GEORGIA INSTITUTE OF TECHNOLOGY

The George W. Woodruff
School of Mechanical Engineering

NUCLEAR ENGINEERING

Ph.D. Qualifiers Exam - Fall Quarter 1996

Math and Engineering Fundamentals
EXAM AREA

Assigned Number **(DO NOT SIGN YOUR NAME)**

-- **Please sign your name on the back of this page** --

Code #________________
Page

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The George W. Woodruff School of Mechanical Engineering

Nuclear Engineering

Ph.D. Qualifiers Exam

Fall Quarter, 1996

Day 1

Instructions

1. You must complete 1 of the 2 problems in each of the following areas (for a total of 7 questions). DO NOT COMPLETE MORE THAN ONE QUESTION IN EACH AREA.

   a. Mathematics
   b. Basics in Fusion
   c. Nuclear Physics
   d. Basics in Fission
   e. Radiation Detection
   f. Radiation Protection
   g. Thermodynamics and Mechanics

2. Place your identifying code letter on the top right corner of each page of your question and answer sheets.

3. Use a separate page for each answer sheet (no front to back answers).

4. The question number should be shown on each answer sheet.

5. Staple your question sheet to your answer sheets and turn in.

Code #________________

Nuclear Physics

NE.I.1. a. If you were to bombard ^{63}**Cu** ($Z = 29$) with energetic **alpha** particles, what would be the minimum kinetic energy of the **alpha** particles before we could expect **any** significant nuclear reactions to occur? (i.e. to overcome the Coulomb barrier)

answer ________ MeV

b. For this bombardment, what would be the product, $^{A}_{Z}$**X**, of a ^{63}**Cu** (α, **p**) reaction?
Write the balanced nuclear reaction equation, showing **A, Z, and N** for each term.

c. What would be the **Q** for this reaction? The atomic mass of ^{63}**Cu** is 62.929599 μ; of ^{A}**X** is 65.926035 μ?

answer _______ MeV

Useful Constants:
1 Ci = 3.7×10^{10} dis/sec, **1 eV** = 1.60×10^{-19} Joule, **e** = 1.60×10^{-19} Coulomb
1 μ = 931.502 MeV/c^2 = 1.660566×10^{-27} kg **$k_{coulomb}$ = $1/4\pi\varepsilon_0$** = 9.0×10^9 Newton•meter^2/Coulomb^2
m (^{1}**H**) = 1.007825 μ, m (**n**) = 1.008665 μ, m (**e**) = 5.485803×10^{-4} μ = 0.511 MeV/c^2 = 9.11×10^{-31} kg
m (^{4}**He**) = 4.002603 μ.

Code #________________

Nuclear Physics

NE.1.2. A 10 MeV gamma ray is Compton scattered at **75°**:

a. What is the energy of the scattered photon? answer ________MeV

b. What is the energy of the scattered electron? answer ________MeV

Useful Constants:

1 Ci = 3.7 x 10^{10} dis/sec, **1 eV** = 1.60 x10^{-19} Joule, **e** = 1.60 x10^{-19} Coulomb

1 μ = 931.502 MeV/c^2 = 1.660566 x 10^{-27} kg **$k_{coulomb}$ = $1/4\pi\varepsilon_0$** = 9.0x10^9 Newton•meter^2/Coulomb^2

m (^{1}**H**) = 1.007825 μ, m (**n**) = 1.008665 μ, m (**e**) = 5.485803 x 10^{-4} μ = 0.511 MeV/c^2 = 9.11 x 10^{-31} kg

m (^{4}**He**) = 4.002603 μ.

Code #________________

Fusion

NE.I.3 A tokamak has four magnetic field components - a toroidal field produced by a set of toroidal field coils, a poloidal field produced by the plasma current, a "vertical" (or equilibrium) field produced by a set of poloidal ring coils, and an "ohmic heating" field produced by a central solenoidal magnet. Describe the function of each of these 4 magnetic field components, giving governing equations.

Code #________________

Fusion

NE.I.4. The materials in the "first wall" immediately surrounding a fusion plasma will be subjected to a large flux of 14 MeV neutrons. Discuss the fundamental (microscopic) damage mechanisms and the secondary (macroscopic, observable) damage to the first wall materials.

