Physics 180

Nuclear Weapons, Nuclear War, and Arms Control

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Final Examination With Answers
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Name _____

- This is a closed-book examination of 2 hours duration.
- Answer all 10 questions. All count equally (20 points each).
- Write your answers in the space provided on these pages.
  If you need more room, write on the back of the page.
  For full credit on definitions, give numbers where appropriate.

SCORES

1. __20__	6. __20__
2. __20__	7. __20__
3. __20__	8. __20__
4. __20__	9. __20__
5. __20__	10. __20__

TOTAL SCORE ___200____

1. Acronyms

Decode the following acronyms, abbreviations, or code words. [1 point each]

ABMT—Anti-Ballistic Missile Treaty

ALCM—Air-launched cruise missile

ASAT—Anti-Satellite Weapon

ATBM—Anti-tactical ballistic missile

C^3I—Communications, command, control, and intelligence

CTBT—Comprehensive Test Ban Treaty

EMT—Equivalent megatonnage

GPS—Global Positioning System

MIRV—Multiple independently-targetable reentry vehicle

NATO—North Atlantic Treaty Organization

NORAD—North American Aerospace Defense Command

PNET—Peaceful Nuclear Explosions Treaty

R&D—Research and development

SALT—Strategic Arms Limitation Talks

SCC—Standing Consultative Commission

SIOP—Single Integrated Operational Plan

SLBM—Submarine-launched ballistic missile

START—Strategic Arms Reduction Talks

Trinity—The code-name of the first nuclear weapon test

TTBT—Threshold Test Ban Treaty

2. Nuclear Physics

Define *nuclear fission*. [2 points]

Nuclear fission is the breakup of a heavy nucleus, such as uranium, into two medium-weight nuclei. Fission is usually accompanied by emission of a few neutrons and γ-rays.

Define *fissile nuclide*. [2 points]

A fissile nuclide has some probability of being fissioned by a neutron of any energy. [A non-fissile but fissionable nuclide can only be caused to fission by neutrons with energies above the fission threshold energy.]

Name two fissile nuclides. [2 points]

Three fissile nuclides relevant to the course are U-233, U-235, and Pu-239. [Full credit given for listing any two of these nuclides.]

Explain what is meant by a *subcritical*, a *critical*, and a *supercritical* assembly. [6 points]

A *subcritical* assembly of nuclear materials is one in which there are fewer fissions in each successive generation; stated differently, the neutron multiplication factor is less than one.

A *critical* assembly is one in which the same number of fissions is the same in each successive generation; stated differently, the neutron multiplication factor is exactly one.

A *supercritical* assembly of nuclear materials is one in which there are more fissions in each successive generation; stated differently, the neutron multiplication factor is greater than one.

Explain the difference between an assembly that is *prompt critical* and one that is *delayed critical*. [2 points]

An assembly that is prompt critical can sustain a neutron chain reaction using only the ~99.3% of neutrons that are emitted promptly when a nucleus fissions. An assembly that is delayed critical is subcritical when only prompt neutrons are counted but is critical when the delayed neutrons that are later emitted from the fission fragments (~0.007% of the total) are counted.

What is the diameter and prompt critical mass of a bare sphere of 100% U-235? [2 points]

8.5 cm and 56 kg (full credit given for answers in the ranges 5–10 cm and 40-70 kg)

What is *reactor-grade* plutonium? *Weapon-grade* plutonium? What are the key differences between them? [3 points]

Reactor-grade [high burn-up] plutonium contains more of the isotopes Pu-240, Pu-241, and Pu-242 than does weapon-grade plutonium. [Full credit given for listing Pu-240 alone.]

Could a terrorist group build and explode a device made of reactor-grade plutonium? [1 point]

