HALLIBURTON SERVICES

DRAWER 1431, DUNCAN, OKLAHOMA 73536-0100

GOVERNMENT REGULATIONS DEPARTMENT
RON BECHTEL
Manager
DAN KELLY
Regulatory Specialist

Writer's Direct Dial Number
(405) 251-3569

Senior Environmental Engineers
STEVE BURFORD
RALPH HOUSER
BILL JONES
Environmental Engineer
JOHN PRESGROVE
Radiation Safety Officers
RICHARD LEONARDI
STEVE HOOK

May 13, 1985

Messrs. Chuck Cain
Jack Whitten
U. S. Nuclear Regulatory Commission
611 Ryan Plaza Drive
Suite 1000
Arlington, Texas 76102

Dear Chuck and Jack:

During telephone conversations in April we discussed several aspects of site burial of iridium 192 coated sand as well as training for Otis Engineering personnel to be covered by our present license 35-00502-02.

Several questions concerning the site burial required a written response from this office. It was indicated during our conversation, that a letter was forthcoming to substantiate the items of concern, but this correspondence has not been received. The attached written material should cover all the items as discussed.

Also attached is an outline of the classroom instruction to be provided to two or more Otis Engineering employees that will represent Otis under this license as Assistant Radiation Safety Officers. The material as outlined will provide three to four weeks of classroom instruction as well as "hands-on" instruction and experience. These personnel completing the classroom instruction will be given written tests (sample attached) and oral examinations to assure their competency. Once the personnel have satisfied these training requirements they will provide the classroom and on-the-job training to the selected operators that will have the "hands-on" responsibility of using and handling radioactive materials as job sites.

Upon successful completion of all the training requirements resumes will be submitted for each individual approved by the present "Radiation Safety Officers" to serve as Assistant Radiation Safety Officers representing Otis Engineering.

If you have questions concerning any of the written material please contact this office at the above address or telephone number.

Respectfully submitted,

Dan G Kelly

Dan G. Kelly

DGK/cdd
Enclosures

cc: Mr. Richard A. Leonardi, Jr.
Mr. Steve Hook

Item 1

Halliburton Services will not dispose of Ir-192 coated tracer sand by the proposed burial procedure of more than 10 mCi at a well site. when a "sand-out" occurs the tubulor goods in the well bore is filled with "tagged" sand. The tubing ranges in size from 1.05 inches to 4.50 inches O.D. (0.824 inches to 3.958 inches I.D.).

The volume of this tubing ranges from 0.00370 cubic feet per linear foot to 0.08544 cubic feet per linear foot. A cubic foot of sand weighs 100 pounds. The normal concentration of Iridium-192 is one millicurie per 4,000 pounds of proppant (sand). Based on the above figures and knowing the depth at which the well was treated the quantity of sand and isotope can readily be calculated.

Example: Well treatment depth is 12,000 feet.
Tubing size is 2.875" I.D. or .03250 cubic feet per linear foot.
Radioactively tagged with Ir-192 at 1 mCi/4,000 pounds.

Calculation:

1) Total volume (assumed tubing is filled to surface)
   12,000 x .02350 = 282 cubic feet
2) Total weigh of sand
   282 x 100 = 28,200 pounds
3) Total number of mCi of Ir-192
   28,200 ÷ 4,000 = 7.05 mCi

Item 2

The disposal of 10 mCi Ir-192 or less by this procedure will be immediately followed with a report to NRC Region IV within thirty days of the disposal. The report will include the following details.

1) The calculated quantity of sand in pounds and the calculated quantity of isotope in millicuries.
2) The well name and number as applicable
3) The Company name
4) The State, County and legal description
5) A statement signed by the landowner granting permission for the disposal
6) Results of the before and after disposal surveys.

Item 3

The wells at which such disposals will be made are in remote areas with access generally controlled by both the landowner and well operator by locked gates and fences. Once the well is completed and placed on production the well area, as well as the land the well is on, is fenced and the gates kept locked permanently to prevent theft of equipment, oil or gas. If adequate security is not provided disposal by this procedure will not be employed.

Item 4

The attached Laboratory Report best details the adsorption properties of radioactive isotopes on formation material. This is proprietary information and must not be made available to the general public. It is a fact that Iridium-192 will be totally absorbed onto soil, dirt or formation upon contact and is essentially non-releasable.

Item 5

The disposal of any hazardous material requires reporting to State and Federal agencies. When related materials are disposed of by this procedure the report to the NRC will definitely include the identity of such organization(s) including such specifics as agency names, addresses and individuals.

Item 6

Both Research data and experience has proven that when a burial of Iridium 192 is made the adsorptive properties will prevent the migration of Ir-192. The Ir-192 will not migrate an inch into the surrounding formation. However, Halliburton Services will not make a disposal within ten feet of a known aquifer.

Item 7

No disposal will be made within 200 yards of a domesticated animal or human occupancy.

FORM 1012 R-6

D. Kelly

RRK

CHEMICAL RESEARCH AND DEVELOPMENT DEPARTMENT

HALLIBURTON SERVICES
DUNCAN, OKLAHOMA

LABORATORY REPORT

No. A19-0003-84

To Mr. R. M. Lasater
Manager - CRD
Research Center

Date December 31, 1984

We give below results of our examination of adsorption of radioactive isotopes on formation material.

Submitted by

Marked

PURPOSE

The purpose of this project is to determine if the radioactive isotopes Iridium (Ir-192) and Iodine (I-131) would adsorb onto formation material. Both sandstone and limestone materials are used.

CONCLUSIONS

The radioactive isotope Iridium-192 (Ir-192) is substantially removed from a liquid solution upon flowing through Berea sandstone and Cordova cream limestone cores. Eighty-seven to ninety-one percent of the Ir-192 radiation is retained within Berea core. Ninety-four percent of the Ir-192 radiation is retained within Cordova cream core.

Reverse flow with deionized water only removed two to four percent of the retained Ir-192 radiation.

The radioactive isotope Iodine-131 (I-131) is not effectively retained by either Cordova limestone or Berea sandstone core. Only twenty-seven to forty-nine percent of the I-131 radioactivity is retained within the cores. Reverse flow with deionized water removed eight to sixteen percent of the retained I-131 radiation.

Virtually all of the I-131 remained with the decanted liquid in the slurry tests. The Ir-192 isotope was proportionally retained on the formation material. Very little removal of Ir-192 was observed with multiple washing.

The Iridium-192 (Ir-192) standard (1 millicurie) from Gulf Nuclear was found to be contaminated with Iodine-131 (I-131). Radiation measurements indicate that up to one-third of the total radiation purchased was due to I-131.

RECOMMENDATIONS

1. Direct high pressure injection of the radioactive isotope Ir-192 is recommended. The Ir-192 isotope is substantially adsorbed from the liquid by the formation. Both limestone and sandstones show effective removal and retention of Ir-192.

2. The radioactive isotope I-131 is not recommended for use as a tracer in fracturing operations. Less than 50 percent is retained by formation materials and up to sixteen percent was readily removed by deionized water washes. The poor retention of I-131 by formation material could cause return fluids disposal problems on location.

Future Study

1. To test direct injection of Iridium chloride at well head and monitor well return fluid for Iridium being returned.

2. To conduct a quality control of presently used RAYFRAC sand from Gulf Nuclear, Inc. checking for contamination by other radioactive isotopes.

DISCUSSION

Radioactive isotopes have been utilized for years in the oil industry as tracer material in the treatment of oil and gas wells. This study was initiated to determine if a liquid form of Iridium-192 radioactive isotope could be used in RAYFRAC operations. Presently, addition of radioactive sand is either at the blender tub or the suction side of a HT-400 pump. In both cases, contamination of equipment, location, material, and personnel does occur as well as possible excessive exposure to radiation. The use of a high pressure liquid injection at the well head, down stream of all surface equipment would significantly eliminate contamination of equipment (other than that dedicated to radioactive injection), materials and personnel. However, use of liquid radioactive tracers precludes that the radioactive material remains downhole. This report covers core flow and slurry tests with formation material to demonstrate that retention of the radioactive tracer occurs on formation material.

Iridium-192 Standard Solution Characteristics

A one millicurie potassium iridium chloride solution manufactured on October 5, 1984 was received on October 10, 1984 from Gulf Nuclear, Inc., Houston, TX. The concentrated solution was diluted to two liters with deionized water. This diluted solution was used in all subsequent tests and is referred to as Iridium stock solution. Figure 1 is a 0-700 KEV gamma ray spectrum of the diluted solution. This spectrum was obtained on October 12, 1984. The solution contains a significant amount of the radioactive isotope Iodine-131 (I-131). The presence of I-131 results in overlapping peaks for Ir-192 and I-131. Net peak areas were calculated by the background correction method illustrated by the dashed lines in Figure 1.

Table 1 lists the gamma ray characteristics of four radioactive isotopes that maybe present in RAYFRAC sand due to cross contamination at Gulf Nuclear, Inc. Only Iridium and Iodine have been detected in the purchased "Iridium" solution.

Table 1 - Gamma ray emission characteristics for several common radioisotopes.

Isotope	Half Life, Days	Energy, KEV*	Yield**
Ir-192	74.2	296	0.29
		308	0.30
		317	0.81
		468	0.49
		589	0.04
		604	0.09
		612	0.06
I-131	8.05	80	0.03
		284	0.05
		365	0.82
		637	0.07
		723	0.02
Sc-46	84	889	1.00
		1,120	1.00
Cs-137	10950	662	0.85

*Energy, KEV - hundred electron volts.
**Yield - number of gammas per disintegration.

Original Iridium and Iodine Activity Level

The Ir-192 solution was prepared on October 5, 1984, and received October 10, 1984. The solution was assayed at that time and indicated contamination by radioactive I-131. Since concentrate was purchased as 1 millicurie of total radiation, only a portion of the radiation was due to Ir-192. If the total radiation is measured on two different days the I-131 contribution can be estimated assuming only Ir-192 and I-131 are present.

Radioactive decay for any isotope is mathematically defined by the equation:

$$Y = (X)^t \quad (1)$$

t = time, days
where Y = activity at time t
X = constant for given isotope.

The value of X can be calculated knowing the half life ($t_{1/2}$) of a given isotope, which for Ir-192 $t_{1/2}$ is 74.2 days and I-131 $t_{1/2}$ is 8.05 days. Substituting an activity value of 0.5 and $t_{1/2}$ values for Ir-192 and I-131 yields the following equations represent the decay characteristics of:

$$\text{Ir-192: } Y = (0.9907)^t \quad (2)$$

$$\text{I-131: } Y = (0.9175)^t \quad (3)$$

The Iridium solution was activated on October 5, 1984 or t_0 = October 5, 1984. All subsequent references to time are based on this date.

Several readings were taken of total radiation on three dates for a 5 milliliter standard volume.

Date	Time, Days	Activity, cpm
October 12	7	887,145
November 27	54	447,526
December 26	82	342,595

The total radiation activity is assumed to be only from Ir-192 and I-131 an equation relating total radiation, R_t, to the contribution of each isotope can be made.

$$R_t = (0.9907)^t X_o + (0.0175)^t Y_o \qquad (4)$$

where X_o = activity of Ir-192 at t_o
Y_o = activity of I-313 at t_o

Solving two equations for two unknowns where R_t is measured at different times allows the original activity of each isotope to be estimated.

The equations are for t = 7 and t = 54

$$887{,}145 \text{ cpm} = (0.9907)^7 X_o + (0.9175)^7 Y_o$$
$$447{,}526 \text{ cpm} = (0.9907)^{54} X_o + (0.9175)^{54} Y_o$$

solving for X_o and Y_o yields

X_o = 735,477 cpm or 67% Ir-192
Y_o + 362,199 cpm or 33% I-131

for t = 7 and t = 82 yields

X_o = 736,823 cpm or 67% Ir-192
Y_o = 359,895 cpm or 33% I-131

Therefore, of the original one millicurie radiation level purchased as Ir-192, only two-thirds of the radiation is Ir-192.