Code #________________

Fission

NE.I.5 Consider an infinite slab reactor of uniform composition and thickness $2a$ (the slab edges are at $x = \pm a$). the reactor consists of uranium (10% U-235 and 90% U-238 by weight). At position $x = 0$ (at the center of the slab) there is an infinitely thin absorber with an infinitely large absorption cross section. Assume that one-speed diffusion theory is valid and that the uranium density, microscopic cross sections and the atomic weight for each isotope are given.

a. Set up the detailed differential equation and boundary condition for this system.

b. Find the critical (k_{eff}=1) dimension a in terms of the given (assumed) parameters.

Code #________________

Fission

NE.I.6 A triangular pitch is used in a fuel element with a pitch to diameter ratio of 1.000. The fuel pellet diameter is 0.3649 in. The fuel pin diameter is 0.422 in. The clad thickness is 0.0243 in. UO_2 density is 10.14 g/cm^3. Enrichment = 3.35%. Determine the atom density of U^{235} in the fuel cell.

Code #______________

Mathematics

NE.I.7. Laplace's equation in cylinder coordinate, assuming that ϕ is independent of the z coordinate, is

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\phi}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2\phi}{\partial\theta^2}=0$$

Find the general solution to this equation.

Code #______________

Mathematics

NE.I.8. Four radionuclides are present in a mixture (they are not members of a decay chain). You are to determine the activity of each radionuclide that was originally present in the mixture at $t = 0$. You know the decay constants (λ_A, λ_B, λ_C, λ_D) of each of the radionuclides. One way to determine the initial activities is to solve the total activity equation.

$$A_{tot}(t) = Ae^{-\lambda_A t} + Be^{-\lambda_B t} + Ce^{-\lambda_C t} + De^{-\lambda_D t}$$

where A, B, C, and D are the activities of the four radionuclides at time zero. If one has a set of activity measurements, the values of A, B, C, and D could be found by linear least-squares fitting. Remember, "linear" does not mean a straight line fit, rather a fit of linear combination of functions.

a. The first step in performing such a fit is to write the equation for the sum of the residuals (you might also think of it as the variance). Write that equation.

b. From the sum of the residuals, derive the set of equations (four of them) which yields the best fit to values of A, B, C, and D in the least-squares sense.

c. What are the best fit values of A, B, C, and D for the following set of data.

T(min)	Total Activity (Ci)
5	2.7
15	1.6
25	1.1
45	0.6
60	0.4

Other Data:

Radionuclide	$T_{1/2}$ (min)
A	2.0
B	8.0
C	15.0
D	30.0

Code #________________

Radiation Detection

NE.I.9. You were to determine the thermal neutron flux in the thermal column of Georgia Tech Nuclear Research Reactor. You irradiated a thin foil of ^{115}In of 100 mg in the thermal column for 5 hours, and then took it out and counted for 1 hour using a GM counter. The counter recorded a total of 400 counts.

Data given:

(1) the thermal activation cross section for ^{115}In is 160 barns,
(2) the half-life of ^{116m}In is 54 minutes,
(3) the detection efficiency of the counter for measuring a ^{116m}In decay is 1%, and
(4) the contribution from background during counting is zero.

Estimate the thermal neutron flux and its uncertainty (i.e. the expected deviation).

Code #________________

Radiation Detection

NE.I.10. In a very-low-count-rate experiment, the mean count rate was determined to be 1 count per minute. What is the probability that the counting system will record less than 5 counts in 10 minutes.

Code #________________

Thermodynamics and Mechanics

NE.I.11. The first of the Gibbs (Tds) equations is

$$Tds = du + Pdv$$

where

T = Temperature

s = Specific entropy

u = Specific internal energy

P = Pressure

v = Specific volume

a. What thermodynamic law does the equation represent and what type of processes does it apply to?

b. For an ideal gas with constant properties going through an arbitrary process, derive a relation for entropy change, $s_2 - s_1$.