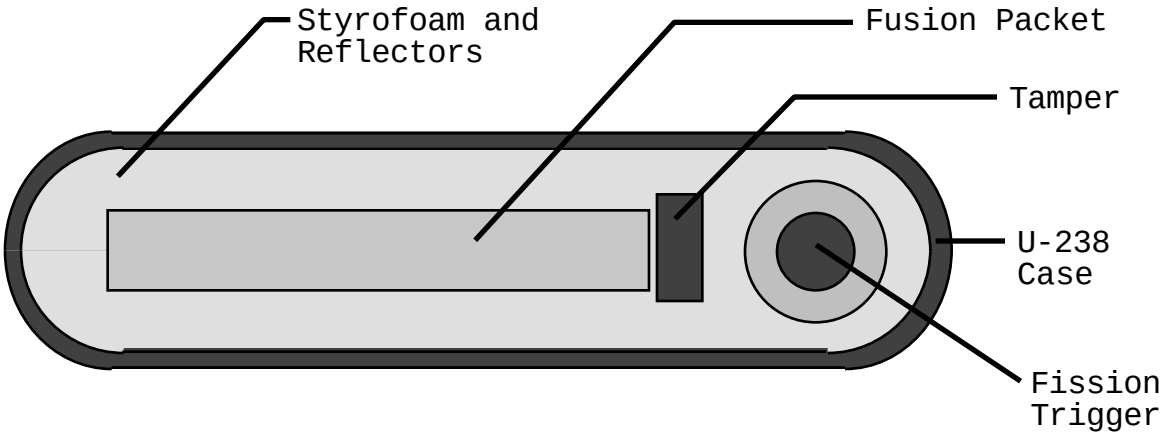
Yes, reactor-grade plutonium can be made to explode.

3. Thermonuclear Weapons

a) Shown here is a schematic diagram of a standard thermonuclear weapon. Indicate on the diagram the locations of the following key components:

- ^{6}LiD fusion packet
- U-238 case
- Fission trigger
- Tamper
- Styrofoam and reflectors

[10 points]



b) Describe briefly the functions of each of these five components. [10 points]

^{6}LiD fusion packet: The thermonuclear 'fuel' of the weapon. When exposed to neutrons, the ^{6}Li acts as a 'catalyst', providing more neutrons and tritium to fuse with the deuterium (D), releasing energy.

U-238 case: Has two purposes: holds the weapon together, increasing the yield of the fusion packet and fissions when exposed to the intense neutron flux from the fusion reactions, adding to the fission yield of the weapon.

Fission trigger: Provides the X- and γ-rays that compress and heat the fusion packet, causing the thermonuclear reaction to go.

Tamper: Slows propagation of the debris and shock wave from the fission trigger into the fusion packet, allowing the fusion reaction to proceed for some time before the fusion packet is disrupted.

Styrofoam and reflectors: Styrofoam holds the fusion packet in place and, when exposed to the X- and γ-rays from the fission trigger, creates a high-pressure plasma that helps to compress the fusion packet. Reflectors direct X- and γ-rays onto the surface of the fusion packet.

4. ICBMs

a) What is an ICBM? [2 points]

An ICBM (intercontinental ballistic missile) is a land-based missile capable of striking targets at intercontinental distances, usually defined as distances of 5500 km or more.

b) List the four phases in the flight of a MIRVed ICBM and indicate the approximate duration of each in minutes. [8 points]

	PHASE	DURATION (MINUTES)
i)	Boost	1-5
ii)	Post-boost [or bus]	5
iii)	Midcourse	20
iv)	Terminal	0.5-1

c) What is the approximate flight time in minutes for U.S. ICBMs to typical targets in the Soviet Union? If one was launched in error, could the U.S. do anything to prevent its warheads from exploding? [2 points]

30 minutes. No.

d) Define the following terms used in discussions of ICBMs and explain their significance. [4 points]

CEP: The radius of a circle that encloses half (and only half) of the impact points of the RVs.

Bias: The distance between the aimpoint and the center of the distribution of RV impact points.

e) Name two technologies that are used to guide or to help guide the warheads of modern ICBMs to their targets. [4 points]

Inertial guidance, star trackers, global positioning satellites. [Any two are sufficient for full credit.]

f) Does the ability of a missile to destroy a hardened target depend more on the yield of the warhead it carries or the accuracy with which it can deliver the warhead? [2 points]

The accuracy with which it can deliver the warhead.

5. Weapon Effects

Give brief (one- or two-sentence) definitions of the following terms. [2 points each]

- Air burst—A burst above ground-level in which the fireball never touches the ground.

- Surface burst—A burst at or above ground-level in which the fireball touches the ground at some point in the evolution of the explosion.

- Electromagnetic pulse (EMP)—The strong burst of electromagnetic radiation produced by a nuclear explosion.

- Thermal pulse—The pulse of heat radiation emitted by the fireball of a nuclear explosion after it has expanded for several seconds.

- Blast wave—The shock wave (a very strong sound wave) produced by a strong explosion of any kind.

- Half-life—The time after which there is a 50% probability that a given radionuclide has decayed. [For a macroscopic quantity of a given radionuclide, the time after which the amount still remaining has fallen to half the original amount. Note that the half-life can be defined only for a *single* radionuclide, since a mixture of radionuclides will have a mixture of half-lifes.]