Table 2 compares the theoretical decay rates for Ir-192 and I-131 with the Iridium stock solution as Intensity_t to Intensity_{to} (I/I_o) ratios. The final column represents the percentage of actual radiation in the Iridium stock solution to the expected radiation assuming no I-131 contamination. There is an excessive radiation loss during the first forty days to only sixty-seven percent of theoretical due to the I-131 contamination. If RAYFRAC sand is similarily contaminated this excessive loss of radiation would result in lower than expected radiation levels for treatments.

Table 2. Iridium stock solution decay rate companion to the theoretical decay of Ir-192 and I-131.

Time, Days	Iridium Solution (I/I_o)*	Ir-192 (I/I_o)	I-131 (I/I_o)	Iridium Solution as % of Theoretical Ir-192
0	1.00	1.00	1.00	1.00
5	.85	.95	.65	.89
10	.75	.91	.42	.82
15	.67	.87	.27	.77
20	.62	.83	.18	.75
30	.53	.76	.12	.70
40	.46	.69	.03	.68
50	.42	.63	.01	.67
75	.33	.50	---	.67
100	.26	.39	---	.67

*I/I_o - Intensity at time t divided by intensity at time t_o.

Non Linear Background Correction for I-131

The net peak area correction assumes a linear background exists under the combined Ir-192/I-131 emission peaks. A gamma ray spectrum for a RAYFRAC sand sample dated October 23, 1982 is shown in Figure 2. There exists a non linear background under the major I-131 line. This non linear background is an additional correction which must be made to the net I-131 peak area. Table 3 compares the net Ir-192 intensities with the apparent net I-131 intensities of this aged sand sample which has no active I-131 present (Figure 2). There is a positive relationship between the Ir-192 intensity and the apparent I-131 intensity. A log-log plot of the data in Table 3 has a straight line relationship as follows:

$$CPM_I = 0.3468(CPM_{Ir})^{0.8} \quad r = 0.998$$

where CPM_I is the intensity of the I-131

CPM_{Ir} is the intensity of the Ir-192 and

r is the correlation coefficient

The net I-131 intensity measured earlier is then corrected by subtracting out this Ir-192 contribution. The corrected net I-131 intensity calculated by the following relationship.

$$\text{Intensity}_{I-131} = \text{Net Intensity}_{I-131} - 0.3468(\text{Intensity}_{Ir-192})^{0.8}$$

All I-131 intensities reported have been corrected for the Ir-192 contribution.

Table 3. Intensity of Ir-192 and I-131 for aged RAYFRAC sand (October 23, 1982).

Ir-192 Intensity, cpm	I-131 Intensity, cpm
78,141	2,596
154,478	5,433
302,902	8,275
502,690	13,032
5,153,769	79,006

Sample Dilution Correction

When a known volume of radioactive isotope is diluted the effective radiation point source is moved further away from the detector crystal. Five milliliters of Iridium stock solution was diluted to various volumes with deionized water to establish a dilution correction for the test fluids. Table 4 lists the average of two intensity readings for Ir-192 and I-131 and the dilution factor (D.F.) assuming the 5 milliliter sample is unity. A regression analysis of volume versus dilution factor establishes the equation for computing a dilution factor for any given volume of liquid, assuming 5 milliliters of the Iridium stock solution was initially used.

Regression analysis yields the volume versus D.F. equations:

Ir-192: $D.F._v = 0.9387 + 0.0107(v)$ $r = 0.999$

I-131: $D.F._v = 0.8263 + 0.0237(v)$ $r = 0.998$

Table 4. Dilution Factor evaluation data.

Volume, Milliliters	Ir-192 Intensity cpm	D.F.*	I-131 Intensity cpm	D.F.*
5	226,188	1.000	51,713	1.000
25	187,841	1.204	36,809	1.405
50	153,630	1.472	26,484	1.953
75	129,385	1.748	19,632	2.634
100	112,236	2.015	16,743	3.089
125	90.453	2.297	13,349	3.874

*D.F. Dilution Factor = Intensity(v)/Intensity (5)

Establishment of Empirical Radioactive Decay Curves

Radioactive decay is an ongoing phenomena. The half life, $T_{1/2}$, for Ir-192 is 74.2 days and for I-131 is 8.05 days. Thus the radioactivity of each isotope continuously declines with passage of time. Five milliliters of the Iridium stock solution were sealed in a plastic container and periodic net intensities for Ir-192 and I-131 obtained. The data is tabulated in Table 5. Figure 3 is a semi-log plot of intensity in counts per minute versus days for Ir-192 and I-131. Only the data points from 0 to 31 days are used in the regression analysis of the data. All radioactive assay values in this report were obtained within this 31 day period.

A second reference laboratory standard was prepared on October 29, 1984. It consisted of 50 milliliters of Iridium-Iodine stock solution diluted with 25 milliliters of deionized water. It was prepared for comparison to 50 ml elluent and 20 to 25 milliliters wash water. Table 6 lists the periodic radioactive data obtained for the standard.

Table 5. Radioactive decay characteristics for Ir/I standard solution (5 ml size). T_o = October 5, 1984.

Time, Days	Iridium-192 Intensity, cpm	I/I_o*	Iodine-131 Intensity, cpm	I/I_o*
7	253,050	0.921	118,005	0.568
10	247,146	0.899	91,810	0.442
11	244,768	0.891	82,489	0.397
12	241,441	0.879	78,482	0.378
13	236,619	0.861	70,339	0.339
14	234,902	0.855	62,910	0.303
17	228,317	0.831	47,799	0.231
19	220,851	0.804	42,709	0.206
26	206,605	0.752	24,112	0.116
32	197,322	0.718	14,546	0.070
33	189,748	0.691	13,103	0.063
35	187,149	0.681	11,032	0.053
38	180,529	0.657	8,973	0.043

$*I_o^{Ir}$ = 274,781 cpm

I_o^{I} = 207,743 cpm

Regression analyses of the data results in the following equations for the decay curves:

$$\text{Ir-192:} \quad CPM_t = 274{,}781\ (0.989)^t \qquad r = -0.998$$

$$\text{I-131:} \quad CPM_t = 207{,}743\ (0.920)^t \qquad r = -0.999$$

Table 6. 50/75 milliliter laboratory reference standard t_o - October 5, 1984.

Time, Days	Iridium Intensity, cpm	Iodine Intensity, cpm
24	1,445,716	141,607
26	1,415,361	106,750
27	1,408,161	97,162
28	1,394,565	93,284
31	1,347,807	73,230
33	1,306,055	63,322
34	1,303,895	56,976
38	1,268,837	40,139

The equations resulting from the regression analysis of time, where time equals 0 through 14 days versus log intensity are:

$$\text{Ir-192:} \quad CPM_t = 1,834,858\ (0.990)^t \qquad r = -0.991$$

$$\text{I-131:} \quad CPM_t = 999,735\ (0.919)^t \qquad r = -0.996$$

Formation Slurry Tests

Several formations core samples were evaluated for Ir-192 and I-131 retention. Formations evaluated were Rodessa, Cotton Valley, Pettit, Travis Peak, Olmos and Frontier. Also, silica flour (SSA-1), Berea sandstone and Cordova limestone were evaluated.

The general procedure was to add 5 milliliters of the Iridium stock solution to a known amount of formation material. The resulting slurry was centrifuged, decanted, the solids washed with 20 milliliters deionized water, and the wash water added to the initial supernatant liquid. Liquid volumes were obtained by weight measurements as volumes were not easily measured in the containers used. The density was assumed to be unity. Representative gamma intensities were obtained for both the supernatant liquid and the solids (Table 7). Figure 4 is representative of the partition of isotopes between liquids and solids for the Olmos formation sample. Four samples were subjected to several water washes, followed by a potassium chloride water wash to check for washoff rates (Table 8). Table 7 is a tabulation of data obtained for the slurry tests.

Ir-192 is selectively retained by the formatio s. The amount retained varied from a low of 20 percent fo 1 gram of SSA-1 to a high of 58 percent for 1 gram of Petti limestone. Also with larger quantities of formation materia more Ir-192 was retained on the solids to a high of 78 percent for 5 grams of Pettit limestone. In contrast, I-131 was not effectively retained by the formation materials.

Table 7. Slurry tests using formation material and 5 ml of the Iridium stock solution.

Formation	Sample Wt., gms.	% of 5 ml Reference Solution: Solids Ir-192	Solids I-131	Liquids Ir-192	Liquids I-131
Berea	5	47	3.0	46	100
	10	53	3.1	34	97
	20	60	3.6	23	96
Cordova	5	71	8.9	23	100
SSA-1	1	20	1.4	80	99
Travis Peak	1	51	3.8	43	100
Cotton Valley	1	53	9.2	42	93
Rodessa	1	37	2.3	60	100
Olmos	1	37	2.8	52	94
	3	37	1.9	65	100
	5	59	4.5	48	100
Frontier	1	25	1.3	74	99
	3	22	1.4	72	98
	5	25	1.3	77	100
Pettit	1	57	6.7	34	100
	3	71	7.4	29	100
	5	78	9.1	23	100
	10	77	1.1	15	94

Table 8. Slurry tests, repeated washings with deionized water and 2% KCl water. All 5 gram samples except SSA-1 (1 gram).

		% Radiation of 5 ml Reference Solution			
		Solids		Liquids	
Sample	Wash No.	Ir-192	I-131	Ir-192	I-131
SSA-1	1	20	1.4	80	99
	2	20	1.3	1.1	<0.5
Olmos	1	59	4.5	48	100
	2	47	2.2	11	0.6
	3	45	1.0	2.9	<0.5
	KCl	45	0.7	12	<0.5
Frontier	1	25	1.3	77	100
	2	17	<0.5	10	<0.5
	3	17	0.6	1	<0.5
	KCl	17	<0.5	<0.5	<0.5
Pettit	1	78	9.1	23	100
	2	71	3.9	5.3	1.1
	3	70	4.3	2.4	<0.5
	KCl	67	4.8	1.9	<0.5
Cordova	1	71	8.9	23	100
	2	64	5.7	7	<0.5
	3	61	0.8	3.2	<0.5
	KCl	60	5.3	1.7	<0.5

The data indicate that less than twenty percent of I-131 radioactivity remains with the formation material. The data also indicate that the amount of sample used results in more retention. In contrast significantly more Ir-192 radioactivity is retained on the solids and is directly dependent on the quantity of solids used.

Washoff tests with deionized water indicates less than ten percent removal of Ir-192. I-131 is essentially all removed by one wash. The KCl water wash had little effect on Ir-192 removal except for the very smectitic Olmos formation where 17 percent was released. This indicates the adsorption may be by ion exchange where smectite is present in the formation.

Core Flow Tests

Core flow tests were performed using quarried Berea and Cordova samples. The cores were prepared using epoxy to seal the sides and then sawed to length. One or two fifty milliliters of deionized water flowed through each plug. The data for each flow plug is tabulated in Table 9.

Berea Sandstone

Two flow tests were performed and the data analyzed. The radioactive isotope Ir-192 is 89 percent retained by the core, with 11 percent eluted. Deionized water reversed flow tests shows two and one half of percent washoff of the retained Ir-192. I-131 has 35 percent of the total radiation retained by the core. Deionized water removes 16 percent of the I-131 retained radiation.

Cordova Limestone

The radioactive isotope Ir-192 is 95 percent retained in the plug. Deionized water washes out 2.3 percent of the retained Ir-192 radiation. The I-313 isotope is only 35 percent retained. Deionized water removed 14 percent of the I-131 radiation which was originally retained.