Code #________________

Thermodynamics and Mechanics

NE.I.12. During the initial startup testing of a two-loop, 1600 MWt PWR, steady state operation was established at the conditions listed in Table 1. In order to test the pressurizer response to load changes, the operator disabled all the pressurizer heaters and opened one of the steam generator relief valves, thereby releasing steam to the atmosphere and increasing the total main steam flow rate by nearly 10%. **(Attached two sheets)**

a. Estimate the initial primary system cooldown rate (°F/hr) following steam generator relief valve opening.

b. Estimate the time required for the pressurizer low pressure alarm to sound indicating that the pressurizer pressure has decreased to 2100 psia. **(List all assumptions).**

Table 1

Primary System Conditions Prior to Opening of SG Relief Valve

Core Power Level	50%
Primary Coolant Average Temperature	572°F
Pressurizer Pressure	2200 psia
Total Primary System Volume (excluding the Pressurizer)	5600 ft^3
Pressurizer Volume	1000 ft^3
Saturated Liquid Volume in the Pressurizer	500 ft^3

Table 2: Saturated Steam: Pressure Table

Abs Press Lb/Sq In. p	Temp Fahr t	Specific Volume: Sat. Liquid v_f	Specific Volume: Evap v_{fg}	Specific Volume: Sat. Vapor v_g	Enthalpy: Sat. Liquid h_f	Enthalpy: Evap h_{fg}	Enthalpy: Sat. Vapor h_g	Entropy: Sat. Liquid s_f	Entropy: Evap s_{fg}	Entropy: Sat. Vapor s_g	Abs Press. Lb/Sq In. p
0.08865	32.018	0.016022	3302.4	3302.4	0.0003	1075.5	1075.5	0.0000	2.1872	2.1872	**0.08865**
0.25	59.323	0.016032	1235.5	1235.5	27.382	1060.1	1087.4	0.0542	2.0425	2.0967	**0.25**
0.50	79.586	0.016071	641.5	641.5	47.623	1048.6	1096.3	0.0925	1.9446	2.0370	**0.50**
1.0	101.74	0.016136	333.59	333.60	69.73	1036.1	1105.8	0.1326	1.8455	1.9781	**1.0**
5.0	162.24	0.016407	73.515	73.532	130.20	1000.9	1131.1	0.2349	1.6094	1.8443	**5.0**
10.0	193.21	0.016592	38.404	38.420	161.26	982.1	1143.3	0.2836	1.5043	1.7879	**10.0**
14.696	212.00	0.016719	26.782	26.799	180.17	970.3	1150.5	0.3121	1.4447	1.7568	**14.696**
15.0	213.03	0.016726	26.274	26.290	181.21	969.7	1150.9	0.3137	1.4415	1.7552	**15.0**
20.0	227.96	0.016834	20.070	20.087	196.27	960.1	1156.3	0.3358	1.3962	1.7320	**20.0**
30.0	250.34	0.017009	13.7266	13.7436	218.9	945.2	1164.1	0.3682	1.3313	1.6995	**30.0**
40.0	267.25	0.017151	10.4794	10.4965	236.1	933.6	1169.8	0.3921	1.2844	1.6765	**40.0**
50.0	281.02	0.017274	8.4967	8.5140	250.2	923.9	1174.1	0.4112	1.2474	1.6586	**50.0**
60.0	292.71	0.017383	7.1562	7.1736	262.2	915.4	1177.6	0.4273	1.2167	1.6440	**60.0**
70.0	302.93	0.017482	6.1875	6.2050	272.7	907.8	1180.6	0.4411	1.1905	1.6316	**70.0**
80.0	312.04	0.017573	5.4536	5.4711	282.1	900.9	1183.1	0.4534	1.1675	1.6208	**80.0**
90.0	320.28	0.017659	4.8779	4.8953	290.7	894.6	1185.3	0.4643	1.1470	1.6113	**90.0**
100.0	327.82	0.017740	4.4133	4.4310	298.5	888.6	1187.2	0.4743	1.1284	1.6027	**100.0**
