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AMERICIUM-241 FOIL INTEGRITY TESTS:

Performed for Nuclear Radiation Developments Corporation

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INTRODUCTION

A series of independent environmental stress tests were performed on Nuclear Radiation Developments Corp. Model A001, Americium-241 foils mounted in source holders used in fire detection devices. Different groups of foils were subjected to prolonged immersion in Buffalo City water; exposure to constant relative humidity and temperature; and finally, to a test simulating the human digestive process. All tests were performed between February 27, 1976 and March 23, 1976. The purpose of these tests is to determine whether or not the surface integrity of the foil is affected by such conditions, and if the radioactivity is lost, is it in a soluble or an insoluble form. All foils tested contained an original activity of 2 microcuries of Americium-241, in the form of Americium-241 dioxide. The oxide is incorporated in a gold matrix and rolled into a final source foil containing several laminations of gold and silver, effecting a sealing of the Americium.

MATERIALS and METHODS

Immersion Test

Three NRD Model A001 Americium-241 foils were placed in separate 50 milliliter Erlenmeyer flasks, into which 3 ml of Buffalo City tap water was added.* The top of the flasks were sealed with Parafilm, leaving an orifice large enough to allow a 1 ml glass pipette to be inserted and samples withdrawn. Two ml aliquots were removed from each flask every 24 hours. The volume removed was immediately replaced with fresh tap water. One ml was placed on a one inch planchette and allowed to air dry. The other one ml sample was drawn through a 0.45 micron (um) Millipore filter to assay for possible particulate activity. The filters were allowed to dry by evaporation. Both samples were then assayed for their radioactive

*Buffalo City water is classified as hard water, with a pH of 7.56 as determined by a pH meter.

content by counting them in a 2π gas-flow proportional detector.** Samples were removed on a 24 hour basis over a 12 day period, beginning February 27, 1976 and ending March 9, 1976. A one ml aliquot was left in each flask from March 9, 1976 until March 21, 1976. These samples were removed and placed on one inch aluminum planchettes, allowed to dry, and then assayed for radioactive content.

A new test to assay for particulates began on March 21, 1976 and ended 48 hours later on March 23. The purpose of this test was to determine if any appreciable amounts of radioactivity could be detected, in the particulate form, beyond the original 12 day test period. In this test only 1 ml of tap water was added to each flask. The flasks were then aggitated and allowed to stand for the duration of the test. Samples were then assayed for particulate activity, as per previously described methods.

Three Week Environmental Test

Three NRD Model A001 Americium-241 foils were subjected to an environment of constant relative humidity (80%) and constant temperature (112° Fahrenheit, 44.44°C) for a three week period, in separate closed systems. See Figure I for a representation of the system.

The paper by D. S. Carr and B. L. Harris, Solutions for Maintaining Constant Relative Humidity[I]; and the work by R. H. Stokes, entitled Standard Solutions for Humidity Control at 25°C[I], were used to formulate the conditions necessary to maintain the relative humidity of the chamber at 80%. From the data presented in these papers, it was determined that a saturated solution of potassium chloride (KCl) at 70°C would maintain the relative humidity at exactly 80%. However, the desired temperature for this experiment was 112°F, or 44.44°C. A saturated KCl solution, kept at 44.44°C, will yield a relative humidity of 81.5%. This value is derived from graphic interpolation. (See Figure XI., % Relative Humidity vs. Temperature in °C.) Therefore, the relative humidity used for this test was 1.6% higher than

**For type of instrument used, etc., see RESULTS

the desired value. This minor alteration should have no affect on the results since higher humidity would make the conditions even more adverse. The Americium foil was suspended from the top of the chamber in a one inch aluminum planchette supported by copper wire. The units were then sealed with a combination of grease, paraffin and Parafilm, and placed in a Blue-M Stabil-Therm gravity oven at 44°C for a three week period beginning 2/27/76 and ending 3/17/76. Reeve Angel glass fiber circular filters (size: 2.4 cm, grade: 934AH), were used to take wipe samples of all surfaces on the interior of the chamber, in addition to sampling the KCl solution itself. All filters were allowed to dry, then placed on planchettes and assayed for their radioactive content in a gas flow Proportional detector.

Digestion Test

The purpose of this test was to determine to what extent the Americium-241 foils would be degraded by normal human digestive processes if one of the foils were accidently swallowed.

A.) Saliva Test - The normal physiologic make-up of human saliva is 99% water and 1% of a mixture of enzymes, salts and proteins. Amylase, the most significant protein, serves to catalyze the breakdown of polysaccharides to disaccharides. Saliva normally has a pH of 6.8. The Americium foil was immersed in a fresh specimen of human saliva, in a sterile test tube. After 5 minutes of agitation, in a water bath at 37°C(98.6°F), the foil was removed from the tube and placed into another test tube containing a solution of gastric juices (see below). The saliva was then placed on an aluminum planchette, allowed to dry and assayed for possible radioactive content.

It is assumed that prolonged exposure to salivary juices would have little or no effect on the integrity of the foil coating since saliva has been proven to be inactive against gold. This is documented in many dental references[2], since, today, the use of gold in dentistry is a common practice.

B.) Gastric Test - After immersion in saliva for five minutes, the foil was wipe tested and transferred to a new test tube contain-

ing normal digestive juices for 7.5 hours. Normal gastric mucosal secretions include: an isotonic acid of 150 mN H^+, 150 mN Cl^- and 5mN K^+; a collection of enzyme precursors, an example being pepsinogen, which is converted to its active form (pepsin) by H^+ at a pH of 1-6; several complex mucoproteins; and the intrinsic factor. The most important digestive factor in the stomach is hydrochloric acid, since this acid, in the proper concentrations, is capable of degrading almost all substances. Another important substance in gastric digestion is pepsin. It was assumed, since most, if not all of the degradation of the foil coating would occur due to its exposure to HCl, that the experimental model would contain 150 mN HCl, 5 mN K^+ and 1% pepsin (swine). This solution was mixed thoroughly and brought to a temperature of 37°C with a water bath. The pH of the solution was 1.96.

In this test, one must consider gastric emptying the major factor in determining how long the foil will remain in the stomach. If the foil was accidently or intentionally swallowed, the longest stay-time in the stomach would occur if it were swallowed just before bedtime. The maximum elapsed time for retention of the foil would be approximately 7.5 hours. The foil would definitely be passed onto the small intestine following breakfast the next morning, unless the foil should be lodged in a diverticulum somewhere between the esophogeal orifice and the pyloric sphincter, in which case, the amount of digestion would depend on the location of the diverticulum.

C.) Pancreatic Test - The normal physiologic make-up of the small intestine includes such enzymes as trypsin, chymotrypsin, carboxypeptidase, lypase, etc., which are available commercially as Pancreatin. A one percent solution of Pancreatin, containing 150 mN sodium bicarbonate (Na_2CO_3) and 15 mN HCl was prepared for this test. The pH of the solution was measured at 8.1. The foil was transferred from the gastric test tube, wipe tested, and placed in a new test tube containing the pancreatic solution for a period of 20 hours, in a water bath at 37°C.

D.) Large Intestine Test - As a final test to simulate the passage of the foil through the large intestine, a test tube was prepared containing Escherichia coli and normal Buffalo tap water. The pH of the solution was measured at 7.56. This test was run for a 50 hour period in a water bath at 37°C.

Note: The normal oral-rectal transit time as established by Dr. Danield Burkitt[3], is approximately 90 hours for people living in western cultures.

Radioactive Assay

All sample counting was done on a Nuclear Chicago 186-A Proportional preflush gas-flow detector. The counting gas employed was P-10, which contains 90% argon and 10% methane. The alpha plateau of the detector was determined with a New England Nuclear alpha reference standard (model NES-302-S, Americium-241) containing 5.0×10^{-2} microcuries (6.7×10^{4} alphas per minute). This standard was calibrated in October of 1973. The operating voltage was determined to be 1270 volts. (See Figure II.) An alpha reference source of lesser activity was then used to determine the alpha counting efficiency at this voltage. This alpha refcrence source was also made by NEN and contained 3.29×10^{-2} microcuries on September 11, 1975. The data for these tests appears on page 17. The detector uses a 2π counting geometry and it is not known to what extent backscatter of the alpha particles contributes to the net counting rate of the source. The counting efficiency was determined to be 55.83% $\pm$ 0.04%.

Statistical Analysis

Statistical evaluation of the counting data was deemed necessary due to the very low background counting rate, and in most cases to the equally low sample count rate. Such a procedure allows for reporting of the results to a significant confidence interval.

Nuclear Chicago's Technical Bulletin number 14, How to Apply Statistics to Nuclear Measurements, was used as a reference for this analysis. The number of microcuries removed from the foil surface and the % error involved in counting each sample were calculated. The parent equation used to determine the per cent error is as follows:

$$\% \text{ Error} = \frac{\text{Observed Value} - \text{Expected Value}}{\text{Expected Value}} \times 100$$

For the purpose of calculating the % error of all samples, the above equation was substituted as follows:

$$\% \text{ Error} = \frac{CPM_{net} + 1.96\left(\frac{\text{Gross Counts}}{T_G^2} + \frac{\text{Bkg Counts}}{T_{Bkg}^2}\right)^{\frac{1}{2}}}{\text{Efficiency} - \text{Efficiency Error}} - \frac{CPM_{net}}{\text{Eff.}} \times 100$$

$$\frac{CPM_{net}}{\text{Efficiency}}$$

Where T_G is the counting time in minutes for the gross counts; T_{Bkg} is the background counting time (in minutes). By subtracting the error from the counting efficiency in the numerator, the value of the entire equation is maximized for the per cent error. Then, multiplying the square root expression by 1.96 gives a 95% level of confidence to the values obtained employing this equation.

The activity removed from the foil surface, in microcuries, was calculated as follows:

$$\text{Activity Removed (uCi)} = \frac{CPM_{net}}{\text{Counting Efficiency}} \cdot \frac{1}{2.22 \times 10^6 \text{ dpm/uCi}}$$

All values are reported in terms of uCi removed from the foil surface. Tables I. through III. present the results of all tests in terms of uCi removed.

RESULTS

Immersion Test

The data for the immersion test appears on page 18 through page 24. The corresponding graphs of counts per minute verses time (in days), are contained in Figures III. through X. Figure IX is a composite of the average values of all three gross sample assays, while Figure X. is a similar composite of the Millipore filter tests. The values obtained by the additional tests performed on March 21 and March 23 are plotted on their respective composites, on an insert labeledTIME EXTENSION DATA. Table I. contains data pertaining to the activity leached in the gross and Millipore filter assays.

The foil surface and particularly the foil structure showed extensive corrosion and pitting in almost all area due to its exposure to Buffalo tap water.

Three Week Environmental Test

Only eight out of the 30 filters assayed in this test yielded sufficient counts to give a positive number after background counts had been subtracted. However none of these counts were statistically different from background on a 2 sigma basis. The actual counting data is presented on pages 29 and 30. Special disposable gloves were used in handling the individual parts of each chamber when it was dismantled. The glove fingertips were then assayed for possible contamination at the end of all handling procedures. No significant activity (greater than background) was obtained by these assays.

Digestion Test

A.) Saliva Test - The data obtained when the saliva samples were analyzed proved insignificant; the gross count rate was only twice the background rate. This test had the least effect of all of the digestion procedures with respect to removing radioactivity from the foil surface. A wipe sample was taken from the foil surface at the conclusion of this test using a glass fiber filter. The wipe test data also showed that no significant activity was removed from the foil. (See Table II. and page 27.)

B.) Gastric Test - As was expected, the larger amount of degradation of the foil surface was caused by the action of HCl. Table II contains the results of this test. The test tube used was rinsed with distilled water and this sample was assayed as per previous procedures. A wipe sample was taken of the foil surface and subsequently assayed.

C.) Pancreatic Test - Since the pH of this solution was 8.1, foil surface integrity was less affected as compared to the gastric test. The test tube used was rinsed and assayed for residual activity. The foil surface was again wipe tested before beginning the next procedure.

D.) Large Intestine Test - Due to the continuing degradation of the foil surface and the long exposure of the foil to this solution, this test proved to be second only to the gastric test in its ability to remove activity from the foil surface. The test tube was rinsed with distilled water, the sample was allowed to dry and assayed. Finally a wipe sample was taken of the foil surface. (See Table II. and page 27.)