- Ionizing radiation—Radiation (UV, X-rays, and γ-rays) that is energetic enough to strip electrons from atoms and molecules.

- Acute exposure—Exposure to radiation lasting less than 24 hours. [To be distinguished from chronic exposure, which is exposure lasting more than 24 hours.]

- Physical dose—The energy deposited in the target tissue or material by the incident radiation. Measured in rads.

- Relative biological effectiveness (RBE)—The factor that describes the relative effectiveness of the particular type of radiation in causing the type of biological damage of interest; converts a dose in rads into a dose in rems.

6. Nuclear Policies

Give short (one or two sentence) definitions of each of the following nuclear policies and give the approximate time interval, if any, during which it was *declared* U.S. policy (you may specify the interval by giving a range of years or presidential administrations). [4 points each]

- Counterforce—A policy of emphasizing the ability to quickly launch devastating attacks on the leadership and nuclear forces of an adversary. Major elements of this policy include a large arsenal of prompt, hard-target killer weapons (powerful and accurate); a large menu of pre-programmed targets; quick and effective early warning; and communications, command, and control, and post-attack assessment capabilities, to permit shoot-look-shoot tactics to assure complete destruction of the adversary's forces. This has been operational U.S. policy since the mid-1960s and declared U.S. policy since the early 1970s.

- Assured destruction—A policy of deploying secure retaliatory nuclear forces of sufficient size to destroy any attacker, even after a first strike is absorbed. The emphasis is on the security of the forces and command and control, and their sufficiency for deterrence. This was declared U.S. strategic policy during 1963–1973.

- First use—A policy of attacking with nuclear weapons first, if one is losing a conventional war. This has been declared U.S. and NATO policy since the early 1950's. The term “first use” was introduced to avoid having to use the politically and psychologically less palatable term “first strike” to describe this policy.

- Minimum deterrence—A policy of deterring nuclear attack by deploying only the nuclear forces needed to cause unacceptable damage to the population and industry of any attacker. The emphasis of this policy is on avoiding an arms race while still deterring nuclear attack. Defense Secretary Robert McNamara reportedly considered 400 deliverable EMTs sufficient to deter the Soviet Union from attacking the U.S. This has never been U.S. policy.

- Flexible response—A policy of responding to any attack by choosing among a variety of options (weapons, targets, timing), including use of nuclear weapons to counter a conventional attack. This has been declared U.S. and NATO policy since 1965.

7. Nuclear Arms Control Treaties

Three treaties that limit nuclear testing are listed below. For each treaty—
- Give the year the agreement was signed and state whether the treaty is now in force
- Describe which nations are parties to the agreement
- List the key provisions and the duration of the agreement
- Describe one way compliance with the agreement can be monitored

- Limited Test Ban Treaty (LTBT) [7 points]

  Year/in force? Signed August 5, 1963; went into force October 10, 1963.

  Parties: Original signatories were US, UK, and SU; now signed by more than 100 nations.

  Key provisions: Prohibits testing of nuclear weapons in the atmosphere, underwater, and in space. Of unlimited duration (with the usual escape clause in case of supreme national interest).

  One method of monitoring: Air-sampling of radionuclides/satellite detection of double optical flash. [Either example is sufficient.]

- Second Strategic Arms Reduction Treaty (START II) [7 points]

  Year/in force? Signed in January 1993; not yet in force. [It was ratified in January 1996 by the U.S. Congress but has not yet been ratified by the Russian Duma.]

  Parties: US and Russia.

  Key provisions: Limits US and Russia to no more than 3,500 strategic nuclear warheads. Eliminates MIRVed ICBMs. Of unlimited duration (with the usual escape clause in case of supreme national interest).

  One method of monitoring: Overhead photoreconnaissance using satellites; interception of missile test telemetry; collection of infrared signatures using early-warning satellites. Listing any one of these methods is sufficient for full credit.]

- Comprehensive Test Ban Treaty (CTBT) [6 points]

  Year/in force? Signed in September 1996; not yet in force.

  Parties: Signed by 94 countries; India has refused to sign.

  Key provisions: Bans all nuclear explosions of any size and for any purpose.

  One method of monitoring: Monitoring methods include remote monitoring by networks of seismic sensors, hydroacoustic sensors,

radionuclide detectors, and infrasound sensors as well as on-site inspections. [Listing any one of these methods is sufficient for full credit.]