110.0	334.79	0.01782	4.0306	4.0484	305.8	883.1	1188.9	0.4834	1.1115	1.5950	**110.0**
120.0	341.27	0.01789	3.7097	3.7275	312.6	877.8	1190.4	0.4919	1.0960	1.5879	**120.0**
130.0	347.33	0.01796	3.4364	3.4544	319.0	872.8	1191.7	0.4998	1.0815	1.5813	**130.0**
140.0	353.04	0.01803	3.2010	3.2190	325.0	868.0	1193.0	0.5071	1.0681	1.5752	**140.0**
150.0	358.43	0.01809	2.9958	3.0139	330.6	863.4	1194.1	0.5141	1.0554	1.5695	**150.0**
160.0	363.55	0.01815	2.8155	2.8336	336.1	859.0	1195.1	0.5206	1.0435	1.5641	**160.0**
170.0	368.42	0.01821	2.6556	2.6738	341.2	854.8	1196.0	0.5269	1.0322	1.5591	**170.0**
180.0	373.08	0.01827	2.5129	2.5312	346.2	850.7	1196.9	0.5328	1.0215	1.5543	**180.0**
190.0	377.53	0.01833	2.3847	2.4030	350.9	846.7	1197.6	0.5384	1.0113	1.5498	**190.0**
200.0	381.80	0.01839	2.2689	2.2873	355.5	842.8	1198.3	0.5438	1.0016	1.5454	**200.0**
210.0	385.91	0.01844	2.16373	2.18217	359.9	839.1	1199.0	0.5490	0.9923	1.5413	**210.0**
220.0	389.88	0.01850	2.06779	2.08629	364.2	835.4	1199.6	0.5540	0.9834	1.5374	**220.0**
230.0	393.70	0.01855	1.97991	1.99846	368.3	831.8	1200.1	0.5588	0.9748	1.5336	**230.0**
240.0	397.39	0.01860	1.89909	1.91769	372.3	828.4	1200.6	0.5634	0.9665	1.5299	**240.0**
250.0	400.97	0.01865	1.82452	1.84317	376.1	825.0	1201.1	0.5679	0.9585	1.5264	**250.0**
260.0	404.44	0.01870	1.75548	1.77418	379.9	821.6	1201.5	0.5722	0.9508	1.5230	**260.0**
270.0	407.80	0.01875	1.69137	1.71013	383.6	818.3	1201.9	0.5764	0.9433	1.5197	**270.0**
280.0	411.07	0.01880	1.63169	1.65049	387.1	815.1	1202.3	0.5805	0.9361	1.5166	**280.0**
290.0	414.25	0.01885	1.57597	1.59482	390.6	812.0	1202.6	0.5844	0.9291	1.5135	**290.0**
300.0	417.35	0.01889	1.52384	1.54274	394.0	808.9	1202.9	0.5882	0.9223	1.5105	**300.0**
350.0	431.73	0.01912	1.30642	1.32554	409.8	794.2	1204.0	0.6059	0.8909	1.4968	**350.0**
400.0	444.60	0.01934	1.14162	1.16095	424.2	780.4	1204.6	0.6217	0.8630	1.4847	**400.0**
450.0	456.28	0.01954	1.01224	1.03179	437.3	767.5	1204.8	0.6360	0.8378	1.4738	**450.0**
500.0	467.01	0.01975	0.90787	0.92762	449.5	755.1	1204.7	0.6490	0.8148	1.4639	**500.0**
550.0	476.94	0.01994	0.82183	0.84177	460.9	743.3	1204.3	0.6611	0.7936	1.4547	**550.0**
600.0	486.20	0.02013	0.74962	0.76975	471.7	732.0	1203.7	0.6723	0.7738	1.4461	**600.0**
650.0	494.89	0.02032	0.68811	0.70843	481.9	720.9	1202.8	0.6828	0.7552	1.4381	**650.0**
700.0	503.08	0.02050	0.63505	0.65556	491.6	710.2	1201.8	0.6928	0.7377	1.4304	**700.0**
750.0	510.84	0.02069	0.58880	0.60949	500.9	699.8	1200.7	0.7022	0.7210	1.4232	**750.0**
800.0	518.21	0.02087	0.54809	0.56896	509.8	689.6	1199.4	0.7111	0.7051	1.4163	**800.0**
850.0	525.24	0.02105	0.51197	0.53302	518.4	679.5	1198.0	0.7197	0.6899	1.4096	**850.0**
900.0	531.95	0.02123	0.47968	0.50091	526.7	669.7	1196.4	0.7279	0.6753	1.4032	**900.0**
950.0	538.39	0.02141	0.45064	0.47205	534.7	660.0	1194.7	0.7358	0.6612	1.3970	**950.0**
1000.0	544.58	0.02159	0.42436	0.44596	542.6	650.4	1192.9	0.7434	0.6476	1.3910	**1000.0**