DISCUSSION

A direct comparison of the values obtained in the Immersion test using two different methods of assaying for Am-241 activity (i.e. gross sampling versus Millipore Filter sampling) produced a correlation factor of 99.24%. This is a definite indication that all of the activity which was removed from the foil surface is indeed particulate and therefore insoluble. All foils tested produced nearly the same relationship when plotted as a function of activity (counts per minute) versus time (days). Peak activity appears in the third day of the test in each individual case, as well as when an average was computed (see Figures III-IX.). At the five day mark, the count rate of all samples began to approximate background, and, in general, remained at this low level until the end of the test. The additional gross and particulate assays performed, produced a counting rate near background. The additional particulate test gave a somewhat higher value than the additional gross assay, probably due to the fact that fresh water was added to the flask.

For all practical purposes, it can be assumed that in the immersion test, the total water volume is replaced each day. The one ml that was left in the flask should have produced an increase in its radioactive concentration with time, if the sample was leaching Am-241 activity continuously. However, this was not the case, since the actual concentration decreased with time. Therefore it is possible to make the assumption that the entire volume was replaced each day.

On Table I. a direct comparison is made between the activity detected by the gross and Millipore filter tests, including the margins of error for each determination. The amount of activity detected by the gross assay should always exceed that due to the filter assay since some particulates could conceivably escape being trapped. However, in some instances this is not the case, which would tend to indicate that the Am-241 is not homogeneously distributed in the water sample taken from the flask. This would again lend support to the observation that the Am-241 being leached from the foil is in the particulate form and is therefore insoluble.

CONCLUSION

On the basis of the data obtained in performing the various tests on the Am-241 foils, it must be concluded that their exposure to stressful environmental conditions would produce no significant hazard to the biosphere involved.

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The conditions employed for the immersion test may not duplicate actual (real life) conditions, since the volume used is probably much less than that of expected situations. However, it is assumed that the concentration in uCi per ml of leachate is representative of realistic test conditions. In such instances, the foil would be immersed in a larger volume of water, thus making the relative concentration of Am-241 presumably lower. In addition, in the immersion test the leachate concentration was considerably less than the MPC_w [11] (3×10^{-5} uCi/ml) after the fifth to seventh day. During the first few days, however, the concentrations are slightly larger or equal to MPC_w values (Table III.).

In the immersion test, it is necessary to point out that an average value of uCi removed per day, for the 12 day test, would not be representative of the rate at which activity was removed from the foil surface, since the concentration was constantly changing. The most representative value of uCi removed per ml of leachate would be that which is obtained on the third day of the test, since in almost all cases, it was the largest value obtained. It is then possible to compare this value to the established MPC_w for Am-241 to give the most conservative estimate of actual releases from the foil. The activity removed on the third day as a function of the total activity removed is also calculated to demonstrate that, in most cases, the amount of activity removed on the third day is a significant fraction of the total. Table III. gives a comparison of the amount of activity leached per ml on the third day of the immersion test, and compares it to the MPC_w value for an unrestricted release of Am-241.

The reason why these samples show this particular relationship in the immersion test may be due to the fact that, as the gold coating is placed on the foil surface, some of the Am-241 may be lodged in the upper layer of the coating. Therefore, when the foil is exposed to water, the corrosive properties of water are sufficient to remove this small amount of "tramp" material in the gold coating, however it is not corrosive enough to entirely destroy the coating integrity. This is proven by the observation that after 5 to 7 days, little or no activity is removed from the foil surface upon continued exposure to water.

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Proportional Plateau Determination

COUNTING DATA

Exp No. Test Name Greenberg Date 2/24/76

Scaler ____ Voltage ____ - ____ Bkg ____ - ____

Detector Prop. preflush flow 1 mV Window Baseline ____

Sample	Counting Time, Min.	Total Counts	CPM	CPM-Bkg.	Voltage
Am-241 6.7x10⁴ alpha pm	10/73				
"	1	23,258	23,258		800
"	1	34,930	34,930		850
"	1	42,144	42,144		900
"	1	51,804	51,804		950
"	1	55,236	55,236		1000
"	1	59,888	59,888		1050
"	1	60,828	60,828		1100
"	1	61,494	61,494		1150
"	1	61,602	61,602		1200
"	1	62,326	62,326		1250
"	1	62,723	62,723		1300
"	1	63,141	63,141		1350
"	1	63,752	63,752		1400
"	1	64,109	64,109		1450
"	1	65,532	65,532		1500
"	1	69,694	69,694		1550
"	1	75,570	75,570		1600
"	1	80,432	80,432		1650
Am-241 .0329uCi 9/11/75	3	104,406	34,802		1270

DPM = 7.238×10^4

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Immersion Test with Am-241 Foils in Buffalo City Water

COUNTING DATA

Exp No. One Name Greenberg Date 2/27/76-3/9/76

Scaler _____ Voltage 1270 Bkg Determined Daily

Detector Prop. preflush flow 1mV Window _____ Baseline _____

Sample #1	Counting Time, Min.	Total Counts	CPM	CPM-Bkg.	Bkg/Min
Gross 1ml ea.					
2/27	3	10	3.33	3.33	0
2/28	3	47	15.66	15.66	0
2/29	3	132	44	44	0
3/1	5	118	23.6	23.4	.2
3/2	5	20	4	3.5	.5
3/3	5	104	20.8	20.3	.5
3/4	5	34	6.8	6.7	.1
3/5	5	19	3.8	3.4	.4
3/6	5	31	6.2	5.8	.4
3/7	5	22	4.4	3.6	.8
3/8	5	12	2.2	2.2	0
3/9	5	15	3	2.8	.2

Immersion Test with Am-241 Foils in Buffalo City Water

COUNTING DATA

Exp No. One Name Greenberg Date 2/27/76-3/9/76

Scaler _____ Voltage 1270 Bkg. _____

Detector Prop. flow preflush 1 mV Window ___ Baseline _____

Sample #2	Counting Time, Min	Total Counts	CPM	CPM-Bkg.	Bkg./Min.
Gross 1ml ea.					
2/27	3	31	10.33	10.33	0
2/28	3	42	14	14	0
2/29	3	131	43.67	43.67	0
3/1	5	69	13.8	13.6	.2
3/2	5	28	5.6	5.1	.5
3/3	5	25	5	4.5	.5
3/4	5	8	1.6	1.5	.1
3/5	5	26	5.2	4.8	.4
3/6	5	26	5.2	4.8	.4
3/7	5	9	1.8	1.0	.8
3/8	5	9	1.8	1.8	0
3/9	5	3	.6	.4	.2

Immersion Test with Am-241 Foils in Buffalo City Water

COUNTING DATA

Exp No. One Name Greenberg Date 2/27/76-3/9/76

Scaler _____ Voltage 1270 Bkg. _____

Detector Prop. (FLOW) preflush 1 mV Window _____ Baseline _____

Sample #3	Counting Time, Min.	Total Counts	CPM	CPM-Bkg.	Bkg./Min.
Gross 1ml ea.					
2/27	3	10	3.33	3.33	0
2/28	3	159	53	53	0
2/29	3	207	69	69	0
3/1	5	106	21.2	21	.2
3/2	5	42	8.4	7.9	.5
3/3	5	62	12.4	11.9	.5
3/4	5	20	4	3.9	.1
3/5	5	65	13	12.6	.4
3/6	5	31	6.2	5.8	.4
3/7	5	9	1.8	1.0	.8
3/8	5	5	1.0	1.0	0
3/9	5	10	2	1.8	.2

Immersion Test with Am-241 Foils in Buffalo City Water

COUNTING DATA

Exp No. One Name Greenberg Date _____

Scaler _____ Voltage 1270 Bkg. _____

Detector Prop. preflush flow 1 mV Window _____ Baseline _____

Sample #1	Counting Time, Min.	Total Counts	CPM	CPM-Bkg.	Bkg./Min
.45 um millipore filter					
2/27	3	9	3	3	0
2/28	3	43	14.33	14.33	0
2/29	3	99	33	33	0
3/1	5	167	33.4	32.7	.7
3/2	5	53	10.6	10.6	0
3/3	5	108	21.6	21.4	.2
3/4	5	27	5.4	4.9	.5
3/5	5	8	1.6	1.1	.5
3/6	5	77	15.4	15	.4
3/7	5	33	6.6	5.8	.8
3/8	5	22	4.2	4.2	0
3/9	5	8	1.6	1.4	.2

Immersion Test with Am-241 Foils in Buffalo City Water

COUNTING DATA

Exp No. One Name Greenberg Date 2/27/76-3/9-76

Scaler _____ Voltage 1270 Bkg. _____

Detector Prop. preflush flow 1 mV Window _____ Baseline _____

Sample #2	Counting Time, Min	Total Counts	CPM	CPM-Bkg	Bkg./Min
.45 um millipore filter					
2/27	3	14	4.66	4.66	0
2/28	3	6	2	2	0
2/29	3	222	74	74	0
3/1	5	72	14.4	13.1	.7
3/2	5	23	4.6	4.6	0
3/3	5	40	8	7.8	.2
3/4	5	13	2.6	2.1	.5
3/5	5	30	6	5.5	.5
3/6	5	18	3.6	3.2	.4
3/7	5	11	2.2	1.4	.8
3/8	5	7	1.4	1.4	0
3/9	5	3	.6	.4	.2

Immersion Test with Am-241 Foils in Buffalo City Water

COUNTING DATA

Exp No. One Name Greenberg Date 2/27/76-3/9/76

Scaler ____ Voltage 1270 Bkg. ____

Detector Prop preflush flow 1 mV Window Baseline ____

Sample #3	Counting Time, Min.	Total Counts	CPM	CPM-Bkg	Bkg/Min.
.45 um millipore filter					
2/27	3	4	1.33	1.33	0
2/28	3	113	37.66	37.66	0
2/29	3	222	74	74	0
3/1	5	122	24.4	23.7	.7
3/2	5	43	8.6	8.6	0
3/3	5	23	4.6	4.4	.2
3/4	5	10	2	1.5	.5
3/5	5	69	13.8	13.3	.5
3/6	5	30	6	5.6	.4
3/7	5	14	2.8	2.0	.8
3/8	5	10	2	2	0
3/9	5	5	1	.8	.2

Three Week Environmental Test
80% Relative Humidity and 112 Degrees F

COUNTING DATA

Exp No. Two Name Greenberg Date 2/27/76-3/17/76

Scaler _____ Voltage 1270 Background .5 cpm

Detector Prop. flow preflush 1 mV Window _____ Baseline _____

	Sample	Counting Time, Min.	Total Counts	CPM	CPM-Bkg	
Bottle #1	Water	5	2	.4	-	
	Screen	5	3	.6	.1	
	Wire	5	5	1	.5	
Dry	P.W.T.I	5	1	.2	-	
	P.W.T.O	5	2	.4	-	
	Foil W.T.	5	8	1.6	1.1	
Wet	P.W.T.I	5	1	.2	-	
	P.W.T.O	5	1	.2	-	
	Foil W.T.	5	7	1.4	.9	
	Jar	5	1	.2	-	
Bottle #2	Water	5	2	.4	-	
	Screen	5	0	0	-	
	Wire	5	3	.6	.1	
Dry	P.W.T. I	5	1	.2	-	
	P.W.T. O	5	0	0	-	
	Foil W.T.	5	1	.2	-	
Wet	P.W.T. I	5	2	.4	-	
	P.W.T. O	5	2	.4	-	
	Foil WT	5	0	0	-	
	Jar	5	0	0	-	

Three Week Environmental Test

80% Relative Humidity and 112 Degrees F

COUNTING DATA

Exp No Two Name Greenberg Date 2/27/76-3/17/76

Scaler _____ Voltage 1270 Background .5 cpm

Detector Prop. preflush flow 1 mV Window Baseline _____

	Sample	Counting Time, Min.	Total Counts	CPM	CPM-Bkg	
Bottle #3	Water	5	2	.4	-	
	Screen	5	1	.2	-	
	Wire	5	0	0	-	
Dry	P.W.T. I	5	0	0	-	
	P.W.T. O	5	1	.2	-	
	Foil WT	5	8	1.6	1.1	
Wet	P.W.T. I	5	2	.4	-	
	P.W.T. O	5	2	.4	-	
	Foil WT	5	6	1.2	.7	
	Jar	5	3	.6	.1	

*Fingertips of gloves used during this process were assayed for possible contamination. All results were negative

Digestion Test

COUNTING DATA

Exp No. 3 Name Greenberg Date 3/19/76-3/22/76

Scaler _____ Voltage 1270 Background 0.2 CPM

Detector Prop. preflush flow Gain 1mV Window _____ Baseline _____

	Sample	Counting Time, Min	Total Counts	CPM	CPM-Bkg	
	Bkg.	5	1	.2		
2 Min.	Saliva	5	2	.4	.2	
	Wipe Tst	5	2	.4	.2	
7h32m	Gastric	5	20,779	4156	4155.8	
	Tube*	5	1,354	271	270.3	
	Wipe Tst	5	1,812	362.4	362.2	
27h32m	Pancre-atic	5	418	83.6	83.4	
	Tube*	5	97	19.4	19.2	
	Wipe Tst	5	1,550	310	309.8	
77h32m	L.I.	5	1,466	293.3	293	
	Tube*	5	808	161.6	161.4	
	Wipe Tst	5	1,335	267	266.8	

*All test tubes were rinsed with 2 ml of distilled water. This was then placed on a planchett, dried and counted.

