Physics 180

Nuclear Weapons, Nuclear War, and Arms Control

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Answers to the Midterm Examination Given 1998 March 18

Name _____

ID No. _____

- This is a closed book examination of 50 minutes duration.
- Answer all 5 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
2. 20
3. 20
4. 20
5. 20

TOTAL 100

1. 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]

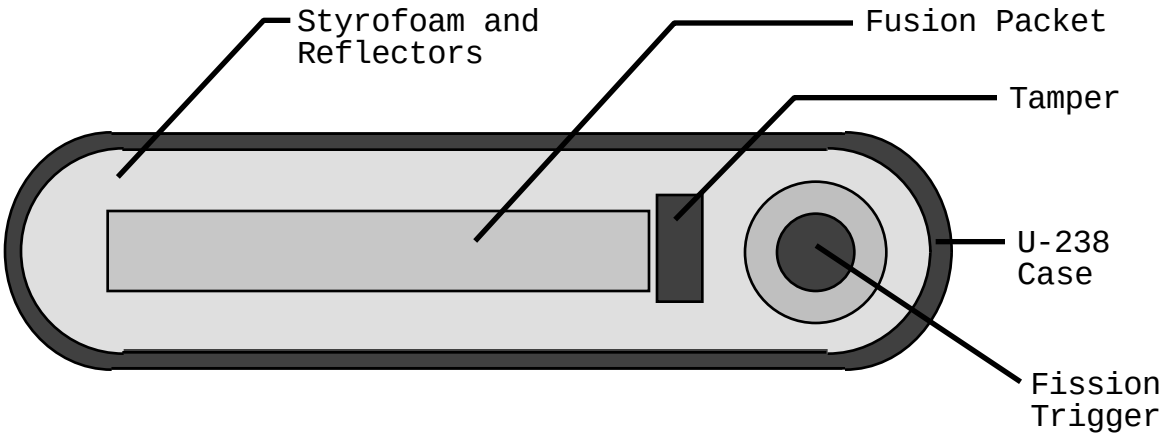
Yes, reactor-grade plutonium can be made to explode.

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

6. a) 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

b) 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? [4 points]

30 minutes. No.

c) Define the terms *circular error probable* (CEP) and *bias* as used in discussions of ICBM warhead accuracy. [8 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.

4. Acronyms and Arsenals

Translate each of the following acronyms and explain in one sentence what they refer to. [2 points each]

SLBM—Submarine- (or sea-) launched ballistic missile. Nuclear-tipped missiles carried in submarines and able to be launched from them.

MIRV—Multiple independently-targetable reentry vehicle: Configuration of a ballistic missile payload to carry multiple reentry vehicles, each of which can be aimed at a different target.

NORAD—North American Aerospace Defense Command. The command post deep in Cheyenne Mountain outside Colorado Springs into which information from nuclear attack detection sensors are relayed and from which an assessment of any attack would be communicated to the President.

ALCM—Air-launched cruise missile. An air-breathing [turbofan-powered] missile that can be launched from an airplane [usually a bomber]. [A cruise missile may be armed with a conventional (chemical) warhead or nuclear warhead.]

C^3I—Communications, command, control, and intelligence. The human and hardware components of the nuclear attack warning system and the nuclear strike command and control system.

GPS—Global Positioning System. The constellation of satellites with on-board atomic clock and radio transmitters that can be used to determine the location and velocity of any GPS receiver to high accuracy.

About how many strategic nuclear warheads does the US currently have on alert?

7,957 (full credit given for answers in the range 7,000-8,000)

About how many of these are on ICBMs?

2,400 = 30% (full credit given for answers in the range 2,000-3,000)

About how many strategic nuclear warheads does Russia currently have on alert?

6,750 (full credit given for answers in the range 6,000-7,000)

About how many of these are on ICBMs?

3,700 = 55% (full credit given for answers in the range 3,000-4,000)

5. Weapon Effects

a) Give brief (one- or two-sentence) definitions of the following terms. [12 points]

- Air burst—A burst in which the fireball does not touch the ground.
- Slant range—The straight-line distance from the center of an air burst to the target (the target is usually assumed to be on the ground).
- Firestorm—An intense, large-scale fire in which the winds created by the updraft of the heated air become so strong that the fire is concentrated in a central area and is fed by fuel sucked into the central area. [In contrast, a *conflagration* is an intense, large-scale fire with a burning front that gradually expands, leaving behind the burned fuel.]
- Electromagnetic pulse (EMP)—The short pulse of electromagnetic radiation produced by nuclear explosions of all types, but especially explosions near the ground or at high altitudes. The EMP typically lasts $\sim 10^{-8}$–10^{-9} sec and may produce large currents and high voltages that severely damage electrical or electronic equipment. [EMP is generated by the asymmetry of the explosion, which can produce large, rapidly varying electrical currents. Explosions at or near the earth's surface produce the strongest electrical fields, but high-altitude explosions may produce damaging fields over a much larger area. For example, a megaton-size explosion at 200 miles above Omaha, Nebraska would produce potentially damaging EMP over the whole continental United States, as well as parts of Mexico and Canada.
- Ground zero—For an airburst, the point on the ground vertically below the center of the explosion. [For an underground burst, the point vertically above the center of the explosion.]
- Fireball—The rapidly expanding, very hot region of heated air and vaporized weapon debris in which the X and UV radiation from the burst is initially trapped.

b) Number the following effects in the order in which a person would experience them if she/he were located 3 miles from the center of an airburst produced by a 1 Mt thermonuclear weapon? Describe each effect in one or two sentences. [8 points]

- Fallout [4th]—The radioactive dust that is produced when the fireball touches the ground and radioactive vapor condenses on dust and soot. These particle are carried upward by the mushroom cloud and then fall down or are washed down, forming a coating of radioactive dust over the ground, structures, and people.
- Thermal pulse [2nd]—The pulse of heat (infrared) radiation produced within the first few seconds after a nuclear explosion as the radiating surface of the fireball expands and temperature of the fireball falls.
- Blast wave [3rd]—The very strong sound wave that breaks away from the expanding fireball and races outward, producing a sudden compression followed by a strong outward wind and then a weaker inward wind.
- Prompt nuclear radiation [1st]—The nuclear radiation produced during the fission and fusion reactions that take place in the nuclear weapon.