1050.0	550.53	0.02177	0.40047	0.42224	550.1	640.9	1191.0	0.7507	0.6344	1.3851	**1050.0**
1100.0	556.28	0.02195	0.37863	0.40058	557.5	631.5	1189.1	0.7578	0.6216	1.3794	**1100.0**
1150.0	561.82	0.02214	0.35859	0.38073	564.8	622.2	1187.0	0.7647	0.6091	1.3738	**1150.0**
1200.0	567.19	0.02232	0.34013	0.36245	571.9	613.0	1184.8	0.7714	0.5969	1.3683	**1200.0**
1250.0	572.38	0.02250	0.32306	0.34556	578.8	603.8	1182.6	0.7780	0.5850	1.3630	**1250.0**
1300.0	577.42	0.02269	0.30722	0.32991	585.6	594.6	1180.2	0.7843	0.5733	1.3577	**1300.0**
1350.0	582.32	0.02288	0.29250	0.31537	592.3	585.4	1177.8	0.7906	0.5620	1.3525	**1350.0**
1400.0	587.07	0.02307	0.27871	0.30178	598.8	576.5	1175.3	0.7966	0.5507	1.3474	**1400.0**
1450.0	591.70	0.02327	0.26584	0.28911	605.3	567.4	1172.8	0.8026	0.5397	1.3423	**1450.0**
1500.0	596.20	0.02346	0.25372	0.27719	611.7	558.4	1170.1	0.8085	0.5288	1.3373	**1500.0**
1550.0	600.59	0.02366	0.24235	0.26601	618.0	549.4	1167.4	0.8142	0.5182	1.3324	**1550.0**
1600.0	604.87	0.02387	0.23159	0.25545	624.2	540.3	1164.5	0.8199	0.5076	1.3274	**1600.0**
1650.0	609.05	0.02407	0.22143	0.24551	630.4	531.3	1161.6	0.8254	0.4971	1.3225	**1650.0**
1700.0	613.13	0.02428	0.21178	0.23607	636.5	522.2	1158.6	0.8309	0.4867	1.3176	**1700.0**
1750.0	617.12	0.02450	0.20263	0.22713	642.5	513.1	1155.6	0.8363	0.4765	1.3128	**1750.0**
1800.0	621.02	0.02472	0.19390	0.21861	648.5	503.8	1152.3	0.8417	0.4662	1.3079	**1800.0**
1850.0	624.83	0.02495	0.18558	0.21052	654.5	494.6	1149.0	0.8470	0.4561	1.3030	**1850.0**
1900.0	628.56	0.02517	0.17761	0.20278	660.4	485.2	1145.6	0.8522	0.4459	1.2981	**1900.0**
1950.0	632.22	0.02541	0.16999	0.19540	666.3	475.8	1142.0	0.8574	0.4358	1.2931	**1950.0**
2000.0	635.80	0.02565	0.16266	0.18831	672.1	466.2	1138.3	0.8625	0.4256	1.2881	**2000.0**
2100.0	642.76	0.02615	0.14885	0.17501	683.8	446.7	1130.5	0.8727	0.4053	1.2780	**2100.0**
2200.0	649.45	0.02669	0.13603	0.16272	695.5	426.7	1122.2	0.8828	0.3848	1.2676	**2200.0**
2300.0	655.89	0.02727	0.12406	0.15133	707.2	406.0	1113.2	0.8929	0.3640	1.2569	**2300.0**
2400.0	662.11	0.02790	0.11287	0.14076	719.0	384.8	1103.7	0.9031	0.3430	1.2460	**2400.0**
2500.0	668.11	0.02859	0.10209	0.13068	731.7	361.6	1093.3	0.9139	0.3206	1.2345	**2500.0**
2600.0	673.91	0.02938	0.09172	0.12110	744.5	337.6	1082.0	0.9247	0.2977	1.2225	**2600.0**
2700.0	679.53	0.03029	0.08165	0.11194	757.3	312.3	1069.7	0.9356	0.2741	1.2097	**2700.0**
2800.0	684.96	0.03134	0.07171	0.10305	770.7	285.1	1055.8	0.9468	0.2491	1.1958	**2800.0**
2900.0	690.22	0.03262	0.06158	0.09420	785.1	254.7	1039.8	0.9588	0.2215	1.1803	**2900.0**
3000.0	695.33	0.03428	0.05073	0.08500	801.8	218.4	1020.3	0.9728	0.1891	1.1619	**3000.0**
3100.0	700.28	0.03681	0.03771	0.07452	824.0	169.3	993.3	0.9914	0.1460	1.1373	**3100.0**
3200.0	705.08	0.04472	0.01191	0.05663	875.5	56.1	931.6	1.0351	0.0482	1.0832	**3200.0**
3208.2*	705.47	0.05078	0.00000	0.05078	906.0	0.0	906.0	1.0612	0.0000	1.0612	**3208.2***