Table I.

Digestion Test

Date	uCi/ml of Leachate ($x10^{-6}$)		uCi/ml of Leachate ($x10^{-6}$)		uCi/ml of Leachate ($x10^{-6}$)	
	Gross	Filter	Gross	Filter	Gross	Filter
2/27	2.7 ± 1.7	2.4 ± 1.6	8.3 ± 2.9	3.8 ± 2.0	2.7 ± 1.7	NSS*
2/28	1.3 ± 0.4	11.5 ± 3.5	11.3 ± 3.4	1.6 ± 1.3	42.7 ± 6.8	30.4 ± 5.8
2/29	33.5 ± 5.7	26.5 ± 5.3	35.2 ± 6.0	NSS*	55.6 ± 7.8	59.7 ± 7.8
3/1	18.9 ± 3.4	26.3 ± 4.2	11.0 ± 2.6	10.6 ± 2.8	16.9 ± 2.2	19.1 ± 3.6
3/2	2.8 ± 1.5	8.5 ± 2.3	4.1 ± 1.8	3.7 ± 1.5	6.4 ± 2.1	6.9 ± 2.1
3/3	16.4 ± 3.3	17.0 ± 3.2	3.6 ± 1.7	6.3 ± 2.0	9.6 ± 2.5	3.5 ± 1.5
3/4	5.4 ± 1.9	3.9 ± 1.7	1.2 ± 0.9	NSS*	3.1 ± 1.4	NSS*
3/5	2.7 ± 1.4	0.9 ± 0.8	3.9 ± 1.7	4.4 ± 1.8	$1.0 \pm .25$	10.7 ± 2.7
3/6	4.7 ± 1.8	12.1 ± 2.8	3.9 ± 1.7	2.6 ± 1.4	4.7 ± 1.8	4.5 ± 1.8
3/7	2.9 ± 1.6	4.7 ± 1.9	NSS*	NSS*	NSS*	1.6 ± 1.5
3/8	1.8 ± 1.1	3.4 ± 1.5	1.4 ± 0.9	1.1 ± 0.8	0.8 ± 0.7	1.6 ± 1.0
3/9	2.3 ± 1.3	1.1 ± 0.9	NSS*	NSS*	1.4 ± 1.0	NSS*
Total	95.4 (± 25.1)	118.4 (± 29.7)	83.9 (± 23.6)	34.4 (± 13.6)	144.9 (± 28.3)	138.0 (± 27.8)

Additional Immersion Test Assays

uCi/ml of Leachate ($x10^{-6}$)

Sample	Gross	Filter	Wipe Test**
#1	1.3	8.1	5.1
#2	3.7	2.9	7.1
#3	NSS*	1.1	4.5
Total	5.0	12.0	16.7

* Not Statistically Significant
**Performed at the conclusion of the Immersion Test

Table II.

Digestion Test

Sample	Activity Removed (uCi)
Saliva	NSS*
Wipe Test	NSS
Gastric	$(3.4 \pm 0.1) \times 10^{-3}$
Wipe Test	$(2.9 \pm 0.1) \times 10^{-4}$
Tube	$(2.2 \pm 0.1) \times 10^{-4}$
Pancreatic	$(6.7 \pm 0.6) \times 10^{-5}$
Wipe Test	$(2.5 \pm 0.1) \times 10^{-4}$
Tube	$(1.5 \pm 0.3) \times 10^{-5}$
Large Intestine	$(2.4 \pm 0.1) \times 10^{-4}$
Wipe Test	$(2.2 \pm 0.1) \times 10^{-4}$
Tube	$(1.3 \pm 0.1) \times 10^{-4}$
Total (excluding Wipe Tests)	$(4.1 \pm 0.1) \times 10^{-3}$
Total Wipe Tests	$(7.6 \pm 0.4) \times 10^{-4}$
Total Activity Removed	$(4.9 \pm 0.1) \times 10^{-3}$

Table III.

Comparison of Results with Non-occupational Exposure Limits

Gross Sample	uCi/ml of Leachate (Day 3)	% Total	Fraction of MPC_w**
#1	3.4×10^{-5}	28.2	1.13
#2	3.5×10^{-5}	29.6	1.16
#3	5.6×10^{-5}	46.8	1.86
Ave.	4.2×10^{-5}		1.46
Millipore Sample			
#1	2.7×10^{-5}	22.4	0.90
#2	6.0×10^{-6}	13.8	0.20
#3	6.0×10^{-5}	40.6	2.00
Ave.	3.1×10		1.03

Digestion Test	uCi Removed	Fraction MPBB***
Total (excluding Wipe Tests)	4.1×10^{-3}	0.136
Total Wipe Tests	7.6×10^{-4}	0.025
Total Activity Removed	4.9×10^{-3}	0.163

* Not Statistically Significant
** 3×10^{-5} uCi/ml
*** 0.03 uCi

Figure I
Schematic Representation of the Environmental Test Chamber

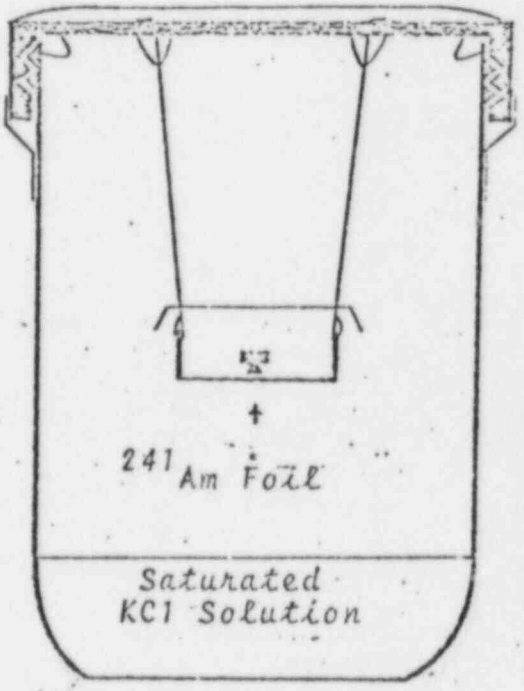
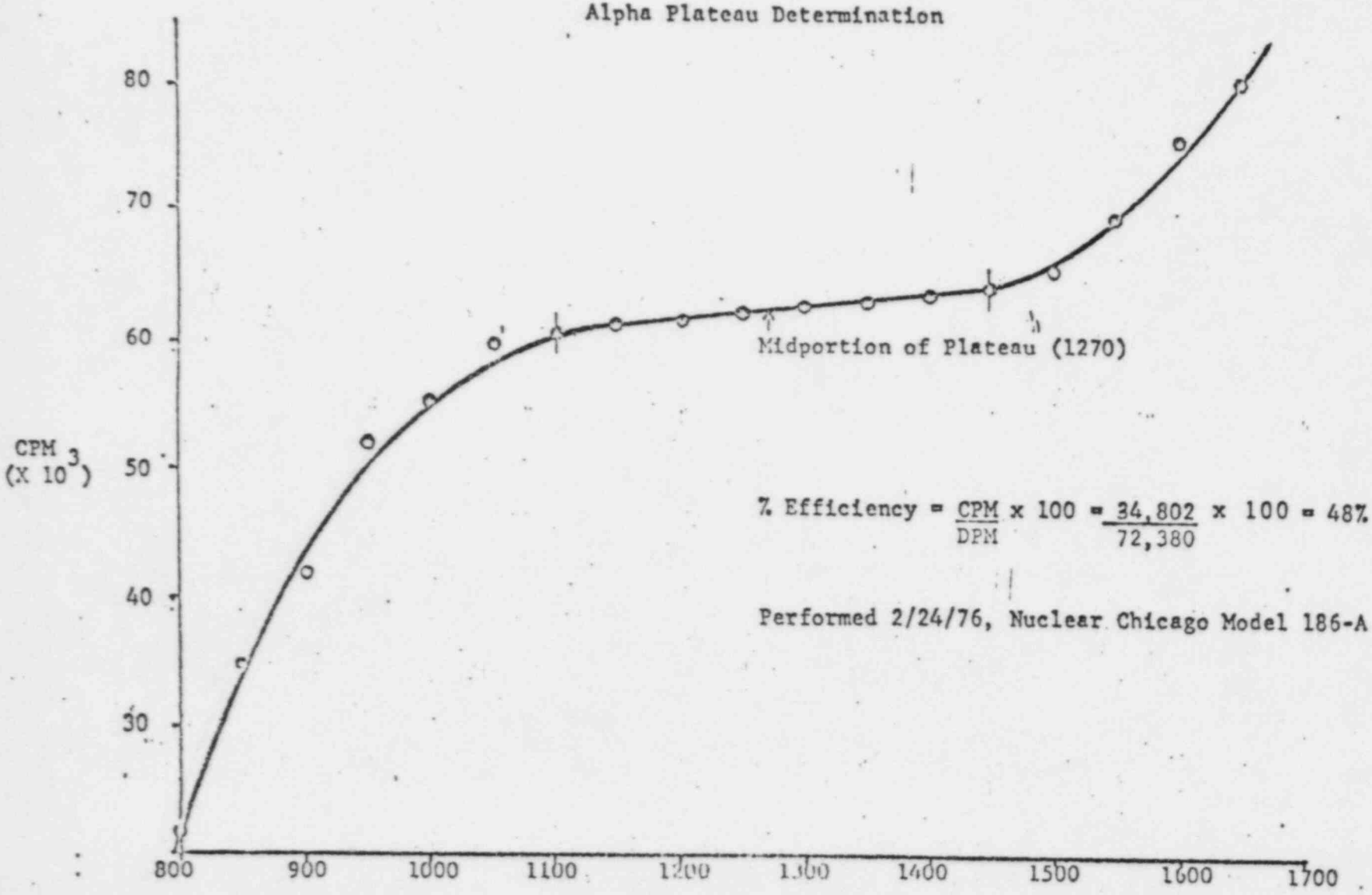


FIGURE II.

Alpha Plateau Determination



% Efficiency = $\frac{\text{CPM}}{\text{DPM}} \times 100 = \frac{34,802}{72,380} \times 100 = 48\%$

Performed 2/24/76, Nuclear Chicago Model 186-A

APPLIED VOLTAGE

FIGURE III.