Table 9. Core Flow Tests

Sample	Fluid Tested(Vol.)	Percent of Radiation for 50 ml Reference Solution			
		Liquid Eluted		Retained Core	
		Ir-192	I-131	Ir-192	I-131
Berea 'A'	Iridium (100 ml)	9	56	91	44
	DIW (100 ml)	1.9	7.1	89	37
	% Washed Off**/ Retained	2.1	16	98	84
Berea 'B'	Iridium (50 ml)	13	73	87	27
	DIW (100 ml)	3.3	4.4	84	23
	% Washed off**/ Retained	3.8	16	97	84
Cordova	Iridium (100 ml)	5.0	65	95	35
	DIW (100 ml)	2.2	4.9	93	30
	% Washed off**/ Retained	2.3	14	98	86

* Calculated by difference 100% - Liquid Value
** Calculated with % Retained as unity.

Distribution of Radioactivity Within Cores

After cores were removed from cell they were surveyed for radioactivity levels within the core. The inlet end on all flow plugs was significantly higher than the outlet end level of radiation. This data is tabulated in Table 10.

Table 10. Radioactivity distribution within core plugs.

Sample	Inlet Intensity, cpm Ir-192	Inlet Intensity, cpm I-131	Outlet Intensity, cpm Ir-192	Outlet Intensity, cpm I-131
Berea A	2,479,604	211,239	1,222,442	23,620
Berea B	816,846	63,655	327,546	0
Cordova	2,156,191	180,484	936,990	24,163

To further describe the distribution of radioactivity within the flow plugs, each plug was split lengthwise, and intensities measured with a 4 mm thick lead shield placed between the plug and detector. A second 4 mm thick lead shield containing a 3 by 25 mm slit was used to scan the plug in 3 mm increments from outlet to inlet with the increased activity due to the presence of the slit. The data is presented in Table 11.

The Ir-192 is located nearer the inlet end of the plugs and has three to six times the intensity of the outlet intensity level.

The inlet one-third contains fifty one percent of the Ir-192 radiation, and thirty six percent of the I-131 radiation. The middle one-third contains twenty six percent of the Ir-192 radiation and thirty four percent of the I-131 radiation. The outlet one-third contains twenty three percent of the Ir-192 radiation and thirty percent of the I-131 radiation. Thus the Ir-192 is preferentially concentrated at the inlet end of the core plugs, whereas the I-131 is fairly evenly distributed throughout the cores.

Table 11. Net intensities of split plugs along length.

	Intensity, cpm					
	Berea A		Berea B		Cordova	
Position, mm	Ir-192	I-131	Ir-192	I-131	Ir-192	I-131
Inlet - 3	161,130	8,640	62,291	2,046	150,696	5,453
3 - 6	123,208	8,061	27,406	2,082	81,273	5,083
6 - 9	99,202	7,666	21,475	1,978	60,229	5,316
9 - 12	80,810	6,486	19,122	1,924	50,343	4,853
12 - 15	77,854	5,882	18,489	1,860	42,615	4,126
15 - Oulet	78,817	7,798	17,919	1,429	54,196	4,990
Inlet 1/3	46%	38%	54%	36%	53%	35%
	284,338	16,701	89,697	4,128	231,969	10,536
MID 1/3	29%	32%	24%	34%	25%	35%
	180,012	14,152	40,597	3,902	110,572	10,169
Outlet 1/3	25%	31%	22%	29%	22%	31%
	156,671	13,680	36,408	3,289	96,811	9,116

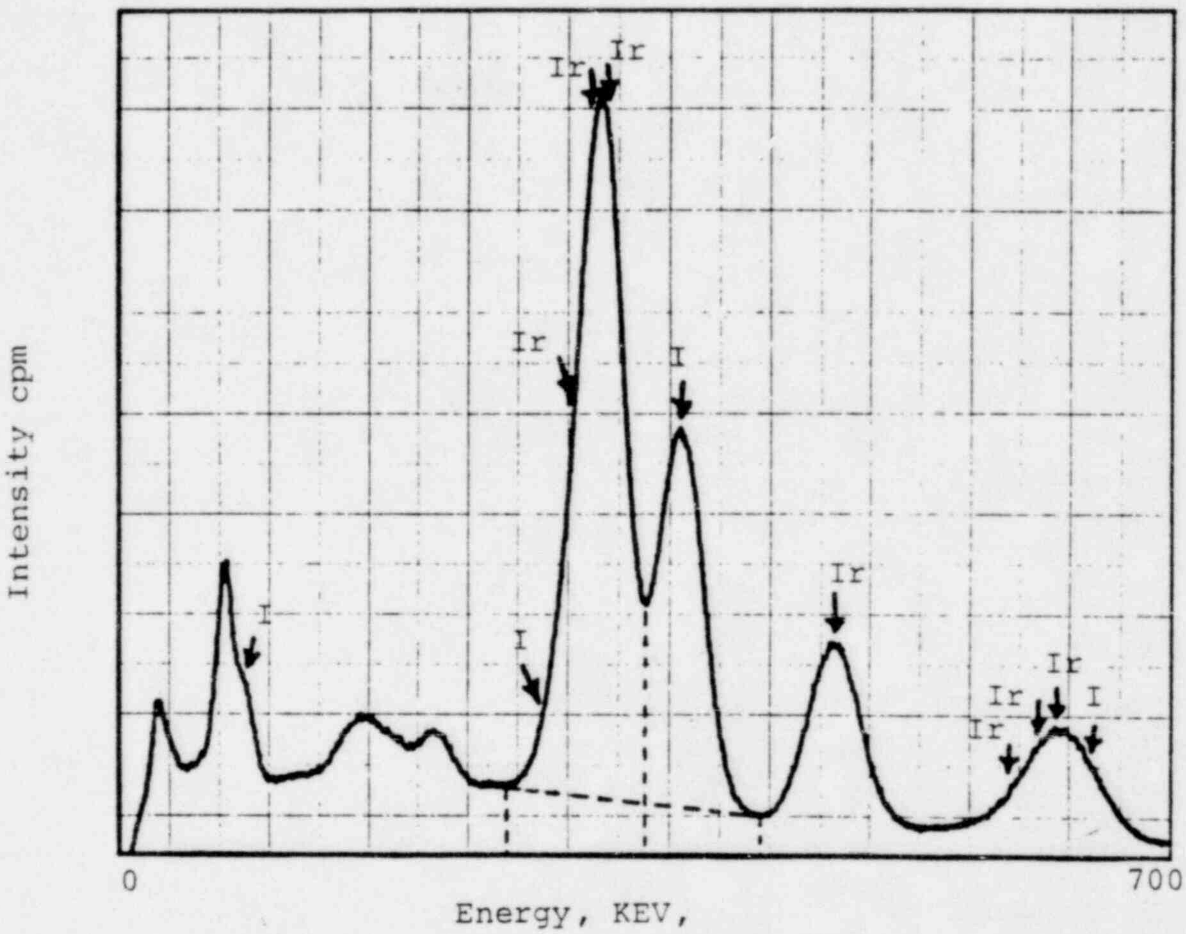


Figure 1. Gamma ray spectra obtained on October 12, 1984 for 5 ml of Ir/I stock solution.

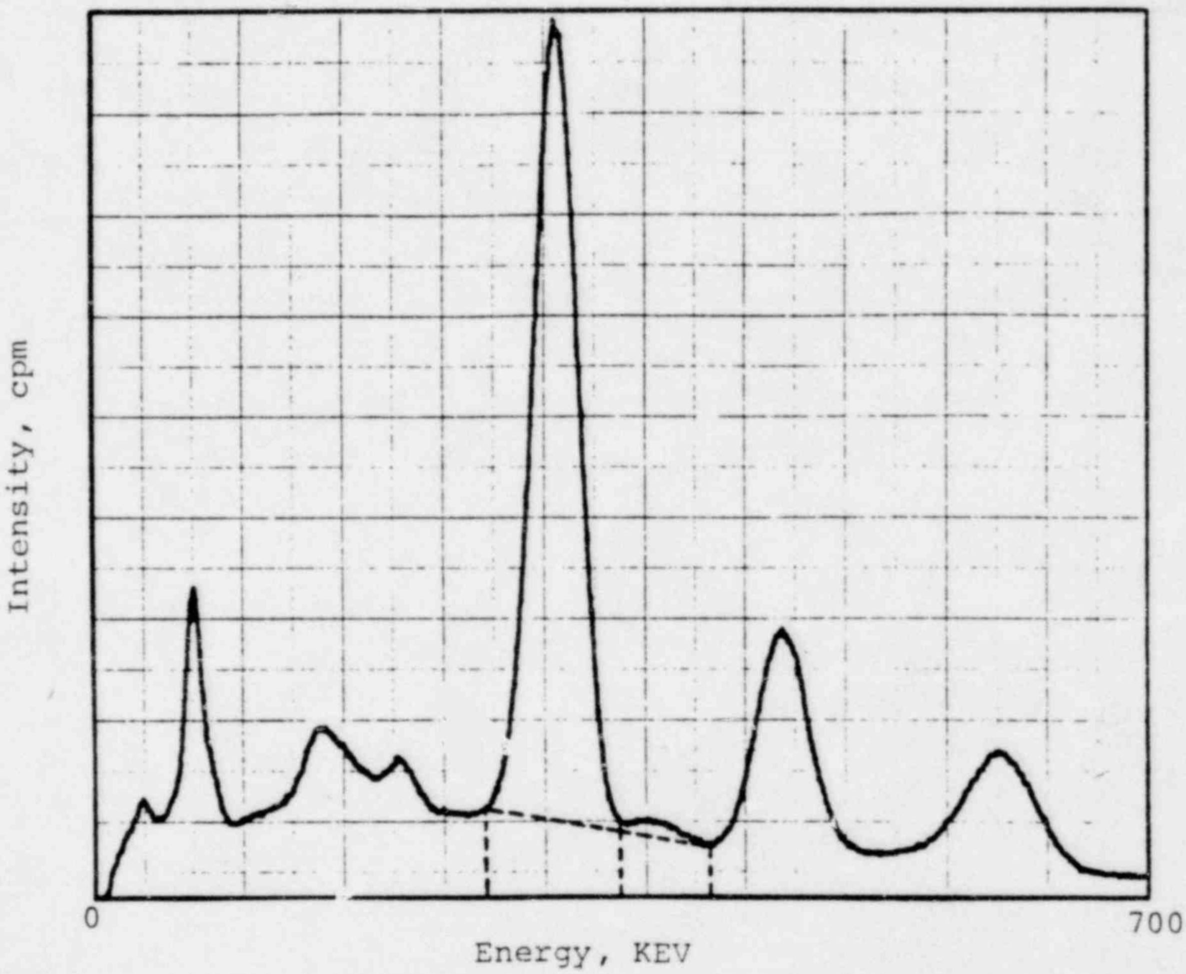


Figure 2. Gamma ray spectrum for RAYFRAC® sand manufactured October 23, 1982. Any I-131 which may have been present has since completely decayed.