*Critical pressure

NE.I.12.

①

Table 1. Saturated Steam: Temperature Table—*Continued*

Temp Fahr t	Abs Press Lb per Sq In p	Specific Volume Sat Liquid v_f	Specific Volume Evap v_{fg}	Specific Volume Sat Vapor v_g	Enthalpy Sat Liquid h_f	Enthalpy Evap h_{fg}	Enthalpy Sat Vapor h_g	Entropy Sat Liquid s_f	Entropy Evap s_{fg}	Entropy Sat Vapor s_g	Temp Fahr t
460.0	466.87	0.01961	0.97463	0.99424	441.5	763.2	1204.8	0.6405	0.8299	1.4704	460.0
464.0	485.56	0.01969	0.93588	0.95557	446.1	758.6	1204.7	0.6454	0.8213	1.4667	464.0
468.0	504.83	0.01976	0.89885	0.91862	450.7	754.0	1204.6	0.6502	0.8127	1.4629	468.0
472.0	524.67	0.01984	0.86345	0.88329	455.2	749.3	1204.5	0.6551	0.8042	1.4592	472.0
476.0	545.11	0.01992	0.82958	0.84950	459.9	744.5	1204.3	0.6599	0.7956	1.4555	476.0
480.0	566.15	0.02000	0.79716	0.81717	464.5	739.6	1204.1	0.6648	0.7871	1.4518	480.0
484.0	587.81	0.02009	0.76613	0.78622	469.1	734.7	1203.8	0.6696	0.7785	1.4481	484.0
488.0	610.10	0.02017	0.73641	0.75658	473.8	729.7	1203.5	0.6745	0.7700	1.4444	488.0
492.0	633.03	0.02026	0.70794	0.72820	478.5	724.6	1203.1	0.6793	0.7614	1.4407	492.0
496.0	656.61	0.02034	0.68065	0.70100	483.2	719.5	1202.7	0.6842	0.7528	1.4370	496.0
500.0	680.86	0.02043	0.65448	0.67492	487.9	714.3	1202.2	0.6890	0.7443	1.4333	500.0
504.0	705.78	0.02053	0.62938	0.64991	492.7	709.0	1201.7	0.6939	0.7357	1.4296	504.0
508.0	731.40	0.02062	0.60530	0.62592	497.5	703.7	1201.1	0.6987	0.7271	1.4258	508.0
512.0	757.72	0.02072	0.58218	0.60289	502.3	698.2	1200.5	0.7036	0.7185	1.4221	512.0
516.0	784.76	0.02081	0.55997	0.58079	507.1	692.7	1199.8	0.7085	0.7099	1.4183	516.0
520.0	812.53	0.02091	0.53864	0.55956	512.0	687.0	1199.0	0.7133	0.7013	1.4146	520.0
524.0	841.04	0.02102	0.51814	0.53916	516.9	681.3	1198.2	0.7182	0.6926	1.4108	524.0
528.0	870.31	0.02112	0.49843	0.51955	521.8	675.5	1197.3	0.7231	0.6839	1.4070	528.0
532.0	900.34	0.02123	0.47947	0.50070	526.8	669.6	1196.4	0.7280	0.6752	1.4032	532.0
536.0	931.17	0.02134	0.46123	0.48257	531.7	663.6	1195.4	0.7329	0.6665	1.3993	536.0
540.0	962.79	0.02146	0.44367	0.46513	536.8	657.5	1194.3	0.7378	0.6577	1.3954	540.0
544.0	995.22	0.02157	0.42677	0.44834	541.8	651.3	1193.1	0.7427	0.6489	1.3915	544.0
548.0	1028.49	0.02169	0.41048	0.43217	546.9	645.0	1191.9	0.7476	0.6400	1.3876	548.0
552.0	1062.59	0.02182	0.39479	0.41660	552.0	638.5	1190.6	0.7525	0.6311	1.3837	552.0
556.0	1097.55	0.02194	0.37966	0.40160	557.2	632.0	1189.2	0.7575	0.6222	1.3797	556.0
560.0	1133.38	0.02207	0.36507	0.38714	562.4	625.3	1187.7	0.7625	0.6132	1.3757	560.0
564.0	1170.10	0.02221	0.35099	0.37320	567.6	618.5	1186.1	0.7674	0.6041	1.3716	564.0
568.0	1207.72	0.02235	0.33741	0.35975	572.9	611.5	1184.5	0.7725	0.5950	1.3675	568.0
572.0	1246.26	0.02249	0.32429	0.34678	578.3	604.5	1182.7	0.7775	0.5859	1.3634	572.0
576.0	1285.74	0.02264	0.31162	0.33426	583.7	597.2	1180.9	0.7825	0.5766	1.3592	576.0