Gross Sample #1

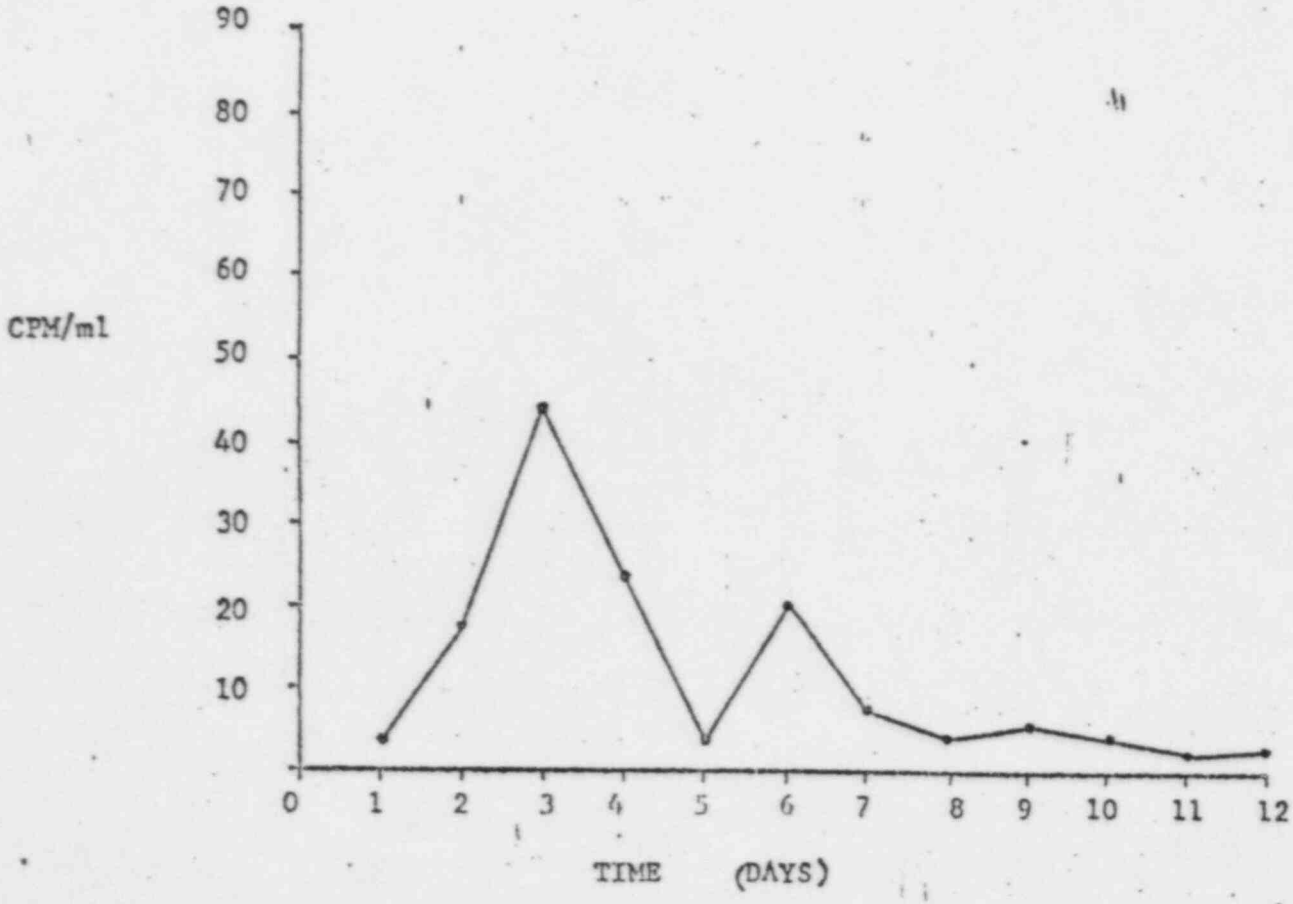


FIGURE IV.

Gross Sample # 2

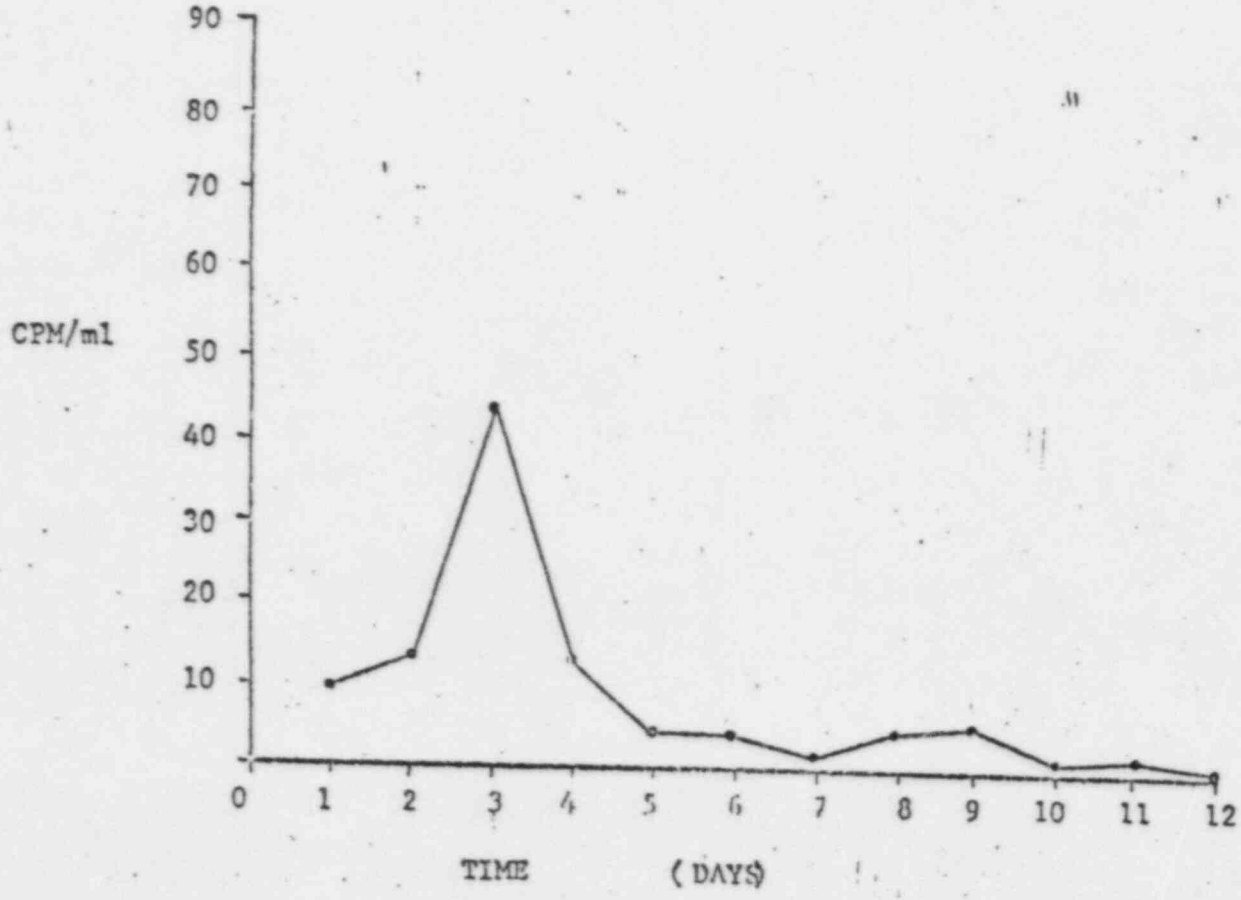


FIGURE V.

Gross Sample #3

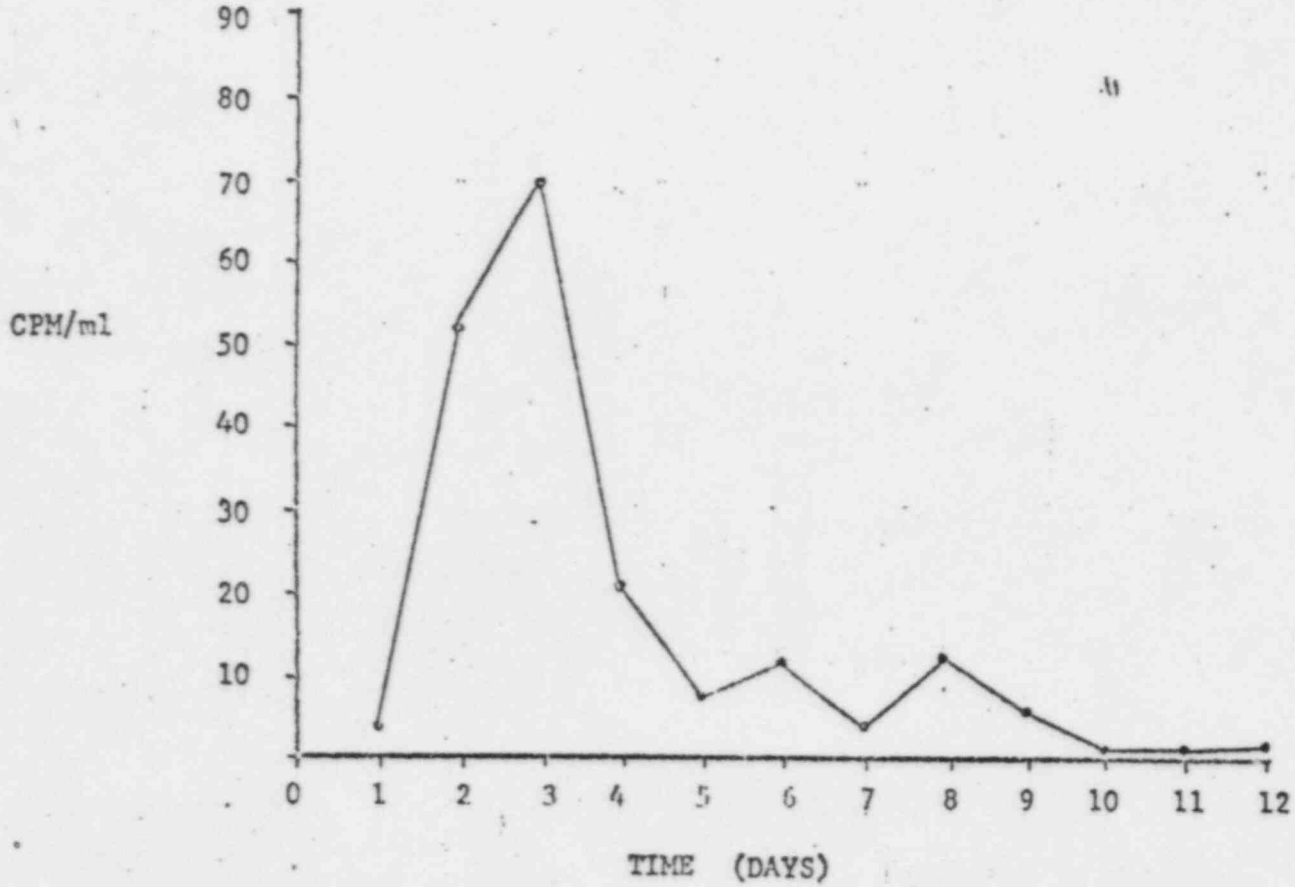


FIGURE VI.

Millipore Filter Test - Sample # 1

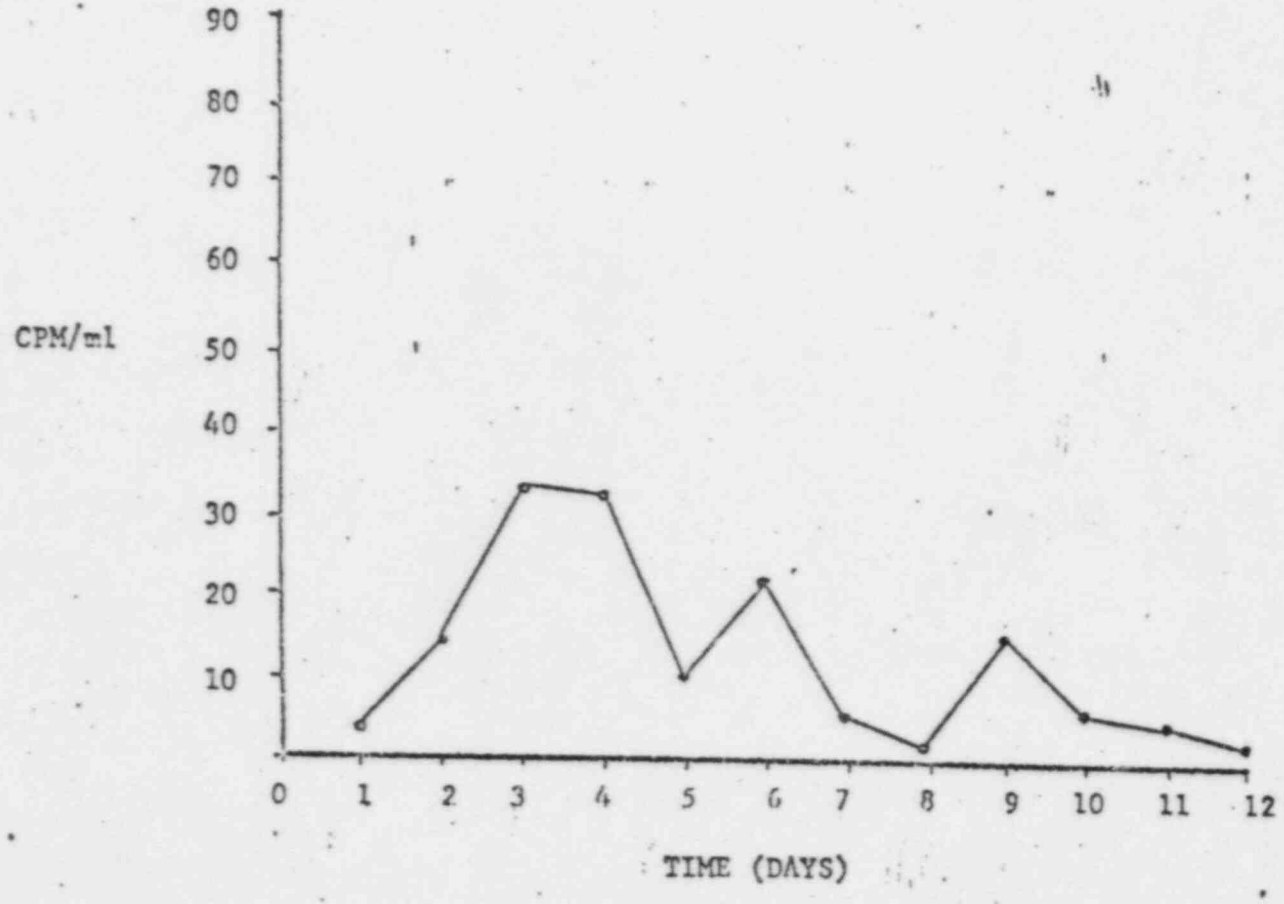


FIGURE VII.