8. Proliferation

List the five countries that openly possess nuclear weapons (the declared nuclear weapons states). Give the year in which each first exploded a nuclear device. [10 points]

United States (1945), Soviet Union (1949), Great Britain (1952), France (1960), People's Republic of China (1964).

List the three countries that are thought to have nuclear weapons or near-nuclear capability, even though they do not acknowledge having nuclear weapon programs (the *de facto* nuclear weapon states). [3 points]

India, Pakistan, and Israel.

Which previously *de facto* nuclear weapon state recently gave up its nuclear weapons and agreed to the provisions of the Non-Proliferation Treaty? [1 point]

South Africa.

Give short (two- or three-sentence) definitions of the following terms. [6 points]

- Enrichment—Physical processing of fissionable material by means such as gaseous diffusion, centrifugal separation, and laser separation, to increase the fraction of the material that is fissile. An example is enrichment of natural uranium (mostly U-238) to increase the fraction of nuclei that are fissile (U-235).

- Reprocessing—Chemical processing of fissionable material to separate desired nuclides from undesired nuclides. An example is processing of partially-used reactor fuel to separate Pu-239 from the fuel, for use in making nuclear weapons.

- Dual-use technologies—Technologies that can be used either for peaceful purposes or to produce nuclear weapons.

9. The Non-Proliferation Treaty (NPT)

The NPT divides signatories into *nuclear-weapon states* and *non-nuclear-weapon states*.

- What are the major *restrictions* on the *nuclear-weapon states*, under the terms of the treaty? [4 points]

  NWS must not transfer nuclear weapons or control over nuclear weapons to any NNWS, directly or indirectly. [Article I]

  NWS must not assist, encourage, or induce any NNWS to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices, or control over such weapons or explosive devices. [Article I]

- What are the major *obligations* of the *nuclear-weapon states*, under the terms of the treaty? [4 points]

  NWS agree to help NNWS with "potential benefits from any peaceful applications of nuclear explosions". [Article V]

  NWS agree to pursue negotiations in good faith to end the nuclear arms race at an early date and to move toward nuclear disarmament. [Article VI]

- What are the major *restrictions* on the *non-nuclear-weapon states*, under the terms of the treaty? [4 points]

  NNWS must not receive nuclear weapons or other nuclear explosive devices, or control over such weapons or devices, directly or indirectly. [Article II]

  NNWS must not manufacture or otherwise acquire nuclear weapons and must not seek or receive any assistance in the manufacture of nuclear weapons or other nuclear explosive devices. [Article II]

  NNWS must accept IAEA safeguards to prevent diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices. [Article III]

- Under the terms of the treaty, what conditions, if any, are there on the transfer or sale of nuclear reactors and related peaceful nuclear technologies to non-nuclear-weapon states? [4 points]

  None. [Article IV]

- Under the terms of the treaty, after 25 years a conference must be held at which the treaty must be extended indefinitely, extended for another definite period, or canceled. What is the status of this conference? [4 points]

  It was held in 1995 and extended the NPT indefinitely.

10. Anti-Ballistic Missile (ABM) Weapons

- Has the U.S. ever had an operational ABM weapon system? If so, when was it operational and for how long? [3 points]

  Yes, the U.S. had an operational ABM system in 1976, for three months. [It was turned off after three months because it was too expensive and ineffective.]

- List the three "non-nuclear-weapon" or "undeclared-nuclear-weapon" states that already have or soon will have ballistic missiles with ranges greater than 1,500 km. [3 points]

  Saudia Arabia, India, and Israel

- Are any of these three countries current or prospective adversaries of the US or its allies? [2 points]

  No.

- List the four countries that now have or are expected to have within the next 15 years ballistic missiles capable of reaching the US. [4 points]

  China, France, Russia, U.K.

- Does the US government think that any of these four countries are likely to engage in armed conflict with the US or its allies in the next decade? [2 points]

  No.

- What was the declared goal of the SDI ("Star Wars") program, according to President Reagan? [2 points]

  To make nuclear weapons impotent and obsolete by protecting the population of the U.S. and its allies against nuclear attack.

- The SDI ("Star Wars") program and its successor programs have never attempted to counter delivery of nuclear weapons by which of the following methods: submarine-launched ballistic missiles, bombers, air-launched cruise missiles, sea-launched cruise missiles, ground-launched cruise missiles, ships, trucks. [2 points]

  The SDI program and its successor programs have never attempted to counter delivery of nuclear weapons by *any* of these methods.

- Of the six tests conducted so far of the land-based ABM weapon system that is currently being considered for defending the U.S., how many have been successful? [2 points]

  None.