580.0	1326.17	0.02279	0.29937	0.32216	589.1	589.9	1179.0	0.7876	0.5673	1.3550	580.0
584.0	1367.7	0.02295	0.28753	0.31048	594.6	582.4	1176.9	0.7927	0.5580	1.3507	584.0
588.0	1410.0	0.02311	0.27608	0.29919	600.1	574.7	1174.8	0.7978	0.5485	1.3464	588.0
592.0	1453.3	0.02328	0.26499	0.28827	605.7	566.8	1172.6	0.8030	0.5390	1.3420	592.0
596.0	1497.8	0.02345	0.25425	0.27770	611.4	558.8	1170.2	0.8082	0.5293	1.3375	596.0
600.0	1543.2	0.02364	0.24384	0.26747	617.1	550.6	1167.7	0.8134	0.5196	1.3330	600.0
604.0	1589.7	0.02382	0.23374	0.25757	622.9	542.2	1165.1	0.8187	0.5097	1.3284	604.0
608.0	1637.3	0.02402	0.22394	0.24796	628.8	533.6	1162.4	0.8240	0.4997	1.3238	608.0
612.0	1686.1	0.02422	0.21442	0.23865	634.8	524.7	1159.5	0.8294	0.4896	1.3190	612.0
616.0	1735.9	0.02444	0.20516	0.22960	640.8	515.6	1156.4	0.8348	0.4794	1.3141	616.0
620.0	1786.9	0.02466	0.19615	0.22081	646.9	506.3	1153.2	0.8403	0.4689	1.3092	620.0
624.0	1839.0	0.02489	0.18737	0.21226	653.1	496.6	1149.8	0.8458	0.4583	1.3041	624.0
628.0	1892.4	0.02514	0.17880	0.20394	659.5	486.7	1146.1	0.8514	0.4474	1.2988	628.0
632.0	1947.0	0.02539	0.17044	0.19583	665.9	476.4	1142.2	0.8571	0.4364	1.2934	632.0
636.0	2002.8	0.02566	0.16226	0.18792	672.4	465.7	1138.1	0.8628	0.4251	1.2879	636.0
640.0	2059.9	0.02595	0.15427	0.18021	679.1	454.6	1133.7	0.8686	0.4134	1.2821	640.0
644.0	2118.3	0.02625	0.14644	0.17269	685.9	443.1	1129.0	0.8746	0.4015	1.2761	644.0
648.0	2178.1	0.02657	0.13876	0.16534	692.9	431.1	1124.0	0.8806	0.3893	1.2699	648.0
652.0	2239.2	0.02691	0.13124	0.15816	700.0	418.7	1118.7	0.8868	0.3767	1.2634	652.0
656.0	2301.7	0.02728	0.12387	0.15115	707.4	405.7	1113.1	0.8931	0.3637	1.2567	656.0
660.0	2365.7	0.02768	0.11663	0.14431	714.9	392.1	1107.0	0.8995	0.3502	1.2498	660.0
664.0	2431.1	0.02811	0.10947	0.13757	722.9	377.7	1100.6	0.9064	0.3361	1.2425	664.0
668.0	2498.1	0.02858	0.10229	0.13087	731.5	362.1	1093.5	0.9137	0.3210	1.2347	668.0
672.0	2566.6	0.02911	0.09514	0.12424	740.2	345.7	1085.9	0.9212	0.3054	1.2266	672.0
676.0	2636.8	0.02970	0.08799	0.11769	749.2	328.5	1077.6	0.9287	0.2892	1.2179	676.0
680.0	2708.6	0.03037	0.08080	0.11117	758.5	310.1	1068.5	0.9365	0.2720	1.2086	680.0
684.0	2782.1	0.03114	0.07349	0.10463	768.2	290.2	1058.4	0.9447	0.2537	1.1984	684.0
688.0	2857.4	0.03204	0.06595	0.09799	778.8	268.2	1047.0	0.9535	0.2337	1.1872	688.0
692.0	2934.5	0.03313	0.05797	0.09110	790.5	243.1	1033.6	0.9634	0.2110	1.1744	692.0
696.0	3013.4	0.03455	0.04916	0.08371	804.4	212.8	1017.2	0.9749	0.1841	1.1591	696.0
700.0	3094.3	0.03662	0.03857	0.07519	822.4	172.7	995.2	0.9901	0.1490	1.1390	700.0
702.0	3135.5	0.03824	0.03173	0.06997	835.0	144.7	979.7	1.0006	0.1246	1.1252	702.0
704.0	3177.2	0.04108	0.02192	0.06300	854.2	102.0	956.2	1.0169	0.0876	1.1046	704.0
705.0	3198.3	0.04427	0.01304	0.05730	873.0	61.4	934.4	1.0329	0.0527	1.0856	705.0
705.47*	3208.2	0.05078	0.00000	0.05078	906.0	0.0	906.0	1.0612	0.0000	1.0612	705.47*

