T4. The nuclear past of Uzbekistan

6%									
4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	∑
2	3	3	2	2	2	2	2	4	22

Natural uranium consists primarily of two isotopes, ^{235}U and ^{238}U. ^{235}U is responsible for sustaining nuclear fission reactions.

4.1 **Calculate** the atomic abundance of ^{235}U in natural uranium, assuming it consists only of isotopes ^{235}U (235.04 a.u.) and ^{238}U (238.05 a.u.). 2.0 pt

The main reaction occurring in nuclear power plants is the reaction where ^{235}U absorbs a neutron and undergoes fission, releasing energy and producing three additional neutrons, thus sustaining a chain reaction.

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow \ldots + 3^{1}_{0}\mathrm{n}$$

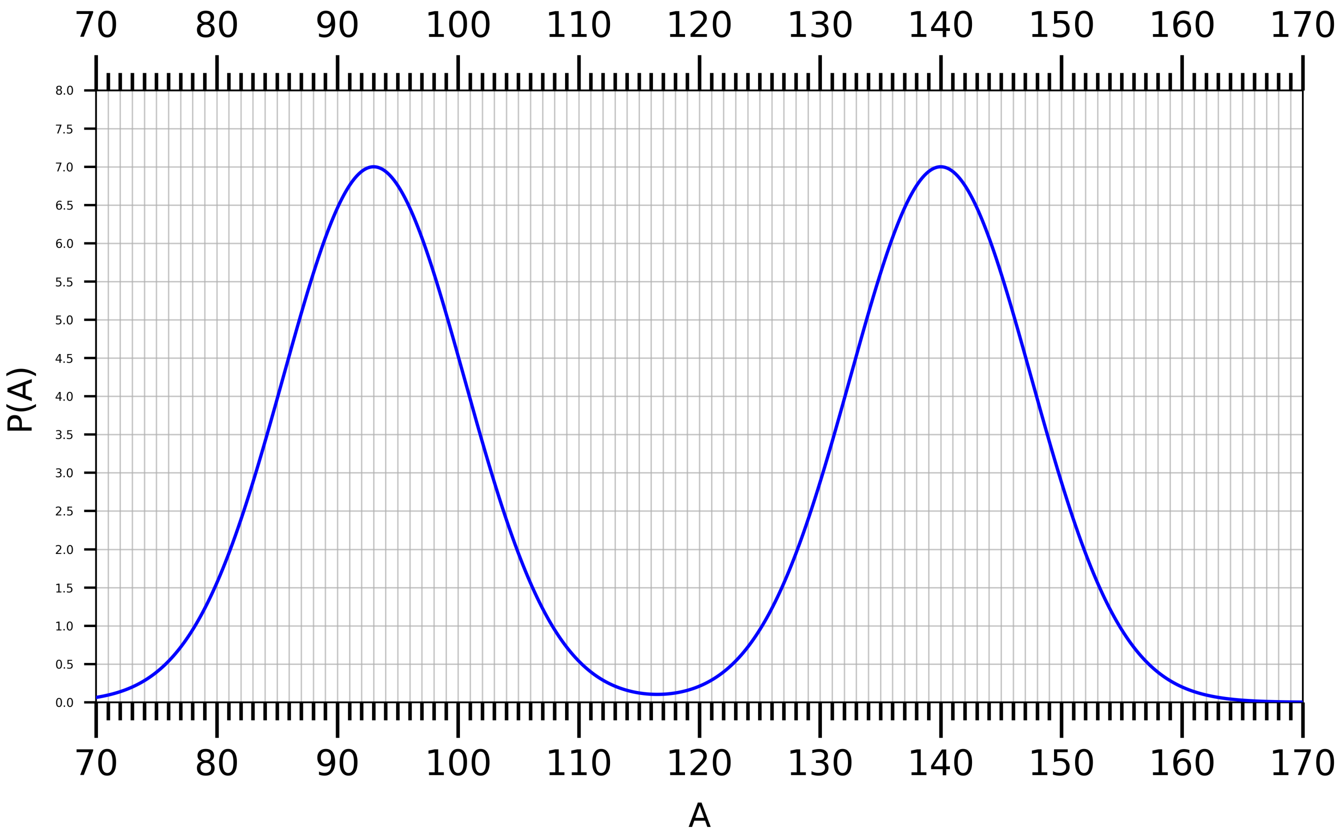
Neutrons that induce the chain reaction are produced by several ways:

a) Reaction of ^{11}B with α-particles inside the reactor core

b) Interaction of γ rays with ^{2}D nuclei present in the reactor coolant water

c) Reaction of ^{9}Be with α-particles produced in an externally installed neutron source.