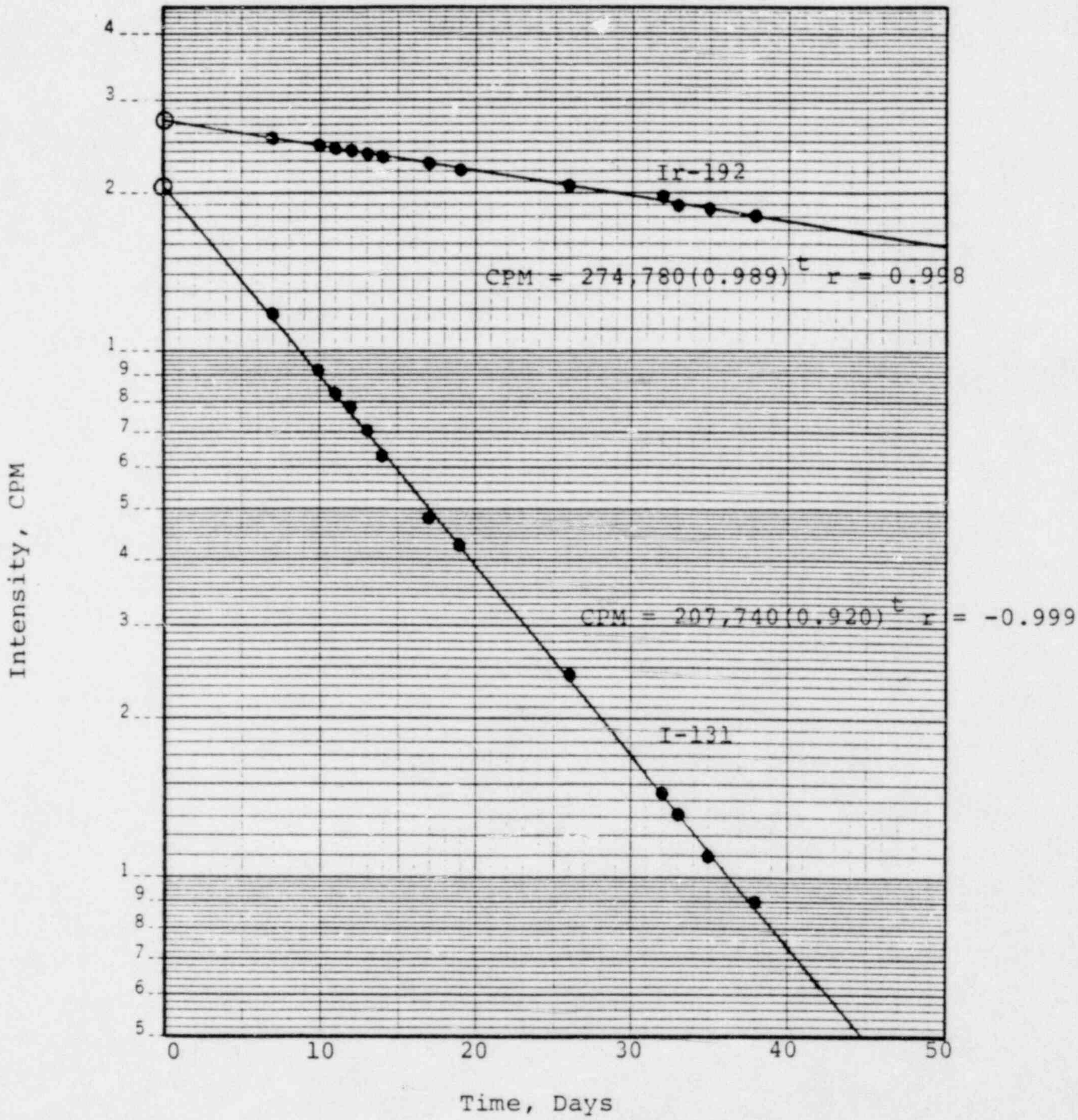


Figure 3. Radioactive decay curves for Ir-192 and I-131 as determined from five milliliter standard. t_o = October 5, 1984

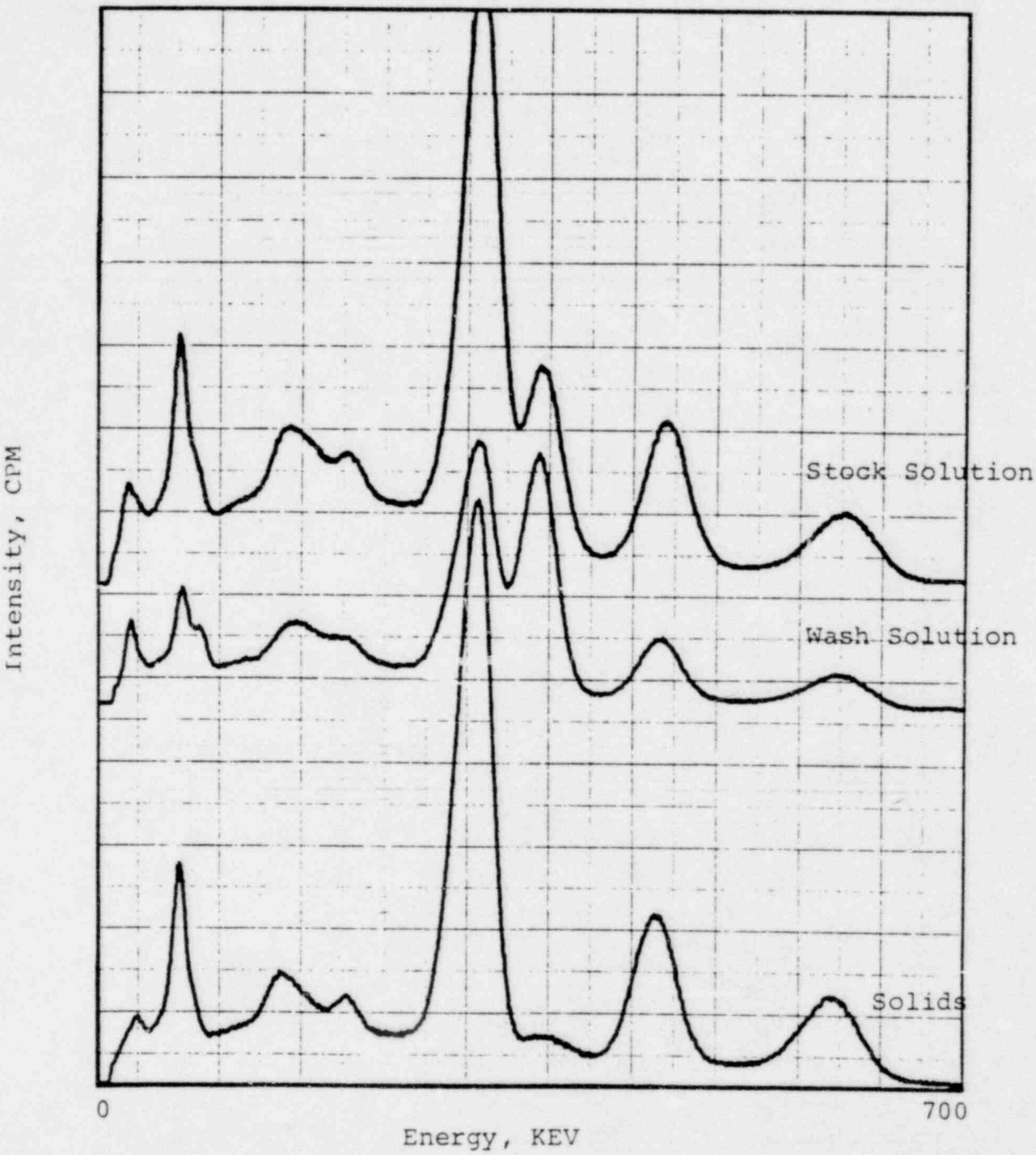


Figure 4. Representative gamma spectra for 5 ml stock solution, washed solids and wash solution.

APPENDIX

Instrumentation

All counting of radioactivity was performed using a Canberra 8180 MCA unit equipped with a scintillation tube. Following is a list of instrument parameters used.

Coarse gain	-	100
Fine gain	-	8.2
Time constant	-	1 usec
Base line restores	-	HI
Pileup rejector	-	IN
LLD	-	0.2
ULD	-	10.0
Convergence gain	-	2,048
Base line	-	4.68
Gate	-	OFF
Digital offset	-	OFF
Preset count time	-	300 sec or 5 minutes (live)
Scintilation Tube HV	-	1,200

The 8180 MCA performs area integration of preset regions-of-interest (ROI). However, deconvolution of overlapping peaks is not performed. Therefore net area calculations were performed separately.

cc: Danny Kelly✓
Jiten Chatterji
Larry Harris

Respectfully submitted,

Laboratory Analyst

HALLIBURTON SERVICES

Simon, Book 5561, pages 30, 31, 32, 34, 35, 36, 37, 38, & 39
jr

By D. E. Simon PhD
D. E. Simon, Ph.D.

TRAINING OUTLINE

I. Fundamentals of Radiation and Radioactivity

A. Atomic Structure

1. Nucleus
   a. Protons
   b. Neutrons
   c. Nucleon
   d. Positron

2. Electron

B. Atomic Notation

1. Atomic Number (Z)
2. Mass Number (A)
3. Chemical Symbol (X)

C. Nuclear Mass and Energy

1. Atomic Mass Units (AMU)
2. Erg
3. Electron Volt

D. Mass and Energy $E = MC^2$

E. Nuclear Binding Energy

F. Nuclear Stability

1. Stable (non-radioactive)
2. Unstable (radioactive)

G. Radioactivity

1. Decay or disintegrate
2. Half-life ($e^{-\lambda\tau}$)
3. Fraction remaining ($A = Aoe^{-\lambda\tau}$)
4. 10 half-lives (99.88% decay)

H. Curie (3.7×10^{10} dps)

1. Sub-multiples

I. Types and Origin of Radiation

1. Spontaneously emitted radiation
   a. Alpha decay

b. Positron decay
c. Orbital electron capture
d. Beta emission
e. Isomeric Transition
f. Gamma Emission
g. Internal Conversion

2. Neutron Radiation
   a. Fission fragments
   b. Nuclear Reactor
   c. Nuclear Bombardment
   d. Spontaneous fission neutron (252 cf.)
   e. Neutron generators (accelerator type)

J. Chart of the Nuclides

1. General arrangement
2. Specific Nuclide Representation
3. Graphical Transition

II. Radiation Interaction with Matter

A. Characteristics of absorption

1. Ionization
2. Type of radiation
3. Nature of absorber
4. Transfer of energy
   a. Specific ionization (SI)
   b. Linear energy transfer (LET)

B. Alpha Radiation

1. Electrical field
2. Interaction
3. Orbital electrons
4. Penetration
5. Range or distance
6. Speed
7. Mass
8. Kinetic energy
9. Range - energy
10. Ionization

C. Beta Radiation

1. Spectrum of energies
2. Interaction
3. Average energy (E avg) = (1/3 E max)
4. Penetration
5. Speed
6. Range
7. Mass
8. Kinetic energy

9. Positrons
   a. Absorption
   b. Two Gamma rays (.51 MeV each)
   c. Annihilation photons

10. X-ray (Bremsstrahlung)
    a. Deacceleration of high speed particles
    b. Deflection
    c. Energy ($f = 3.5 \times 10^{-4} Z\varepsilon$)

D. Gamma, X-rays and Bremsstrahlung

1. No charge
2. No mass
3. Interaction
4. Energy transfer
5. Range
6. Interactions
   a. Photoelectric
      i. low energy photons
      ii. energy absorption
      iii. outer shell electrons
      iv. wavelength
   b. Compton
      i. increased energy
      ii. scattering
      iii. energy absorption
      iv. scatter angle
   c. Pair production
      i. energy (1.02 MeV+)
      ii. energy conversion
      iii. electrostatic field
      iv. pair production (positron-electron)
      v. kinetic energy
      vi. mode contribution

7. Attenuation
   a. $f = 1-e^{-\mu X}$
   b. Build-up factor ($I = Io\ Be^{-\mu X}$

8. Neutrons
   a. Fast $^{-\Delta\varepsilon}$ Slow $^{\Delta\varepsilon}$ Thermal
   b. Range
   c. Inelastic Scattering (high Z)
   d. Elastic Scattering (low Z)
   e. Absorption (low energy)
   f. Cross-section ($\sigma_4 = \sigma si + \sigma se + \sigma a +$ ....)
   g. Barn ($10^{-24} cm^2$/atom)

