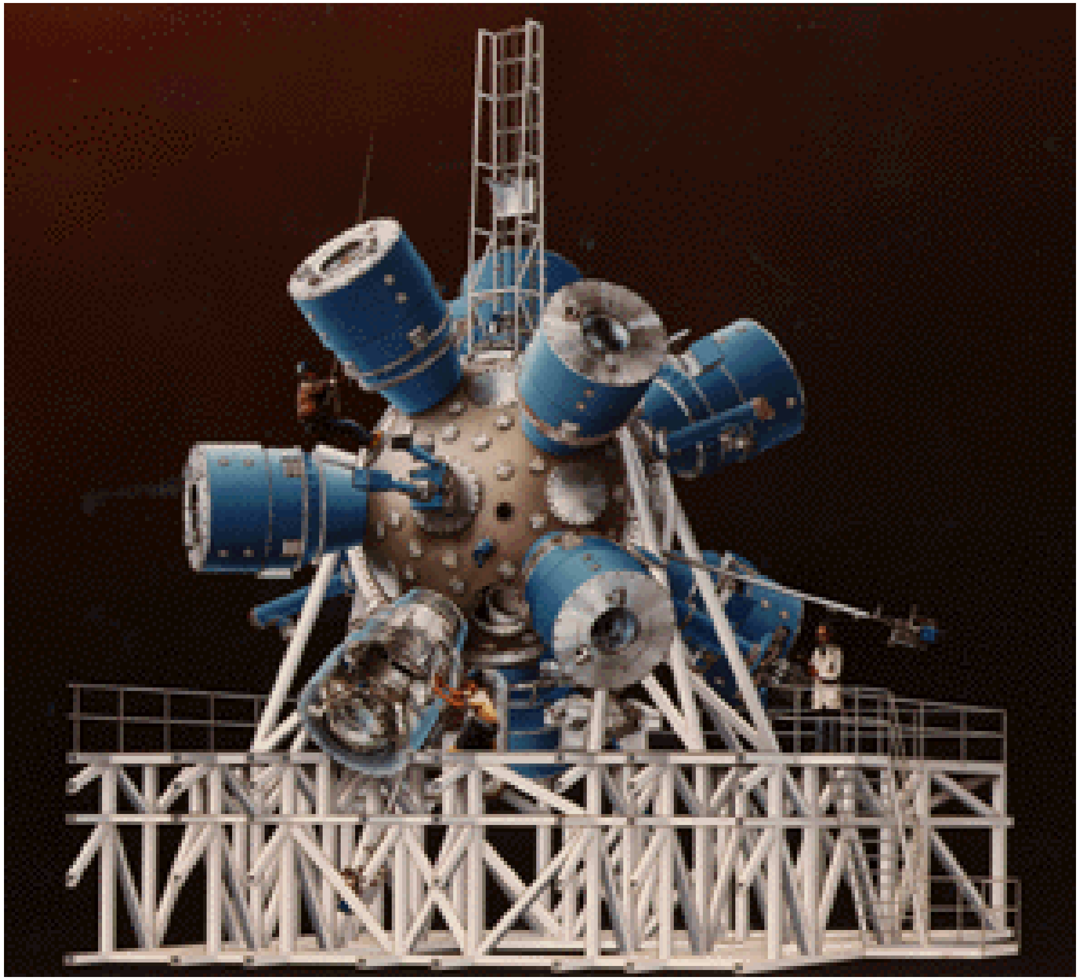


Figure 4. Artist's rendering of the outside of the Nova target chamber, where the ten laser beams converge to heat and shock a tiny hohlraum. Note the two human figures at work on the platform. The entire structure is three stories high, and the spherical target chamber is 4.5 meters (15 feet) in diameter.

Fusion (Hydrogen) Bombs

- GREATLY increases the damage potential by releasing fission and fusion energy from the explosion.
- Payload is in the 50 - 300 Megaton range (50,000,000 – 300,000,000 tons of TNT).
- This version is called the Teller-Ulam configuration of the thermonuclear bomb.