Millipore Filter Test - Sample # 2

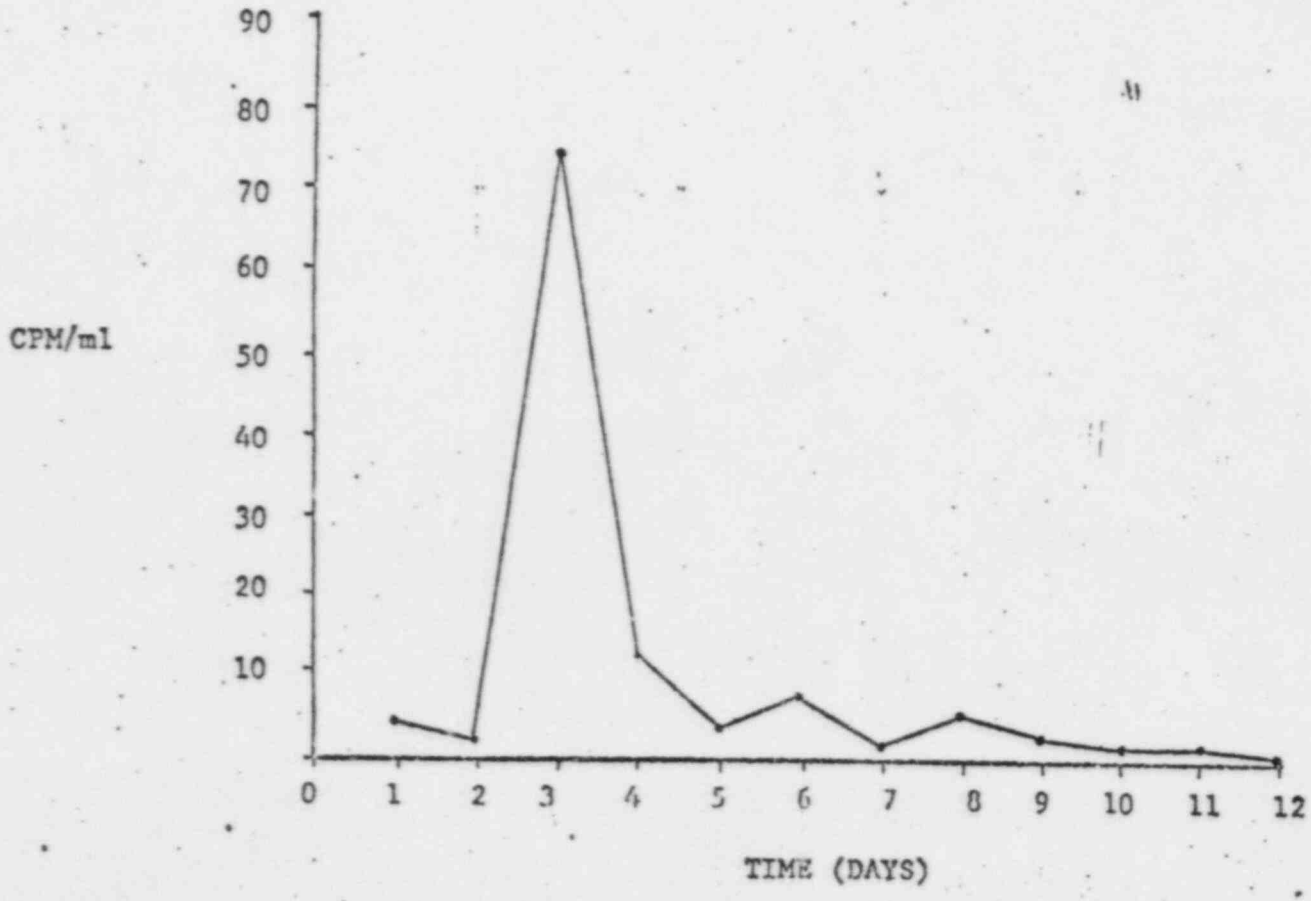


FIGURE VIII.

Millipore Filter Test - Sample # 3

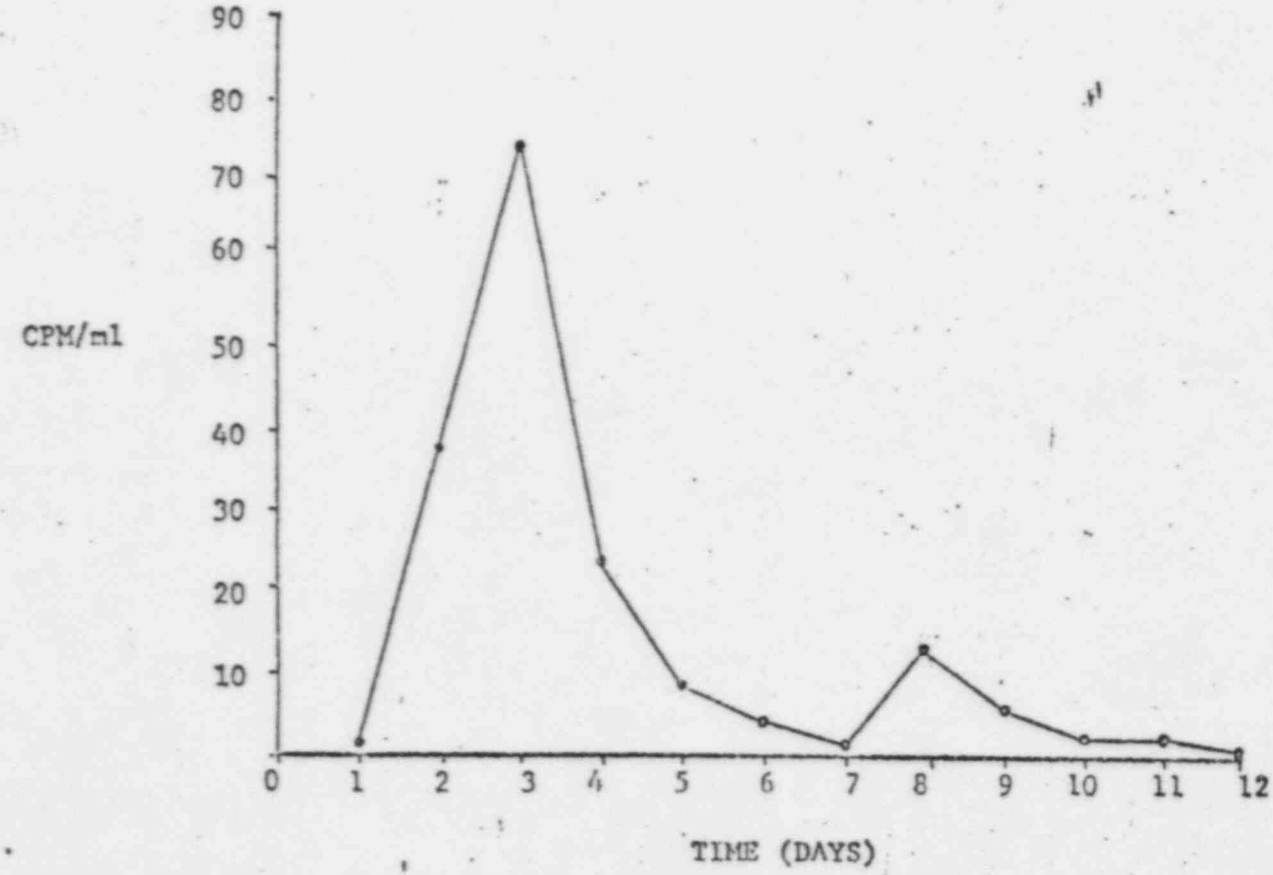


FIGURE IX.

Composite - Gross Samples

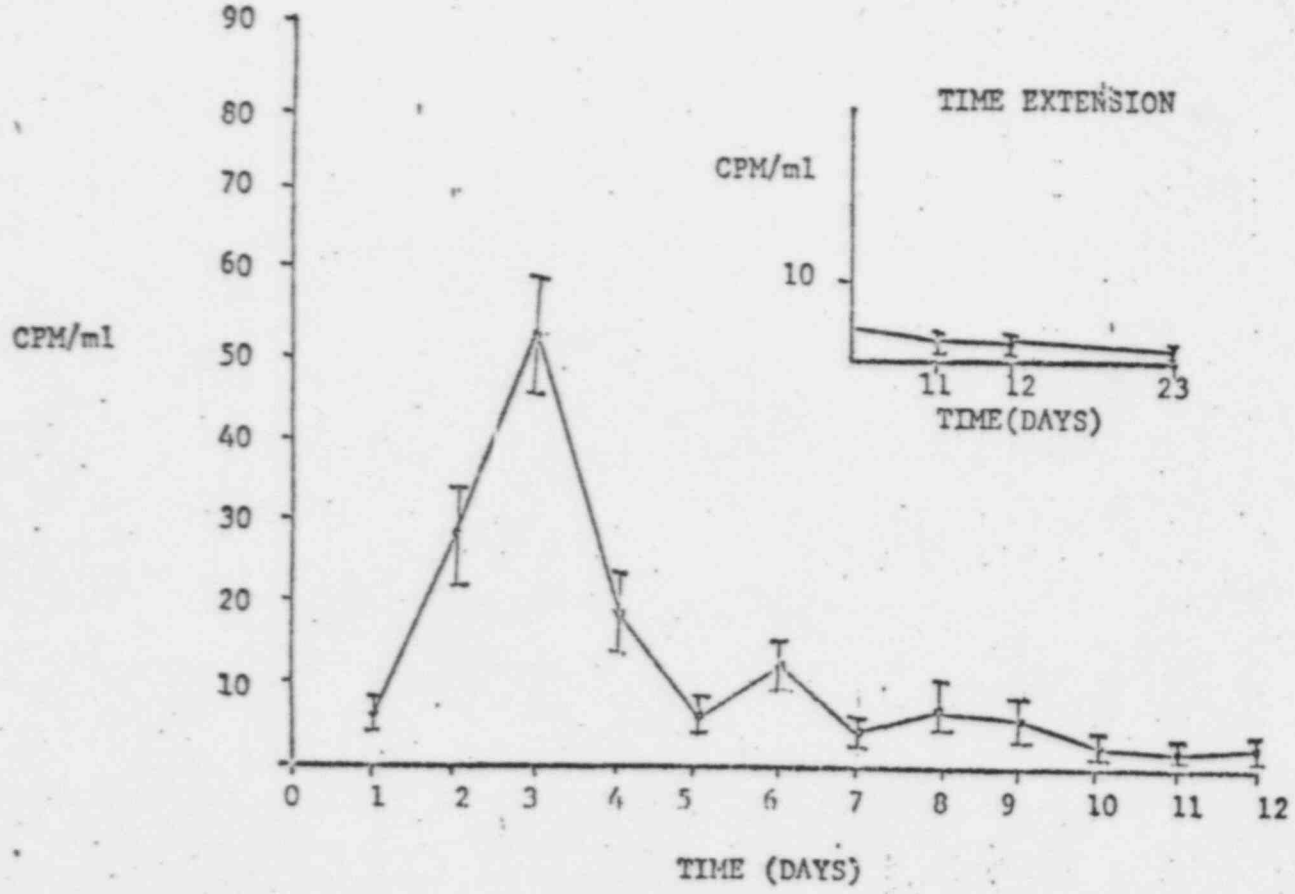


FIGURE X.