III. Radiation Exposure

A. Radiation Units

1. Roentgen

a. Air dose
b. Absolute standard
c. 87.6 ergs 1 g of air
d. Limitations
e. Not time dependent
f. Intensity (R/hr or mR/hr)

2. Rad
   a. Energy absorbed
   b. 100 ergs/g of tissue
   c. Roetgen to Rad
   d. Unity for muscle tissue
   e. Bone and fat differ
   f. Effects of types of radiation

3. REM
   a. Dose equivalent
   b. REM = rad x quality factor
      i. depends on LET
   c. Quality factor
      i. X-ray
      ii. Gamma
      iii. Beta
      iv. Alpha at various energy levels (LET)
      v. Neutrons at various energy levels (MeV)

B. Radiation Effects

1. Acute
   a. Chromosome aberation
   b. Blood cell division inhibition
   c. Bone marrow
   d. Hematopoietic syndrome
      i. above 50R
      ii. Decrease in cells
      iii. Lymphocyte destruction
      iv. replacement inhibited
   e. Gastrointestinal syndrome
      i. above 600R
      ii. duodenum lining
      iii. diarrhea
      iv. intravenous administration
   f. Central nervous system syndrome
      i. 2000 + R
      ii. symptoms

2. Chronic
   a. Latent Period
   b. Natural background
   c. Dose-time-effects

      i. accelerated aging

ii. cancer induction
iii. genetic
iv. life span shortening

C. Radiation effects on Specific Body Areas

1. Skin and hair
   a. 400-500 rem - loss of hair
   b. 500-600 rem - erythema
      i. 7-10 days
      ii. repair, dryness, tanning
   c. 1,500-2,000 rem - severe erythema
      i. blistering
      ii. scars
      iii. inhibition of cell division

2. Reproductive system
   a. 100-150 rem - temporary sterility
      i. 12-36 months in women
   b. 300-800 rem - permanent sterility
      i. older women - less dose required
   c. 10 rem - low sperm count in men
   d. 250 rem - sterility for 2-3 years
   e. 400-600 rem - permanent sterility in men

3. Prenatal development
   a. Preimplantation Period (11 days)
      i. high percentage of prenatal deaths (200 R)
      ii. morphological abnormalities
   b. Organogensis
      i. few prenatal deaths
      ii. morphological abnormalities high
      iii. neonatal deaths increase

4. Eyes
   a. Opacities of eye (cataracts)
   b. 500 rads Beta Gamma
   c. 200 rads Neutron

D. Radiation Protection Limits (External)

1. Risk versus benefit philosophy

2. National Council for Radiation Protection (NCRP)

3. Federal Radiation Council (FRC)

4. International Organizations
   a. International Commission of Radiation Protection (ICRP)
   b. International Commission on Radiological Unit & Measurements (ICRU)

c. International Atomic Energy Agency (IAEA)

5. Occupational Exposure
   a. 18 years of age or older
   b. 10 X non-occupational limit
   c. Skin - 30 rem/yr or 10 rem/13 wks
   d. Hand and forearms - 75 rems/yr or 25 rems/13 wks
   e. Feet and ankles - 75 rems/yr or 25 rems/13 wks
   f. Thyroid - 30 rems/hr or 10 rems/ 13 wks
   g. Bone marrow - 5 rems/hr or 3 rems/ 13 wks
   h. Whole body - 5 rems/hr or 3 rems/ 13 wks
   i. Other internal organs - 15 rems/hr or 43 wks
   j. Fertile women (with fetus) - 0.5 rems/ yr or 0.3 rems/13 wks
   k. D = 5 (n-18)
   l. Dose account concept

IV. Radiation Safety Instrumentation

A. Personnel Dosimeters

1. Film badges
   a. Packet of light tight film
   b. Darkens with radiation exposure
   c. Compare to standard
   d. High or low energy photon sensitive
   e. Neutron sensitive (special emulsion)
   f. Beta particle sensitive
   g. Open window - all types
   h. Selective absorbers
   i. No alpha

2. Pocket Dosimeters
   a. Condenser
   b. Charged fiber
   c. Neither reliable with X time
   d. Both subject to leakage
   e. Both sensitive to unusual shock

3. Thermoluminescent Dosimeters (TLD)
   a. Storage of radiation energy in crystalline material
   b. Released thermally
   c. Produces luminescense
   d. Lithium flouride
   e. Calcium sulfate and LiF
   f. Effective Z that of tissue

g. LiF least energy dependent
h. All types of radiation
i. 100 KeV to 1.3 MeV gamma-range

B. Radiation Detection Instrumentation (Hands-on)

1. Geiger-Mueller Detector
   a. Cylindrical glass or metal tube
   b. Thin mica window
   c. Counting gas (helium or argon)
   d. Quenching gas (bromine or organic vapor)
   e. Anode projects from one end
   f. Cathode plated on inside wall of tube
   g. H.V. across electcdes collect charge
   h. Proper voltage determined for each tube
   i. Count std while adjusting H.V.
   j. Particle entering tube produces ions
   k. Ions attracted to opposing terminals
   l. Pulses routed through pre amp
   m. Descriminator permits scaler response
   n. Pulses fed into scaler component

2. Internal Proportional Counter
   a. Steel hemisphere usually
   b. Sample dish for counting
   c. Tungsten wire loop anode
   d. Hemisphere wall functions as cathode
   e. Counting gas inlet
   f. Will count alpha and beta
   g. Count alpha and beta separately

3. Principles of Counting Statistics
   a. Counts per unit time inconsistant
   b. Short time interval
   c. Low activity of sample
   d. Poisson distribution
   e. Gaussian distribution
   f. Plot observation frequency versus numerical value
   g. Bell shaped or normal curve
   h. Mean count
   i. Standard deviation
   j. Confidence level (C.L.)
   k. Error σ = R/t
   l. Theory of propagation of error
   m. Minimum detectable activity

4. Survey Meters
   a. Portable devices
   b. Three types

5. Geiger-Mueller Survey Meter
    a. Ion collection
    b. Primary and secondary electrons
    c. Incident radiation
    d. Ionizing events
    e. Integrating circuit
    f. Averages output
    g. Specific time
    h. mR/hr or cpm
    i. Beta and gamma
    j. No alpha
    k. Solid metal window
    l. Beta in cpm
    m. Gamma in cpm or mR/hr
    n. Exceed capacity - damage to G.M.
    o. Jamming
    p. Energy dependent
    q. Calibration
        i. known intensity source
        ii. Cs-137 and Co-60
        iii. multiple reading
        iv. ¼ and 3/4 of scale
        v. correct with potentionmeter
        vi. plot meter reading vs. true intensities
        vii. x or gamma radiation only

6. Ionization Chamber Survey Meter
    a. Secondary ion production
    b. No external amplification
    c. 30 to 50 cubic inches
    d. Filled with air
    e. Sensitivity increases with volume
    f. Juno and cutie pie
    g. More precise than G.M.
    h. Little energy dependence
    i. No jamming
    j. Excellent for high radiation areas
    k. Calibrate as a G.M.

7. Scintillation Survey Meters
    a. Salt crystal (NaI)
    b. Responds to radiation by light emission
    c. Light strikes the photocathode
    d. Converted to electrical pulses
    e. Magnified and registered on a microammeter
    f. Operation similar to G.M. and Ion Chamber
    g. Can detect alpha, beta, gamma, x, neutrons
    h. Use proper phosphor
    i. Extremely low level detection
    j. Minimum dead time losses

8. Alpha Survey Meters
   a. Probe much larger than G.M.
   b. Very thin window
   c. Atomospheric pressure
   d. Filled with gas before use (purging)
   e. 10% methane - 90% argon (P-10)
   f. Proportional counter
   g. Alpha detection in presence of beta and gamma

9. Neutron Survey Meter
   a. BF_3 type detector
   b. Proportional counter
   c. Sealed tube with no purging
   d. Boron-10 enriched BF_3 gas
   e. High interaction cross-section
   f. $^{10}B(n,\alpha)^7Li$ reaction with thermal neutrons
   g. Alpha particle released
   h. Tube responds with the formation of a pulse
   i. Meter integrates the number of pulses
   j. Registers a count rate (cpm)
   k. Calibrate with a known source
   l. cpm each n/cm^2-sec.
   m. 267 n/cm^2-sec. = 1mR/hr for thermal neutrons
   n. 7.5 n/cm^2-sec. = 1 mR/hr for fast neutrons
   o. Moderate or slowdown fast neutrons
   p. Plastic or cadmium covered moderator
   q. Acts to thermalize fast neutrons
   r. Voltage setting is optimum
   s. Does not detect gamma

V. Principles of Radiation Protection

A. Historical Review

1. Earliest Concepts
2. Functions of Radiation-protection organizations
3. Development of codes, Standards, and Regulations
4. Administrative Aspects
5. Technical and scientific aspects
6. Legal and Regulatory aspects
7. Development of educational programs

B. Radiation Protection and Control Guides

1. ICRP
2. NCRP
3. ASA
4. Areas of encounter and control standards

a. Source and use of radionuclide
b. Identification of hazards
c. Recommended operation standards
   i. MPBB
   ii. MPC°w
   iii. MPC°a
   iv. MPC
   v. MPC-b
   vi. $MPC^{c}a$
   vii. $MPC^{e}a$
   viii. $MPC^{e}s$
   ix. $MPC^{e}v$
   x. $MPC^{e}m$
d. Properties of radionuclides
   i. nuclear properties
   ii. physical properties
   iii. radiological data
   iv. methods of analysis
   v. maximum permissible levels

5. Protection and control measures
   a. Avoid unnecessary exposure
   b. ALARA
   c. Maintain all exposures below mpc
   d. Area contamination
      i. Mpc
      ii. smearable
      iii. fixed
   e. Environmental Contamination
      i. MPC
      ii. ALARA
      iii. airborne
      iv. waterborne
      v. soil and surface

6. Bioassay and Internal Dose Analysis
   a. All new employees
   b. Urinanlyses
      i. chemical analysis
      ii. radiometric analysis
      iii. spectrum analysis
   c. Fecal analysis
      i. chemical analysis
      ii. radiometric
      iii. spectrum
   d. Breath analysis
      i. C14
      ii. Ra
   e. Blood analysis
   f. Thyroid
      i. I uptake
   g. Wholebody

7. Radiation protection
   a. shielding
      i. H.V.L.
      ii. Attenuation
   b. Time
   c. Distance
      i. inverse square
   d. Medical treatment
   e. Chemical treatment
   f. Clothing (anti-c)
   g. Respirator
   h. Ventilation

8. Policy and Guidelines
   a. Administrative standards
      i. policy statements
      ii. responsibility, authority, accountability
      iii. rules in regulated areas
      iv. working limits
      v. transmittal of exposure information
      vi. investigating radiation hazard incidents
      vii. reporting radiation hazard incidents
   b. Radiation control standards
      i. issuance or RWP
      ii. safe removal of R/M from contamination zone
      iii. ingestion hazard control
      iv. inhalation hazard control
      v. safe control of service work in regulated areas
   c. Radiation protection standards
      i. rules for protection from internal hazard
      ii. rules for use of respirators
      iii. protective clothing program
      iv. prevention of absorption through skin breaks
      v. treatment of injuries
   d. General standards
      i. receipt of R/A material
      ii. storage
      iii. shipment

9. Air Sampling
   a. Objectives
      i. evaluate airborne hazard
      ii. determine ventilation requirements
      iii. determine respiratory protection needs
      iv. establish safe handling procedures
   b. Physical composition