*Critical temperature

NE.I.12.

(2)

Code #____________

Radiation Protection

NE.I.13 An accidental discharge of ^{89}Sr into a reservoir resulted in a contamination level of 37 Bq ($10^{-3}\mu Ci$) per cm^3 of water.

a. Using the basic radiological health criterion of the ICRP-26, would this water be acceptable for drinking purposes for the general public if the turn-over half-time of the water in the reservoir is 30 days?

b. If the water were ingested continuously, what maximum body burden would be reached?

c. How long after ingestion started would this maximum occur?

d. What would be the absorbed dose during the first year?

e. What would be the absorbed dose during 50 years following the start of ingestion?

Data:

$$^{89}Sr \xrightarrow[100\%\,\beta]{} {}^{89}Y \text{ (stable), radiological half-life} = 50.5 \text{ day}$$

Deposition fraction of ^{89}Sr in bone is approximately 0.21.
Effective energy of ^{89}Sr in bone is approximately 2.8 MeV per transformation.
Drinking water consumption is about 2.2 liter per day.

Code #________________

Radiation Protection

NE.I.14. Calculate the threshold energy for the (γ,n) reaction of ^{144}Sm. What is the energy of a neutron produced by absorption of a 15-MeV photon?

Data:

Nuclide	Mass Difference (MeV)
neutron	8.07
^{143}Sm	-79.60
^{144}Sm	-81.98