Composite - Millipore Samples

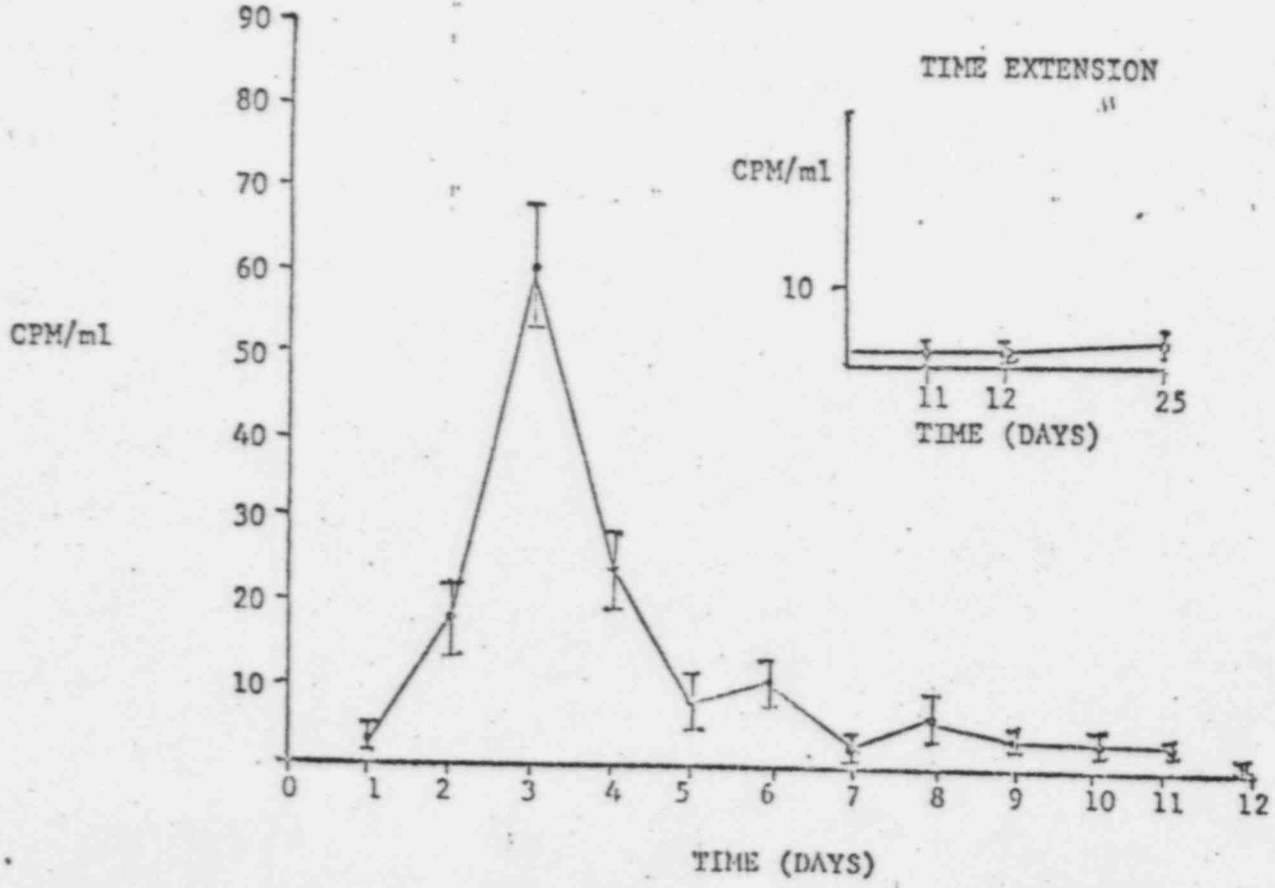
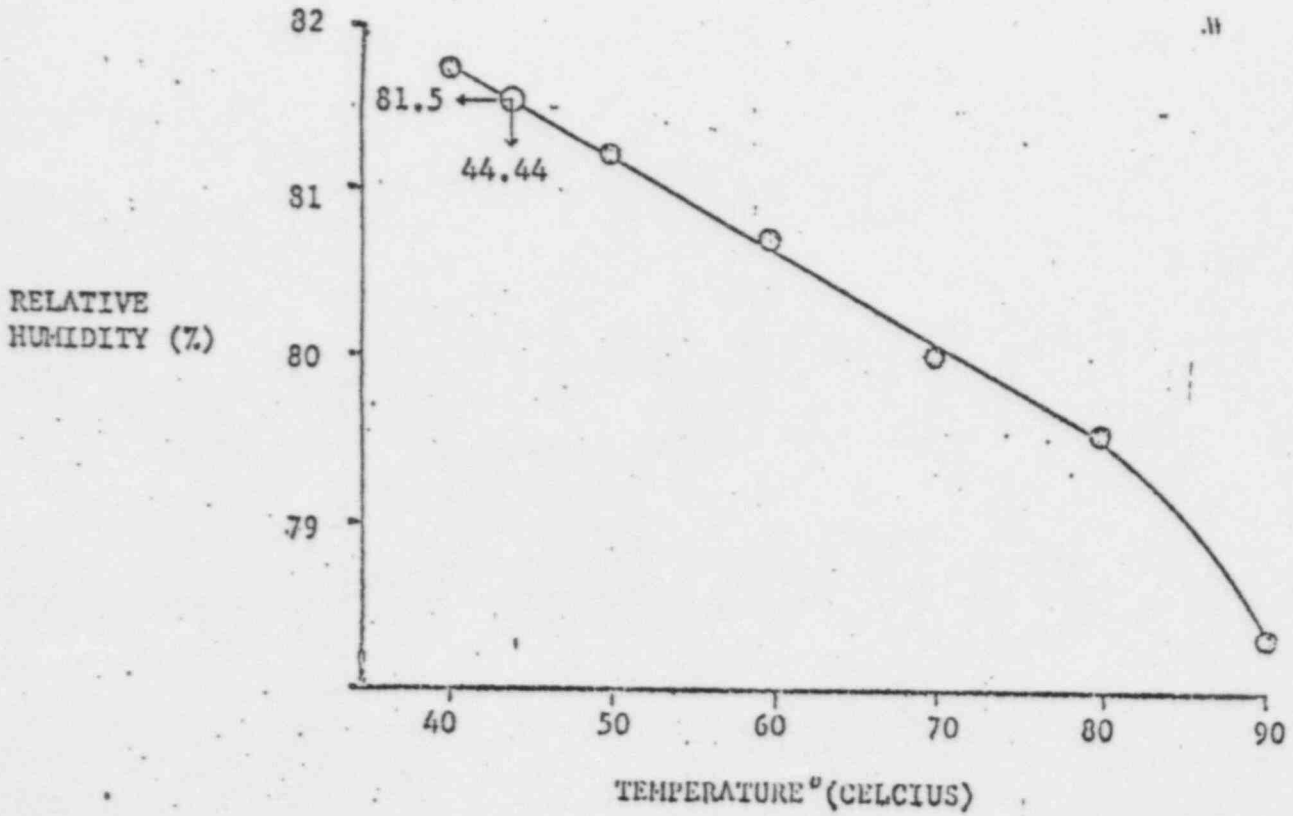


FIGURE XI.

Saturated Potassium Chloride Solution



CALCULATION OF ALPHA PARTICLE RANGE

CALCULATION OF MAXIMUM ENERGY RELEASE IN DECAY OF AMERICIUM 241

$$^{241}_{95}Am \longrightarrow {}^{237}_{93}Np + {}^{4}_{2}He + Q$$

$$Q = BE_{Np} + BE_{He} - BE_{Am}$$

$$Q = 1795.271 + 28.296 - 1817.929$$

$$\therefore Q = 5.638 \text{ MeV}$$

CALCULATION OF $R\alpha$ = RANGE OF α PARTICLE IN CM OF AIR AT 1 ATMOSPHERE AND 15°C

AT THE ENERGY RANGE 4 LEL 8

$$R\alpha = 1.24E - 2.62$$

$$R\alpha = 1.24 \times 5.638 - 2.62$$

$$R\alpha = \underline{\underline{4.37 \text{ cm}}}$$

CALCULATION OF RANGE OF α PARTICLE IN TISSUE

PER BRAGG-KLEEMAN RULE: GIVEN, $R\alpha_{AIR} = 4.37$ cm

$$R\alpha_{Tissue} = \frac{\rho_{AIR}}{\rho_{Tissue}} \left(\frac{A_{Tissue}}{A_{AIR}} \right)^{1/2} \cdot R\alpha_{AIR}$$

$$= \frac{.001293}{1.0} \left(\frac{6}{14.52} \right)^{1/2} \times 4.37$$

$\rho_{AIR} = .001293 \text{ gm cm}^{-3}$

$A_{AIR} = 14.52$

$\rho_{Tissue} = 1.0 \text{ gm cm}^{-3}$

$A_{Tissue} = 6$

$$\therefore R\alpha_{Tissue} = \underline{\underline{.0036 \text{ cm}}}$$

AS THE PROTECTIVE LAYER OF THE SKIN IS APPROX. .007CM THICK, NO ALPHA PARTICLE WILL PENETRATE INTO LIVE TISSUE.

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BY Jim Hampton

CALCULATION OF GAMMA EXPOSURE RATE

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SQUARE D COMPANY ELECTRICAL EQUIPMENT

A 1μCi AMERICIUM 241 SOURCE PRODUCES .060 MeV GAMMA RADIATION WITH A YIELD of 36%.

$$\dot{X}_o = \frac{1.56\times10^5 \cdot A \cdot T_\gamma \cdot Y_\gamma \cdot \mu_{en}}{r^2}$$

$$\dot{X}_o = \frac{1.56\times10^5 (.001)(.060)(36)(3.775\times10^{-5})}{r^2}$$

$$\dot{X}_o = \frac{127.17\times10^{-6}}{r^2}\ Rh^{-1}$$

$A = 1\mu Ci = .001 mCi$

$T_\gamma = .060\ MeV\ \gamma^{-1}$

$Y_\gamma = .36\ \gamma d^{-1}$

$\mu_{en} = .0000 3775\ cm^{-1}$

r = DISTANCE FROM SOURCE

$\dot{X}_o$ = EXPOSURE Rh^{-1}

TO CALCULATE THE RADIATION EXPOSURE RATE AT THE OUTSIDE OF THE SMOKE DETECTOR

A. RADIATION PASSING THROUGH COPPER CLAD of PRINTED CIRCUIT BOARD

LINEAR ABSORBTION COEFFICIENT = MASS ATTENUATION COEFFICIENT × DENSITY OF SHIELD

$$\mu = 1.62 \times 8.94$$

$$\mu = 14.483$$

$$\therefore \mu x = 14.483 \times .005$$

$$\mu x = .072$$

B. RADIATION PASSING THROUGH STEEL SMOKE PLATE

$$\mu = 1.20 \times 7.86$$

$$\mu = 9.432$$

$$\therefore \mu x = 9.432 \times .038$$

$$\mu x = .358$$

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SQUARE D COMPANY ELECTRICAL EQUIPMENT

CALCULATION OF GAMMA EXPOSURE RATE

R-1

$\dot{X}_{Cu\ Shield} = \dot{X}_o e^{-.072}$ $\dot{X}_{Fe\ Shield} = \dot{X}_o e^{-.358}$

$\dot{X}_{Cu\ Shield} = .931\ \dot{X}_o$ $\dot{X}_{Fe\ Shield} = .699\ \dot{X}_o$

EXPOSURE RATE AT OUTSIDE SURFACE OF SMOKE DETECTOR

$\dot{X}_o = \frac{127.17 \times 10^{-6}}{r^2}$ WHERE $r = 3.78$ cm

$\dot{X}_o = \frac{127.17 \times 10^{-6}}{(3.78)^2}$

$\dot{X}_o = 8.90 \times 10^{-6} Rh^{-1}$ AT SURFACE UNSHIELDED

$\dot{X}_{Cu\ SHIELD} = .931\ \dot{X}_o$

$\dot{X}_{Cu\ SHIELD} = .931\ (8.90 \times 10^{-6})$ AT SURFACE SHIELDED BY COPPER