- i. particule size
- ii. biological ½L
- iii. identity

c. Criteria for effective air sampling
- i. knowledge of operation
- ii. selection of air sampling units and methods
- iii. determine air sampling period
- iv. apply appropriate correction factors
- v. evaluation of data

d. General problems in air sampling
- i. improper calibration and maintenance at flowmeters
- ii. plugging of orifices and variation in air-flow rates
- iii. improper seating or rupture of the filter medium
- iv. improper packing at scrubber unit
- v. variation in liquid level in scrubber
- vi. entrainment of scrubber solution
- vii. sublimation of collected activity from deliquified scrubber
- viii. variation of inert atmosphere and background radiation
- ix. splattering or fracturing of particles
- x. agglomeration of particles
- xi. decay
- xii. nonproportional air sampling and equipment failures
- xiii. sampling in wrong area

e. Air-sampling devices
- i. cascade impactors
- ii. staplex
- iii. high volume
- iv. impingers and bubblers
- v. electrostatic precipitator
- vi. thermal precipitator

10. Environmental Analysis and Bioassay

a. Objectives
- i. to protect people
- ii. to protect property
- iii. to determine activity
- iv. to ensure compliance to regulations
- v. customer and public relations

b. Collection of samples
- i. type
- ii. method
- iii. frequency
- iv. specification (location, number, size)
- v. packaging

- c. Method of analysis and detection
  - i. direct, radiochemical, etc.
  - ii. activity to be analysed
  - iii. sensitivity and reproducibility
  - v. correction factors
- d. Evaluation of results
  - i. compare with mpc
  - ii. compare with background
  - iii. determine possible trends
- e. Job operation surveys
  - i. preoperational
  - ii. operational
  - iii. post operational
  - iv. areas to survey
  - v. equipment to survey
  - vi. survey technique
  - vii. records
- f. Bioassay
  - i. prevent somatic injury
  - ii. assure compliance
  - iii. limitations
  - iv. sampling techniques and procedures
  - v. analysis
  - vi. evaluations and interpretations
  - vii. MPBB
  - viii. policies and regulations
  - ix. frequencies
  - x. emergency procedures

VI. Waste Control and Disposal

A. Airbone wastes

1. Ventilation
   - a. 1000 cfm fan and motor
   - b. Hood
   - c. Prefilter
   - d. Hepa filter
   - e. MPCa

B. Liquid wastes

1. Dilution of low activity wastes
   - a. MPCs Schedule B Part 20
   - b. MPCw Schedule B Part 20

2. Storage of high activity wastes
   - a. Consolidate (concrete)
   - b. Ion exchange
   - c. Decay
   - d. Commercial

C. Solid wastes
   1. Decontamination and re-use
   2. Licensed incineration
   3. Burial sites
   4. Holding facilities

VII. Regulations

A. Nuclear Regulatory Commission

   1. Washington, D. C.
   2. Regional Offices
      a. Region I, King of Prussia, PA 215/337-5000
      b. Region II, Atlanta, GA 404/221-4503
      c. Region III, Glen Ellyn, IL 312/790-5500
      d. Region IV, Arlington,TX 817/860-8100
      e. Region V, Walnut Creek, CA 415/943-3700

   3. Title 10, Chapter 1, Code of Federal Regulations
      a. Part 19, Notices, Instructions, and Reports to Workers; Inspection's
      b. Part 20, Standard for Protection Against Radiation
      c. Part 30, Rules of General Applicability to Domestic Licensing of Byproduct Material
      d. Part 31, General Domestic Licenses for Byproduct Material
      e. Part 32, Specific Domestic Licenses to Manufacture or Transfer Certain Items Containing Byproduct Material
      f. Part 39, Proposed, Licenses and Radiation Safety Requirements for well-logging operations
      g. Part 170, Fees

B. Agreement States

   1. Licensing
   2. Reciprocity Agreements
   e. Fees
   f. Notification

QUIZ

FUNDAMENTALS OF RADIATION AND RADIOACTIVITY

1. Described the structure of the atom in terms of electrons, protons, and neutrons.

2. What two particles in the atom must be equal in number for the structure to be electrically neutral?

3. Atoms which are not electrically neutral have undergone what process?

4. What term is used to refer to an atom which is not electrically neutral?

5. How does the energy typically required to remove an electron from an atom compare with the energy required to remove a proton? What does this indicate about stability of the nucleus and orbital shell?

6. Provide the following information for each atomic notation.

	element	atomic number(Z)	mass number(A)	Number of electrons	Number of protons	Number of neutrons
$^{60}_{27}Co$						
$^{40}_{19}K$						
$^{17}_{7}N$						
$^{131}_{56}Ba$						
$^{111}_{47}Ag$						
$^{3}_{1}H$						

7. What unit is most commonly used to express the amount of energy deposited in tissue by radiation?

8. Define the electron-volt. What use is made of this unit in the radiation field?

9. How much energy is released when 1 atomic mass unit of matter is converted to energy? Express in MeV.

10. What is the source of energy in the nucleus of an atom where energy releases occur?

11. What property of the nucleus has a major influence on nuclear stability?

12. What is meant by nuclear stability?

13. What nuclear requirement is necessary for nuclear stability?

14. What is the limiting atomic number above which no completely stable nuclei exists?

15. Define the term isotope; radioisotope; radionuclide.

16. Define radioactivity; radioactive decay; radioactive disintegrations.

17. A quantity of 131I was assayed on January 2, 1979 and yielded an activity of 50 μCi: Calculate the activity of the sample on January 30, 1979.

18. A radiographic source of 137 Cs was calibrated on May 10, 1963. What fraction of the activity would be present on January 15, 1979.

19. A source of 131I is needed with an activity of 10 mCi: if the half-life of 131I is 8.0 days, what activity should be purchased so that the activity in 18 days will be 10 mCi?

20. A series of decay rates of a single radionuclide sample which is known to decay into a stable nuclide were recorded as follows:

Time	Decay Rate (cpm)
0 hours	1200
6 hours	850

Which is the half-life of the radionuclide?

21. A sealed source of ^{60}Co is producing 150 units of radiation intensity on August 6, 1978. What radiation intensity will exist on August 6, 1982?

22. Calculate the percent of the activity remaining in a sample after the following decay times.

Decay Time	Fraction Remaining
5 half-lives	______
10 half-lives	______
15 half-lives	______

23. An unknown samples is observed to undergo 5.2×10^{10} disintegrations per second. What is the activity of the source in Curies; millicuries?

24. A beta emitting radionuclide has an activity of 1.5 μCi. How many beta particles would you expect to be emitted per minute from the sample?

25. Convert the following quantities:

Activity		
20 mCi	=	______ mCi
1.5×10^5 pCi	=	______ μCi
25.2 mCi	=	______ Ci
2.22 pCi	=	______ Ci

26. Determine the type of decay which occurs with the following radionuclides and the percent of occurrence if applicable.

Radionuclide	Type of Decay	Percent occurrence
^{3}H	B^-	100%
^{14}C	______	______
^{26}Al	______	______
^{22}Na	B+ and ε(E.C.)	______

^{36}Cl	______	______
^{40}K	______	______
^{54}Mn	______	______
^{99m}Te	______	______
^{185}Au	______	______
^{210}At	______	______
^{228}Th	______	______
^{63}Zn	______	______

27. Complete the following radioactive decay equations:

(a) $^{137}Cs \longrightarrow B^{-} +$ ______

(b) $^{45}Ca \longrightarrow B^{-} +$ ______

(c) $^{65}Zn \xrightarrow{\varepsilon}$ ______

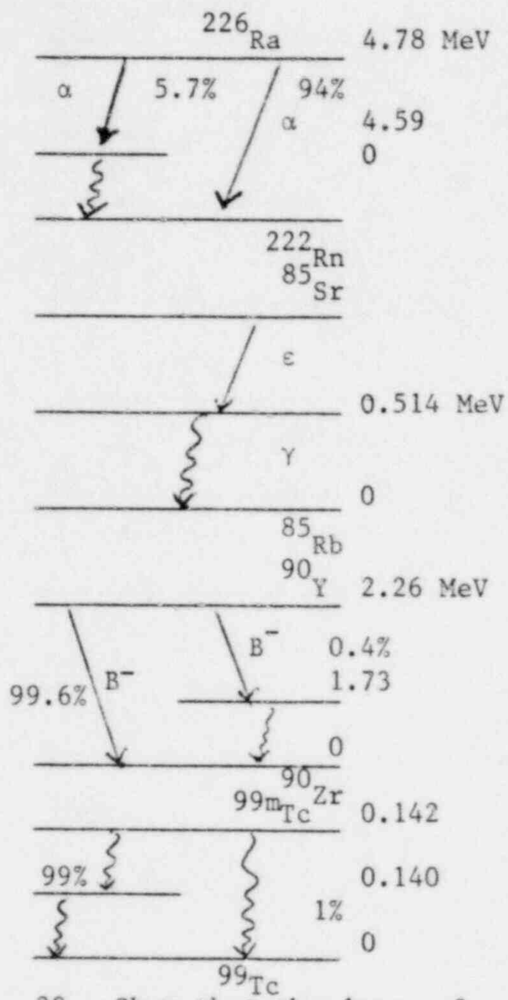
(d) $^{65}Zn \longrightarrow B^{+} +$ ______

(e) $^{69m}Zn \longrightarrow e^{-} +$ ______

(f) $^{226}Ra \longrightarrow He^{++} +$ ______

28. List the type of radiation, percent occurrence and radiation energy for each decay scheme.

Type of Radiation %Occurrence Energy



29. Show that the decay of a radionuclide by alpha decay actually increases the n/p ratio.

30. A table of radionuclide data listed the following information for a series of isotopes. Explain what the information means.

(a) ^{137}Cs — B^- - 1.176 (max.), 0.514 max.
e^- - 0.624, 0.656
α - Ba X-rays 0.662 (85%)

(b) ^{219}Rn — γ - 6.82 (81%), 6.55 (11%), 6.42 (87%)
α_- - Po X-rays, 0.272 (9%), 0.0401 (5%)
e^- - 0.179, 0.255, 0.308

(c) ^{137m}Ba — γ_- - Ba X-rays, 0.662 (89%)
e^- - 0.624, 0.656

(d) ^{25}Al — B^+ - 3.24 max.
γ - 0.511 (200%)

31. Check the appropriate blank to indicate which properties are appropriate for each element.

Element	Radioactive	Non-Radioactive	Naturally occurring	Isomeric States
^{3}H	____	______	__________	________
^{26}Mg	____	______	__________	________
^{40}Cl	____	______	__________	________
^{65}Zn	____	______	__________	________
^{97}Tc	____	______	__________	________
^{115}In	____	______	__________	________
^{154}Sm	____	______	__________	________
^{190}Pt	____	______	__________	________
^{204}Pb	____	______	__________	________

32. Write a brief statement or equation to explain the production of neutron radiation by the following methods.

(a) bombardment -
(b) spontaneous fission -
(c) accelerator -

RADIATION INTERACTION WITH MATTER

1. What is α, β and γ radiation referred to as ionizing radiation?

2. What are the two major types of interaction which occur when a gamma photon passes through a material?

3. What is meant by the term ion-pair in radiation interactions?

4. How much energy is needed to produce an ion pair in air?

5. The amount of energy deposited within a material per unit path length by a radiation particle would be expressed in what units?

6. Specific ionization is usually expressed in what units?

7. Fill in the blanks below which describe the basic characteristics of five types of nuclear radiation which were studied in this unit.