4.2 **Write** the nuclear reaction equations for **(a)**, **(b)**, and **(c)**. 3.0 pt



The graph above displays the percentage yield, *P(A),* of fission products by mass number, *A,* resulting from ^{235}U fission.

4.3	**Write** the main nuclear fission equation for splitting of ^{235}U upon neutron absorption. The pair of elements formed in this reaction are in the same group of Periodic Table.	3.0 pt

4.4	**Calculate** the energy released in this reaction (*ΔE*, MeV), if the binding energy $BE(^{235}\text{U}) = 7.59$ MeV/nucleon and average binding energy for fission products $BE(\text{fis.}) = 8.45$ MeV/nucleon. *Neglect* the binding energy of free neutrons.	2.0 pt

Fission neutrons are produced with an average energy of 2 MeV and slow down through many scatterings with nuclei. After several collisions, their speed decreases until their average kinetic energy matches that of the surrounding atoms or molecules.

The **logarithmic energy decrement,** ξ , shows the average decrease per collision in the logarithm of the neutron energy:

$$\xi = \ln\left(\frac{E_{initial}}{E_{final}}\right)$$

$E_{initial}$ and E_{final} are the initial and final neutron energies per collision.

ξ is a constant for each type of material and does not depend on the initial neutron energy.

4.5	**Determine** the average number of collisions required, n_c, to slow a neutron from 2 MeV to 0.012 eV, using water as the moderator. ξ (water)=0.948	2.0 pt

In 1963, the *Urtabulak* gas field suffered an uncontrolled natural gas well blowout, releasing enormous volumes of burning methane.

4.6	**Calculate** $\Delta_r H^\circ_{298}$ (kJ mol^{-1}) for one mole of methane combustion reaction at 298 K. **Assume** all species are gaseous. Use the thermodynamic data below	2.0 pt

$\Delta_f H^\circ_{298}(CH_4)$	-74.8 kJ mol^{-1}
$\Delta_f H^\circ_{298}(H_2O, gas)$	-241.8 kJ mol^{-1}
$\Delta_f H^\circ_{298}(CO_2)$	-393.5 kJ mol^{-1}
$C_P(CH_4)$	35 J mol^{-1} K^{-1}
$C_P(H_2O, gas)$	34 J mol^{-1} K^{-1}
$C_P(O_2)$	29 J mol^{-1} K^{-1}
$C_P(CO_2)$	37 J mol^{-1} K^{-1}

If you did not get an answer for 4.6, use $\Delta_r H^\circ_{298} = -750\ kJ\ mol^{-1}$ for further calculations.

4.7	**Calculate** $\Delta_r H_{2000}$ (kJ mol^{-1}) per mole of methane combustion reaction at 2000 K. **Assume** all species are gaseous.	2.0 pt

If you did not get an answer for 4.7, use $\Delta_r H_{2000} = -700\ kJ\ mol^{-1}$ for further calculations.

Assume that methane is flowing out the well at 101.325 kPa and 298 K with volumetric flow Q = 2.2 × 10^5 m^3 per day before it catches fire.

4.8	**Calculate** the total energy released per day, E, (in J day^{-1}) by complete isothermic combustion of methane at T = 2000 K	2.0 pt

The *Urtabulak* gas leak was ended by detonating a 30-kiloton in TNT equivalent underground nuclear explosion that collapsed the reservoir and sealed the leak. 1 ton of TNT equivalent is 4.184 GJ of energy.

4.9	Using the value from **4.4**, **calculate** the total number of fissions, *TN*, during the nuclear explosion. **Calculate** the mass, *m*, of enriched uranium used in the explosion (in kg), assuming it contained 90% by mass of the ^{235}U isotope, and 33% of the ^{235}U underwent fission. *If you did not get an answer for 4.4, use $\Delta E = 200$ MeV.*	4.0 pt