$\dot{X}_{Cu\ SHIELD} = 8.29 \times 10^{-6} Rh^{-1}$

$\dot{X}_{Fe\ SHIELD} = .699\ \dot{X}_o$

$\dot{X}_{Fe\ SHIELD} = .699(8.90 \times 10^{-6})$ AT SURFACE SHIELDED BY STEEL

$\dot{X}_{Fe\ SHIELD} = 6.22 \times 10^{-6} Rh^{-1}$

EXPOSURE RATE AT 5cm FROM OUTSIDE SURFACE

$\dot{X}_o = \frac{127.17 \times 10^{-6}}{r^2}$ where $r = 7.78$ cm

$\dot{X}_o = \frac{127.17 \times 10^{-6}}{(7.78)^2}$

$\dot{X}_o = 1.650 \times 10^{-6} Rh^{-1}$

CALCULATION OF GAMMA EXPOSURE RATE

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$$\dot{X}_{Cu\ SHIELD} = 1.650 \times 10^{-6}(.931)$$

$$\dot{X}_{Cu\ SHIELD} = 1.536 \times 10^{-6}\ Rh^{-1}$$

$$\dot{X}_{Fe\ SHIELD} = 1.650 \times 10^{-6}(.699)$$

$$\dot{X}_{Fe\ SHIELD} = 1.153 \times 10^{-6}\ Rh^{-1}$$

EXPOSURE RATE AT 25cm FROM OUTSIDE SURFACE

$$\dot{X}_o = \frac{127.17 \times 10^{-6}}{r^2}$$ where r = 28.78 cm

$$\dot{X}_o = \frac{127.17 \times 10^{-6}}{(28.78)^2}$$

$$\dot{X}_o = 1.535 \times 10^{-5}\ Rh^{-1}$$

$$\dot{X}_{Cu\ Shield} = 1.535 \times 10^{-5}(.931)$$

$$X_{Cu\ Shield} = 1.429 \times 10^{-5}\ Rh^{-1}$$

$$\dot{X}_{Fe\ Shield} = 1.535 \times 10^{-5}(.699)$$

$$\dot{X}_{Fe\ Shield} = 1.073 \times 10^{-5}\ Rh^{-1}$$

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CALCULATION OF GAMMA RADIATION EXPOSURE BY OPERATOR ASSEMBLING SOURCES

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SQUARE D COMPANY
ELECTRICAL EQUIPMENT

IF THE OPERATOR SITS NEXT TO 5 FULL TUBES (145/TUBE) OF ION SOURCES FOR 8 HOURS PER DAY HIS TOTAL BODY EXPOSURE WILL BE:

AT $r = 20cm$ $\dot{X}_{Body} = 85 \times \frac{127.17 \times 10^{-6}}{20^2} = 27.02 \times 10^{-6}$ R/hr

AT $r = 25cm$ $\dot{X}_{Body} = 120 \times \frac{127.17 \times 10^{-6}}{25^2} = 24.42 \times 10^{-6}$ R/hr

AT $r = 30cm$ $\dot{X}_{Body} = 160 \times \frac{127.17 \times 10^{-6}}{30^2} = 22.61 \times 10^{-6}$ R/hr.

At $r = 35cm$ $\dot{X}_{Body} = 160 \times \frac{127.17 \times 10^{-6}}{35^2} = 16.61 \times 10^{-6}$ R/hr

At $r = 40cm$ $\dot{X}_{Body} = 100 \times \frac{127.17 \times 10^{-6}}{40^2} = 7.95 \times 10^{-6}$ R/hr

At $r = 45cm$ $\dot{X}_{Body} = 100 \times \frac{127.17 \times 10^{-6}}{45^2} = 6.28 \times 10^{-6}$ R/hr

TOTAL	725	104.89×10^{-6} R/hr

∴ TOTAL BODY EXPOSURE = 104.9×10^{-6} R/hr

$= 839.2 \times 10^{-6}$ R/DAY

$= .0545$ R/QTR

Which is Below The PERMISSIBLE DOSE LEVEL of 1¼ REMS/QTR per 20.101, "EXPOSURE of INDIVIDUALS TO RADIATION IN RESTRICTED AREAS"

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CALCULATION OF GAMMA RADIATION EXPOSURE OF OPERATOR ASSEMBLING ION SOURCES

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SQUARE D COMPANY ELECTRICAL EQUIPMENT

Assume that the operator has a full tube of 145 ion sources at the work station at all times during an 8 hour day, and he picks up the sources furthest away from his body first, and his hands and forearms are 1cm over the top of the tube of ion sources everytime a source is picked up with tweezers. We can then assume that for 4.0 hours each day his hand is on an average of 1 cm from approximately 145 ion sources

The Exposure to his hand & forearms:

$$\dot{X}_{HAND} = \frac{127.17 \times 10^{-6}}{1.0^2} \times 145 = 18.44 \text{ mR/hr}$$

$$\dot{X}_{HAND} = 18.44 \times 4.0 = 73.76 \text{ mR/DAY}$$

$$\dot{X}_{HAND} = 73.76 \times 65 = 4.79 \text{ R/Cal. Qtr.}$$

which is below the permissible dose level of 18 3/4 rems/Cal. Qtr per 20.101, "Exposure of individuals to radiation in restricted areas"

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CALCULATION OF GAMMA RADIATION EXPOSURE TO OPERATOR ASSEMBLING ION PLATE

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SQUARE D COMPANY ELECTRICAL EQUIPMENT

DURING THE ASSEMBLY OF THE ION PLATE TO THE PRINTED WIRING BOARD, THE OPERATOR WOULD RECEIVE EXPOSURE TO THE HAND AT A DISTANCE OF APPROXIMATELY 4 cm.

THE GAMMA EXPOSURE WOULD BE:

$$\dot{X}_o = \frac{127.17 \times 10^{-6}}{H^2}$$

$$\dot{X}_o = 7.95 \times 10^{-6} \text{ R/hr}$$

IF WE ASSUME THAT HE HANDLES THESE PLATES FOR 6.4 HOURS PER DAY (FROM TIME STUDY OBSERVATION)

THEN, $\dot{X}_{HAND} = 7.95 \times 10^{-6} \times 6.4$

$$\dot{X}_{HAND} = 50.9 \times 10^{-6} \text{ R/DAY}$$

$$\dot{X}_{HAND} = 50.9 \times 10^{-6} \times 65$$

$$= \underline{3.31 \text{ mR/CAL. QTR.}}$$

which is below the permissible dose level of 18 3/4 REMS/CAL. QTR per 20.101, "Exposure of Individuals To Radiation in Restricted Areas"

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CALCULATION OF GAMMA RADIATION EXPOSURE OF OPERATOR CARRYING TUBES OF SOURCES

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SQUARE D COMPANY ELECTRICAL EQUIPMENT

IF THE OPERATOR WENT TO THE STORAGE CABINET 9 TIMES A DAY TO REMOVE 5 TUBES (145 SOURCES/TUBE) EACH TIME AND WE ASSUME THAT HIS HAND WILL BE WITHIN .18CM OF THE EMMITTING SURFACE OF 160 SOURCES, THEN THE TOTAL EXPOSURE TO HIS HAND WILL BE:

$$\dot{X}_{HAND} = \frac{127.17 \times 10^{-6}}{.18^2} \times 160$$

$$\dot{X}_{HAND} = 628 mR/Hr$$

AT 20 SEC 9 TIMES PER DAY:

$$\dot{X}_{HAND} = 628 \times 9 \times \frac{20}{3600}$$

$$\therefore \dot{X}_{HAND} = 31.4 mR/DAY$$

OR $31.4 \times 65 = \underline{2.0 \text{ Rems/Cal Qtr}}$

WHICH IS BELOW THE PERMISSIBLE DOSE LEVEL OF 18 3/4 REMS/CAL. QTR.

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CALCULATION OF GAMMA RADIATION EXPOSURE OF PERSON AT STORAGE CABINET

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SQUARE D COMPANY ELECTRICAL EQUIPMENT

IF WE ASSUME THAT A PERSON STANDING IN FRONT OF THE OPEN STORAGE CABINET CONTAINING 100,000 SOURCES IS EXPOSED AT DISTANCES OF 25, 30, 35, 40, 45 & 50 cm, THE FOLLOWING CALCULATIONS APPLY.

AT $r = 25cm$ $\dot{x} = 16,667 \times \frac{127.17 \times 10^{-6}}{25^2} = 3.391 mRh^{-1}$

AT $r = 30cm$ $\dot{x} = 16,667 \times \frac{127.17 \times 10^{-6}}{30^2} = 2.355 mRh^{-1}$

AT $r = 35cm$ $\dot{x} = 16,667 \times \frac{127.17 \times 10^{-6}}{35^2} = 1.730 mRh^{-1}$

AT $r = 40cm$ $\dot{x} = 16,667 \times \frac{127.17 \times 10^{-6}}{40^2} = 1.325 mRh^{-1}$

AT $r = 45cm$ $\dot{x} = 16,667 \times \frac{127.17 \times 10^{-6}}{45^2} = 1.047 mRh^{-1}$

AT $r = 50cm$ $\dot{x} = 16,667 \times \frac{127.17 \times 10^{-6}}{50^2} = .848 mRh^{-1}$

∴ IF HE STOOD IN FRONT OF THE CABINET FOR AS LONG AS 1 HOUR EACH DAY HIS TOTAL BODY EXPOSURE WOULD BE 10.7 mR/DAY.

HIS WHOLE BODY EXPOSURE PER CALENDAR QUARTER WOULD BE: $65 \times 10.7 = .696$ R/CAL QTR

WHICH IS BELOW THE PERMISSIBLE DOSE LEVEL of 1¼ REMS PER CALENDER QTR.

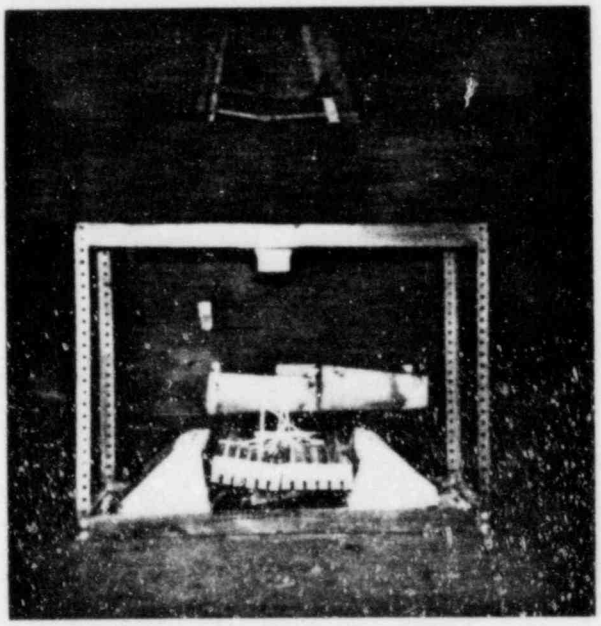
FIRE TEST EGD-6 SERIES SMOKE DETECTOR

I. OBJECTIVE

To test the containment of americium oxide in the source holder and to test the containment of the source holder in the source plate during a fire which destroys the smoke detector.

II. METHOD

The smoke detector was suspended 14" above (4) UL standard 217 wood cribs by the normal mounting holes. The wood cribs were ignited via small kindling and allowed to burn approximately 10 minutes. Flame occurred about 5 minutes into the fire. At approximately 7.5 minutes the detector had melted sufficiently to fall from its mounting into the fire. Test ended at 10 minutes.