RADIATION	SYMBOL	NATURE	MASS	CHARGE	SOURCE	RELATIVE PENETRATING ABILITY (1-10)
Alpha				+ 2		10 (least)
beta	β					
positron					Radioactive material	
gamma		photon				
neutron			1 AMU			1 (most)

8. What happens to an alpha particle when all of its kinetic energy is lost within a material?

9. What role does the electric field of the alpha particle have in radiation interactions?

10. Describe the energy distribution of alpha particles emitted from a radioactive material.

11. Determine the range of the following alpha particles in the various media.

Energy	Material	Range (cm)
4.0 MeV	air ($P=1.29x10^{-3}g/cm^3$)	______
6.2 MeV	water ($P=1.0g/cm^3$)	______
5.5 MeV	tissue ($P=1.1g/cm^3$)	______

12. Describe the energy distribution of a beta- particle and a positron.

13. What is meant by the term E max or 2.0 MeV_{max}?

14. Calculate the E_{avg} for a beta spectrum with an E max of 1.5 MeV.

15. Calculate the range of the following beta particles in the various media.

Energy	Material	Range (cm)
1.2 MeVmax	air	______
2.27 MeVmax	water	______
0.53 MeVmax	tissue	______

16. A commonly used rule of thumb is that the range of a beta particle in air is about 12 ft/MeV. On this basis, calculate the range of the Yttrium-90 beta (E max=2.27MeV).

17. If the dead layer of the skin is about 0.07mm or $7mg/cm^2$ thick, what energy alpha and beta particle is needed to just penetrate this layer.

18. Calculate the specific ionization in keV/μ for a 2.0MeV beta particle in tissue.

19. Describe the fate of a beta-particle which has transferred nearly all of its kinetic energy within a material.

20. Explain how positrons produce annihilation photons and characterize the photons produced.

21. How is bremsstrahlung produced by interaction of beta particles with surrounding materials.

22. What two factors determine the fraction of incident energy converted from beta particles to bremsstrahlung.

23. Compare the difference in bremsstrahlung produced by beta radiation absorbed in aluminum and in Lucite (Z=3.6) by using the fractional energy converted.

24. What is the difference in interaction between particles and gamma photons since gamma photons have no definite range.

25. List the three modes of interaction of gamma radiation with matter.

26. Describe how the three modes of interaction of gamma radiation vary with the Z of the absorbing material and the energy of the photons.

27. Define attenuation coefficient.

28. Determine the attenuation coefficient in units of 1/cm for the following photon energies and materials.

Energy	Material	Attenuation Coefficient 1/(cm)
0.5 MeV	air	______
1.5 MeV	lead	______
2.0 MeV	air	______
0.5 MeV	iron	______

29. Calculate the fraction of a beam which would be attenuated when passing through 2 cm of lead if the photon energy is 1.0 MeV: through 1.5m of air if the photon energy is 1.5 MeV.

30. Describe the two types of scattering interactions which neutrons of various energy undergo. How is each effected by the Z of the material and the energy of the neutron.

31. Explain how the absorption process removes neutrons from a beam. What precautions must be taken when stopping neutrons by this process?

32. Define the terms microscopic and macroscopic cross-section.

33. Determine the macroscopic cross-section for a material which has cross-section of 1.5 barns if it contains 5.0×10^{22} atoms per cm^3.

34. Calculate the total macroscopic cross-section for the following material:

Material	Macroscopic cross-section
H_2O	____________
C	____________
Al	____________
Pb	____________

RADIATION EXPOSURE

1. Define the Roentgen according to the original definition.

2. Why was the Roentgen defined for air?

3. One Roentgen is defined as how many ergs of energy absorbed per gram of air.

4. Calculate the amount of energy absorbed per gram of air for an exposure of 10 Roentgens: What is the absorbed dose in air in rads.

5. What would be the exposure rate in rads per hour in tissue if the exposure rate was 2 Roentgen per hour.

6. Calculate the dose in rem for the following quantities:

   a. 2 R of X-rays____________________

   b. 1.5 mR/hr of gamma____________________

   c. 1.2 rads of alpha____________________

   d. 20 mrads of beta____________________

   e. 2.5 mrads/hr of thermal neutrons____________________

7. Exposure to radiation falls into two categories: (a) acute, and (b) chronic. Describe the general meaning of each.

8. The acute radiation syndromes involve radiation damage to which major organ systems?

9. What is the approximate threshold dose for detection of radiation inducing injury to the body?

10. Which change in body components provide one of the earliest methods of detecting radiation exposure?

11. Indicate the major symptoms associated with radiation damage of the following blood cell formers:

Blood Cell Type	Symptoms
a. red blood cells	______________________
b. white blood cells	______________________
c. lymphocytes	______________________
d. platelets	______________________

12. What dose is required to observe the hematopoietic syndrome in its entirety?

13. Which portion of the gastrointestional syndrome is most sensitive? What dose range is required to produce damage to this segment?

14. Describe how radiation damages this sensitive protion of the gastrointestinal tract.

15. What deterious effects are brought about by damage to the gastrointestinal lining?

16. Describe the central nervous system syndrome; What dose range is required to produce this effect?

17. What is meant by "latent period" associated with radiation exposure?

18. How does the latent period vary from chronic to acute exposure?

19. What are the four major long term effects of radiation?

20. Indicate the dose range which will produce the following effects.

Symptom	Dose
a. temporary hair loss	______________
b. skin reddening	______________
c. skin blistering	______________

21. Indicate the approximate dose required to produce the following symptoms in the male and female reproductive system.

MALE

Symptom	Dose
low sperm count (12 mo.)	______
2-3 year sterility	______
permanent sterility	______

FEMALE

Symptom	Dose
temporary sterility	______
permanent sterility	______

22. Indicate the major radiation effect observed during prenatal development and the time period at which each is most critical.

Developmental State	Radiation Effect	Time Period
a. preimplantation	______	______
b. organogenesis	______	______
c. fetal	______	______

23. Which portion of the eye is most sensitive to radiation? Why?

24. What is the major radiation effect observed in the eyes?

25. Which type of radiation is most effective in producing damage to the eyes?

26. What is meant by occupational and non-occupational exposure?

27. What is the age limit for an employee to be occupationally exposed?

28. What is the maximum allowable accumulated dose which an occupational worker may have whose age is 35?

29. What dose would a worker be allowed per year to his hands if that was the only portion of his body exposed?

30. Why is the dose limit for the whole body restricted to 3 rem per quarter when many other organs have a higher dose limit?

31. To what dose limit should a woman of reproductive capacity be limited?

32. Should your medical X-rays be included in the occupational dose limit?

33. Should your occupational dose limit include exposure you receive from other radiation sources after work hours?

34. Describe how exposure of women of reproductive capacity is handled differently than men.

RADIATION SAFETY INSTRUMENTATION

1. What dose the term personnel dosimetry mean?

2. Describe briefly the mechanism of action of film badge, TLDs and pocket dosimeters?

3. Which is the most commonly used type of personnel dosimeters? Can you suggest a reason for this?

4. What is the purpose of the open window in the film badge holder?

5. Why are selective absorbers such as lead, copper and aluminium used in film badge holders?

6. Is it possible to measure an alpha dose on a film badge? Explain.

7. How does neutron dosimetry differ from gamma dosimetry?

8. Is gamma and neutron dosimetry performed on the same film?

9. Distinguish between a condenser and a charged fiber dosimeter.

10. What are the major problems encountered in the use of pocket dosimeter for personnel dosimetry?

11. For what purpose are pocket dosimeters used? What is the major usefulness?

12. For what period of time can TLDs usually be worr

13. What is the composition of the TLD-100 and how does this effect the usefulness as a dosimeter?

14. What is the major difference between film badge and TLD-100s in relative to accurate dose determination?

15. On what part of the body should personnel dosimeters be worn if only one dosimeter is to be worn?

16. What are the basic differences between a Geiger Mueller counter and an internal proportional counter?

17. What type of radiation would you expect to be able to measure with reasonable efficiency by use of Geiger Mueller counter; an internal proportional counter? Explain.

18. What are the two major advantages for the use of the internal proportional counter for counting alpha and beta activity?

19. What is meant by the term "determining the operating plateau" used in reference to Geiger Mueller counters and internal proportional counters.

20. What is the danger in operating a Geiger Mueller or proportional tube within the so-called "break down voltage"?

21. Why is it usually advantageous to use a preamplifier on an proportional counter and not on a Geiger Mueller counter?

22. What is the composition of P-10 counting gas and for what is it used?

23. Define a normal distribution.

24. How is a normal or bell-shaped curve obtained from radiation counting data? Does the radioactive decay of an element follow the normal distribution?

25. In a normal distribution, what percent of the events occur within one standard deviation; 2 standard deviations; 3 standard deviations?

26. Calculate the standard deviation of a series of counts which have a true mean count of 625.

27. Suppose a radioactive sample is counted for 5 minutes and gives a total of 300 counts. Within what limits does the true mean count lie at the 99.7% C. L.?

28. Report a sample in proper notation which gave 1600 total counts in 4 minutes. Report at the 99.7% C.L.

29. Suppose a sample was counted and gave 1320 total counts in 3 minutes. The background count was 120 counts in 3 minutes. Calculate the standard deviation of the difference in sample-plus-background and background.

30. Report the difference in activity for the count rate given in question 29 at the 99.7% C. L.

31. A background count was taken which yielded 120 counts in 2 minutes. A sample was then counted and yielded 128 counts in 2 minutes. State whether the sample contained radioactivity or not. Report at the 99.7% C. L.

32. The background count of a system was calculated to be 60 counts per minute with a counting time of 2 minutes. What count must a sample-plus-background possess to be considered real and not simply a background count?

33. What is the advantage of counting a sample until a large number of total counts is obtained?

34. Which of the following counts are the same but are different only in statistical variation? Express at the 99.7% C. L.

    a. 250 cpm in 1 minute and 510 counts in 2 minutes
    b. 150 counts and 165 counts
    c. 375 counts and 400 counts
    d. 1200 counts in 2 minutes, and 1000 counts in 2 minutes

35. The Geiger Mueller survey meter has two scales from which to read radiation information. List these.

36. Geiger Mueller survey meter is used primarily for what types of radiation?

37. What is the purpose of the solid metal windows included on many Geiger Mueller probes?

38. What scale should be used when radiation is measured with the window open; with the window closed? Why?

39. Under what conditions does "jamming" occur in a Geiger Mueller survey meter? How is this observed on the meter?

40. What is meant by "energy dependency" of a survey meter? How does this affect the reading made on a survey meter?

41. Describe a method for accurate meter calibration.

42. What two ways are used to make corrections for erroneous readings on a survey meter?

43. Which instrument gives more precise measurements, the ionization chamber survey meter or the Geiger Mueller survey meter?

44. Which is a more sensitive instrument for detecting radiation, the Cutie Pie or the Geiger Mueller survey meter?

45. How does the energy dependency vary between the Cutie Pie and the Geiger Mueller survey meter?

46. What is the major advantage of the use of a scintillation detector?

47. Describe briefly how the alpha survey meter functions. Why is it operated as proportional counter?

48. Write an equation to explain the interaction which makes the BF_3 neutron detector possible.

49. How is it possible to measure both fast and thermal neutrons with the same probe?

50. Suppose the count rate on a neutron survey meter read 52 counts per minute of thermal neutrons. The meter is known to produce 32 NCPM per n/cm^2-second. What is the dose rate due to thermal neutrons at the point of interest? Why is it operated as a proportional counter?

PRINCIPLES OF RADIATION PROTECTION

1. Calculate the exposure rate a person would receive when standing 8 feet from a 1.0 Curie source of Co-60 in an unshielded condition.

2. A worker is standing 10 feet from a beta source emitting 1.5 MeV particles which is covered with shield of aluminum which is just thick enough to stop all particles. Calculate the exposure rate from the bremsstrahlung if the source contains 200 mCi of activity.

3. A non-dental X-ray unit is operated 24 inches from the arm of an employee. Calculate the exposure rate if the unit has a total filtration equal to 2.0 m.m. of Al equivalent and is operated at 80 kVp and 20 mA.

4. Calculate the total exposure a patient would receive to the skin surface from a dental X-ray unit containing 2.0 m.m. of Al equivalent filtration if it is operated at 90 kVp and 20 mA. The duration of the exposure was 1/10 of a second and the FSD was 12 inches.

5. What are the three commonly used methods for protecting against external radiation exposure?

6. A worker is standing in a radiation field which produces a dose rate of 5 mRem/hr. How long could he remain in the field and not exceed 20 mRem for the 8 hour day?

7. A worker is standing 2 feet from a gamma source which is producing an exposure rate of 250 mR/hr. To what total distance will he need to move to reduce the exposure rate to 2.5 mR/hr?

8. A sealed gamma source is producing an exposure rate 150 mR/hr at a distance of 20.0 meters. What will be the exposure rate when moved to a position 800 cm from the source?

9. What range of plexiglass or lucite would be necessary to stop the most energetic beta particles from the sources below?

radionuclide	thickness (cm)	thickness (in.)
$^{90}Sr - {}^{90}Y$	______	______
^{235}Pa	______	______
^{85}Kr	______	______
^{32}P	______	______

10. A Co-60 source in an unshielded position produces a dose rate of 150 mRem/hr. Calculate the shield thickness necessary to reduce the exposure to 100 mRem/hr if build-up is neglected for the thin shield? The shield is made of a slab of lead.

11. Calculate the fraction of Cs-137 gamma beam which would be transmitted through a 2 mm shield of aluminium.

12. A source of Co-60 is to be stored behind a plane slab shield of lead. The unshielded exposure rate is 5 R/hr at the point of interest. What shield thickness is necessary to reduce the exposure rate to 2.5 mR/hr?

13. A 100 mCi source of P-32 is shielded with a lead shield which is the same thickness as the range of the most energetic beta particles. Calculate the bremsstahlung flux in photons/cm^2-sec. which would be produced when the beta particles interact with the shield. The point of interest is 1.5 meters from the source.

14. Calculate the exposure rate a worker would receive at a distance of 1.5 meters from the source in Question 9. Convert the dose to rem/hr.

15. A shielded source of $^{90}SR - {}^{90}Y$ is producing an exposure rate of 2.6 R/hr from the bremsstrahlung emitted. Calculate the shielding required to reduce the exposure rate to 2.5 mR/hr.

16. A PuBe source is producing a flux of 120 n/cm^2-sec. with an average energy of 4 MeV. Calculate the dose in mRem/hr at this point. What would be the dose if the beam was allowed to penetrate a thermalizing material and 60% of the beam emerged thermalized?

17. Define the term fast diffusion length of a neutron. Describe how this is used for radiation protection purposes.

18. Describe how you could accomplish the complete removal of all thermal neutrons from a thermalized neutron source. What precautions must be taken if this is done for radiation protection purposes?

19. Describe what is meant by neutron activation. Why is this process of concern when working around neutron sources?

20. Compare the relative amount of saturation activity which would be induced into a silver ring by neutron sources which have fluxes of 10^3 and 10^4 neutrons/cm^2-sec., respectively.

21. Describe the pathways by which material becomes internally deposited by indegestion, inhalation, and absorption through skin and cuts.

22. What are the two most important factors which determine the extent of tissue deposition?

23. Explain why alpha particles are of little hazard externally, compared to beta and gamma radiation.

24. Define the term maximum permissible body burden (MPBB). List the MPBB for the following elements for the critical organ.

Radionuclide	Critical organ	MPBB
^{45}Ca (Sol)	Bone	____
^{60}Co (Insol)	Lung	____
^{131}I (Sol)	Thyroid	____

25. Define the term maximum permissible concentration for air or water (MPCw or MPCa). What is the significance of MPC values?

26. What is the difference between MPC values for a 40 hour week and a 168 hour week?

27. Determine the following MPC values for the following radionuclides for the conditions specified.

28.

Radionuclide	Organ of Reference	Time	Medium	MPC
^{90}SR (Sol)	total body	168 hr/wk	air	___________
^{45}Ca (Sol)	bone	40 hr/wk	water	___________
^{60}Co (InSol)	LLI	168 hr/wk	air	___________
^{137}Cs (InSol)	lung	40 hr/wk	air	___________

29. From the following data which air concentration would be appropriate to use at the limiting concentration in a work area?

(Sol)			(InSol)		
Thyroid	9×10^{-9} Ci/cc	________	Lung	3×10^{-7} μCi/cc	______
Total body	8×10^{-7}	________			
GI(LLI)	7×10^{-6}	________			
GI(LLI)	3×10^{-7}	________			

30. Describe the general pathway followed by inhaled particles through the respiratory tract. Describe this for both soluble and insoluble particles.

31. How do inert gases differ from particulates in their behavior within the respiratory tract and within the body?

32. What are the two generally accepted philosophies governing the disposal of radioactive material?

33. Describe how ventilation and decontamination are applied to disposal of air-borne wastes. What physical systems are commonly used to dispose by these methods?

34. What criteria is used to govern the disposal of liquid wastes into the local sewer system?

35. What consideration must be given to the disposal of solid wastes by incineration if the ash is to be released into the environment?

36. What three methods are used for decontamination of surfaces and materials in plant operation?

37. Which decontamination procedure would be appropriate for each of the conditions below?

Contaminated Material	Contaminating Radionuclide	Decontamination Method
concrete	^{3}H (1.0 μCi)	____________
painted surface	^{60}Co (5 μCi)	____________
hands	^{14}C (0.1 μCi)	____________
glass	^{131}I (10 μCi)	____________

REGULATORY COMPLIANCE

1. Distinguish between a specific and a general license.

2. What is meant by the term exempt quantity?

3. What is the maximum quantity of the following radionuclides which would be classified as an exempt amount?

   barium - 133 (________) strontium - 90 (________)

   cesium - 137 (________) hydrogen - 3 (________)

4. What quantity of hydrogen - 3 (tritium) could be purchased as an exempt quantity when 5 μCi of Ba-133 and 4 μCi of Cs-137 is presently in possession?

5. What information is provided by the Code of Federal Regulations, Title 10, Part 30; Title 10, Part 31; Title 10, Part 35?

6. Describe the organization which is usually required of a company radiation safety program.

7. What information is provided by the Code of Federal Regulations, Title 10, Part 19; Title 10, Part 20?

8. What dose limit requires the use of personnel monitoring devices? To what age limit does this apply?

9. Which NRC forms are used to obtain the occupational external radiation exposure history of a radiation worker; to record the current exposure of a radiation worker?

10. What is the purpose of a restricted are in radiation control? How is the restricted area indicated?

11. What is maximum exposure level which may exist just outside of restricted area?

12. What action should be taken against areas within a restricted area where the dose rate is in excess of 2.5 mRem/hr?

13. What information is required to be posted at the entrance to a restricted area if practical? What procedures may be followed if posting at the entrance of a restricted are or in a conspicious place is not possible or practical?

14. What is the official title given to the NRC-3 form? What basic information is provided on the form?

15. What conditions require the use of the following warning signs?

   a. Caution Radiation Area-
   b. High Radiation Area-
   c. Caution Radioactive Material-
   d. Airborne Radioactivity Area

16. Determine the maximum permissible concentrations of the following radionuclides which are allowable in air and water for an unrestricted area.

	Unrestricted Area	
Radionuclide	MPCw	MPCa
^{32}P	______	______
^{60}Co	______	______
^{137}Cs	______	______

17. What restrictions are placed upon radioactive materials in storage containers as far as labeling is concerned? What information must be stated on the label?

18. What type area survey is required in the restricted area? How are the records of the area survey maintained?

19. What is the purpose of performing wipe tests and leak tests?

20. Describe an acceptable method of performing a wipe test of a work surface? What area is usually involved?

21. What quantity of activity detected on a leak test requires reporting to the NRC regional office or state?

22. What information about a leak test is required for the record?

23. Assuming a resuspension factor of 10^{-6} , what surface contamination consisting of ^{90}Sr could be permitted?

24. A blank filter paper used for wipe tests gives a count of 20 in 2 minutes of counting time. A wipe used to rub a 100 cm^2 area gave a count of 24 in 2 minutes. Determine at the 99.7% C.I. whether the work area was contaminated or not. How would you report the activity of the sources?

25. A cotton swab soaked in alcohol is used to leak test a gauging source. The swab produced a count rate of 40 CPM. Determine at the 99.7% C.I. whether the source was leaking or not if the background count was 32 CPM.

26. A 200 cm^2 area of floor surface in a work area was wiped free of removable contamination. The count rate of the wipe was 300 CPM for a 2 minute counting time. A blank wipe produced a background count rate of 80 CPM for a 2 minute counting time. Determine at the 99.7% C.I. if contamination exists on the floor and if so what is the concentration in $\mu Ci/cm^2$, if an 8000 DPM standard gave a count rate of 2000 CPM. What is the air concentration likely to be if a resuspension factor of 10^{-} is assumed.

27. An airborne sample gives a count of 3,200 CPM after 4 hours. After 24 hours, the count was 2,830 CPM. The collector efficiency is 72%, while the counter efficiency is 20% and the background count rate is 100 CPM. The sample had a flow rate of 20 CFM and was in operation for 1 hour. Calculate the airborne concentration of beta activity in Ci/ml if 0.7 of the filter was counted.

28. A sample of airborne contamination was collected for two hours. The sample was operating at 30 CFM with a collection efficiency of 60%. The sample gave a count rate of 830 CPM for a 2 minute count in a scaler with a 25% efficiency. The background count was 30 CPM for a 2 minute count. Calculate the air concentration in Ci/ml at the 99.7% C.I. if the entire filter was counted.

29. Suppose you are designing an alarm system to detect an air concentration which exceeds the MPCa for a 40 hour week for occupational exposure. What count rate would be required to sound the alarm indicating a concentration in excess of the MPCa? The routine sampling time is one hour at a flow rate of 20 CFM, a filter efficiency of 80% and a counter efficiency of 20%. The total filter is monitored at one time. The radionuclide in question is ^{32}P.

30. What conditions require reporting to the NRC or an agreement state on an immediate basis; 24 hour notification?

31. What obligation does a former employee have to furnish present employees with a copy of past radiation exposure records?

32. How many regional offices of Inspection and Enforcement does the NRC administer in the United States? What are their locations?

33. What is the official title of the NRC-3 form? What is it's purpose? What information does it supply?

34. Under what conditions is an employee required to make a report of radiation exposure to an employee?

35. What is the limit of activity concentration if it is to be classified as non-radioactive for transportation purposes?

36. What is the distinction between type A and type B packaging as far as transportation is concerned?

37. What is meant by the term transport group? How is it used in shipping?

38. List 6 general requirements which pertain to all packaging of radioactive material for transport.

39. What is the difference between special form and normal form material?

40. What three requirements are made of licensees who expect to receive a package containing radioactive material in excess of type A quantities?

41. What is the minimum quantity of each of the following radionuclides which do not require DOT regulations when in normal form?

a) ^{60}Co (__________)   c) ^{55}Fe (__________)
b) ^{241}Am (__________)   d) ^{22}Na (__________)

42. What shipping label would be required for the following quantities of radioactive material?

	Surface Dose	Dose at 3 feet	Label
a)	0.25 mRem/hr	0.08 mRem/hr	__________

b) 3.2 mRem/hr 0.15 mRem/hr ________

c) 0.35 mRem/hr 0.12 mRem/hr ________

d) 25 mRem/hr 2.3 mRem/hr ________

43. What monitoring procedures are required on the receipt of material in excess of type A quantities? Which of the following radionuclides require monitoring procedures?

a) 0.01 Ci of ^{241}Am (__________) c) 5 Ci of ^{22}Na (__________)

b) 10 Ci of ^{45}Ca (__________) d) 1.2 Ci of ^{14}C (__________)

44. What surface radiation levels on a newly received package would require NRC notification?