EGD-6B set up before fire test

7.25 min. into fire test

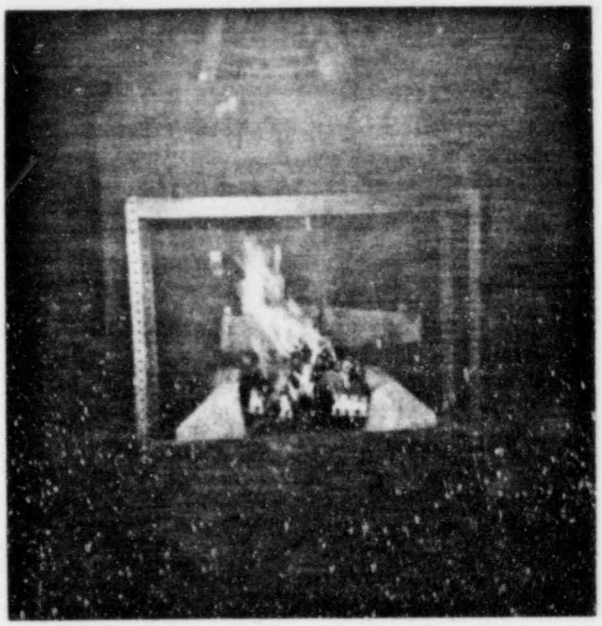
III. RESULTS

1. The incinerated smoke detector was photographed.

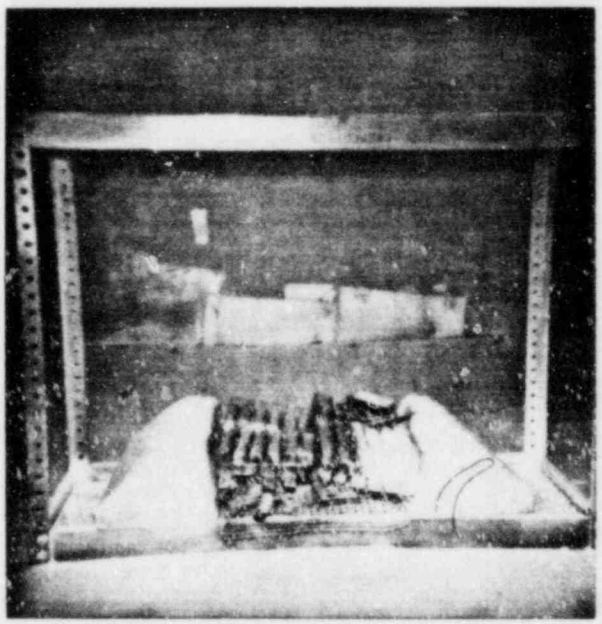
2. The smoke plate could not be removed without the aid of a screwdriver. Examination of the source plate revealed that the source and source holder were still intact and securely fastened to one another.

3. Examination of the source under a microscope revealed no damage to either the source or source holder.

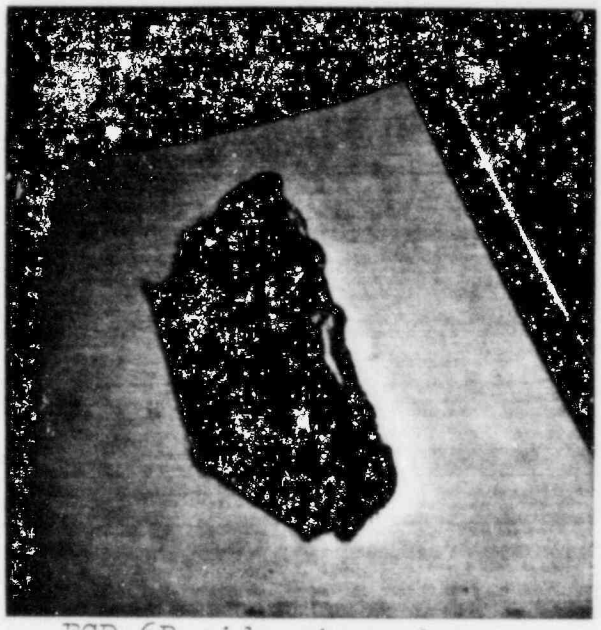
4. The emission level of source was checked and compared to a .6586uCi standard. One reason for the decreased emission level was due to a thick layer of soot and tar which covered both emitting surfaces.



7.50 min into fire test



EGD-6B after fire was extinguished



EGD-6B side view after fire test

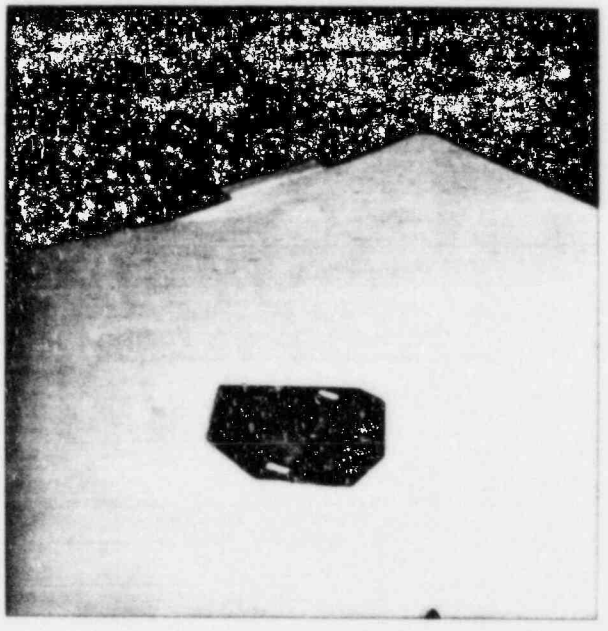
6

EGD-6B after fire test

5

EGD-6B view of source with smoke plate lifted

7

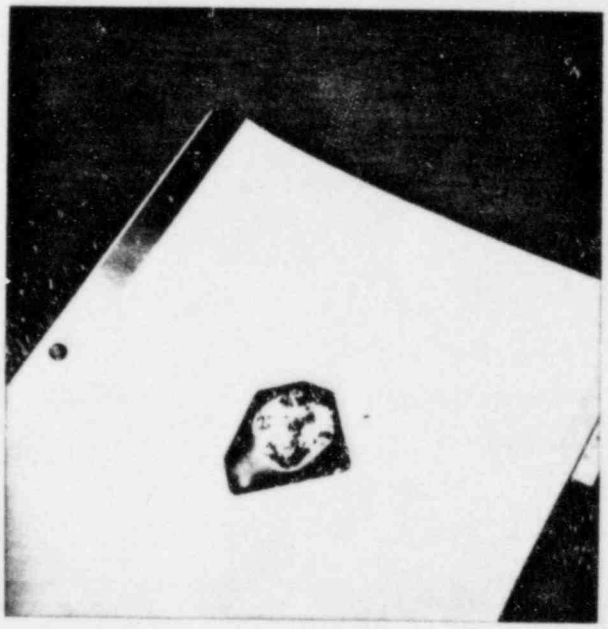


reference chamber side of source after fire test

8

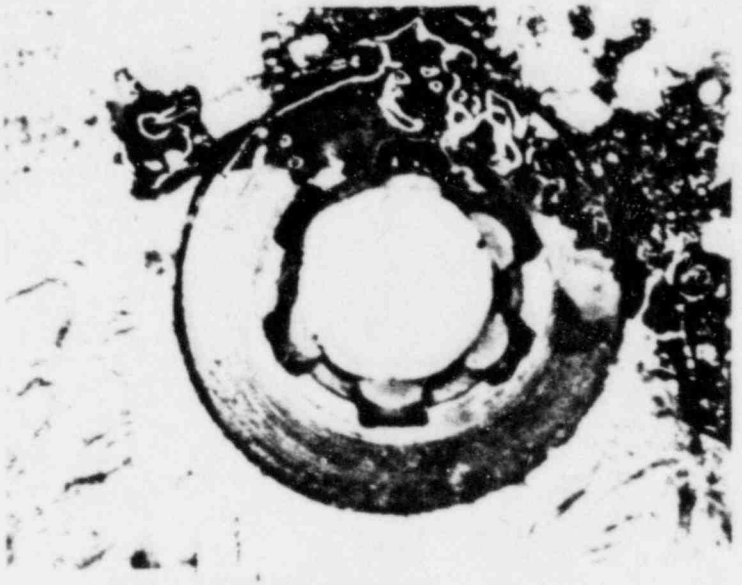
Smoke chamber side of source after fire test

Smoke chamber side of source after being cleaned with alcohol



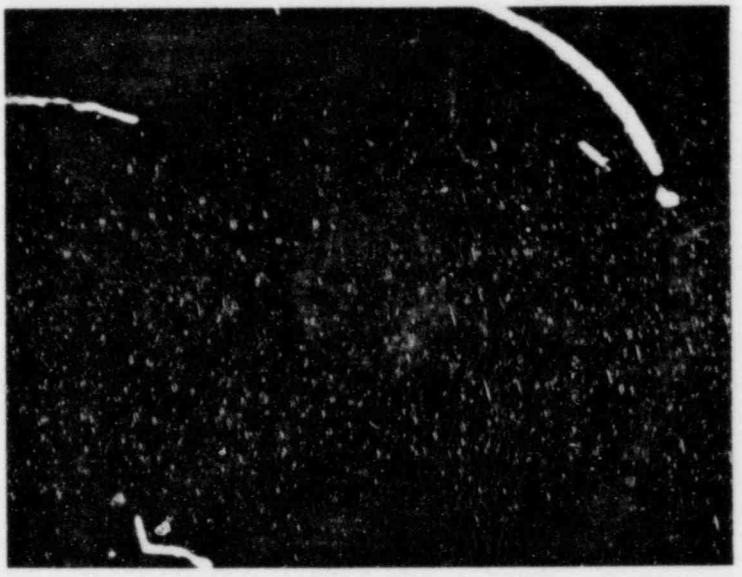
Reference chamber side of source after being cleaned with alcohol

source reference chamber side after fire



MAGNIFICATION 12X

source smoke chamber side after fire



MAGNIFICATION 12X

WIPE TEST RESULTS

1 MINUTE COUNT

WIPE TEST	COUNT #1	COUNT #2	COUNT #3	AVG COUNT	ACTIVITY
Background	0	1	1	.66	.69pCi
Exterior of housing	0	0	0	0	0
Both sides of source	1	0	1	.66	.69pCi

EMISSION TEST RESULTS

TEST	COUNT #1	COUNT #2	COUNT #3	AVG COUNT	ACTIVITY
.6586 4Ci calibration standard	623,571	623,769	624,906	624,082	.6586uCi
Ion source from incinerated detectors:					
a. Smoke Chamber side	150,740	149,954	150,319	150,337	.16uCi
b. Ref Chamber side	178,871	181,785	181,498	180,618	.20uCi

IV. CONCLUSION

From the test results achieved, the following conclusion can be made:

1. Wipe tests indicate no americium oxide was liberated during the fire.

2. The source and source holder remained in tact attached to the source plate.

3. During the fire test, the melting plastic covered the smoke plate making it very difficult to get to the source plate.

Jim Hampton
July 25, 1985

DROP TEST

EGD-6 SERIES DETECTOR

I. OBJECTIVE

The objective of the drop test was to determine if repeated drops of a fully assembled smoke detector would result in the radioactive source being jarred loose or if any other condition would develop that would result in an abnormal radiological survey.

II. METHOD

A test unit was dropped from an 8' height into a concrete surface. The unit was dropped so that the impact was on the face of the detector. This was determined to be the worst case. The test unit was dropped 25 times with a separate wipe over the external surface taken after each drop. After the 25th drop, the unit was disassembled down to te printed wiring board assembly. Wipe tests were then performed on the chamber assembly and the surrounding board area.

III. RESULTS

Each radiological wipe was counted for one minute using the Eberline Instrument Corporation scintillation alpha counter, model SAC-4. No single wipe was found to be in excess of normal background count.

WIPE TEST RESULTS

Wipe Test #	CPM	Activity*	Wipe Test #	CPM	Activity *
1	0	0	14	0	0
2	0	0	15	0	0
3	0	0	16	0	0
4	0	0	17	0	0
5	0	0	18	0	0
6	0	0	19	0	0
7	1	1.1pCi	20	0	0
8	0	0	21	0	0
9	0	0	22	0	0
10	0	0	23	0	0
11	0	0	24	0	0
12	0	0	25	0	0
13	1	1.1pCi	26**	2	2.1pCi

*Activity calculated using .6586uCi standard.

**Wipe test was inside smoke detector housing as well as the PCB and chamber cover.

IV. CONCLUSION

Based on physical examinations and wipe test results, no damage was sustained to the radioactive source and the source remained contained within the confines of the detector and attached to the source plate.

Jim Hampton
August 6, 1985

WATER TEST

I. OBJECTIVE

To test the containment of americuim oxide in the source holder and to test the containment of the source holder in the source plate during the immersion of the smoke detector in water (both room temperature and boiling).

II. METHOD

1. A clean aluminum pot was rinsed with cold deionized water, refilled with deionized water and brought to a boil. The water was then allowed to cool and filtered through a .45 millipore filter. The filter was analyzed for radioactive contamintion and a wipe test performed on the pot and exterior surface of the smoke detector.

2. The pot was refilled with the refiltered deionized water and the smoke detector was immersed in the water. The detector was allowed to soak for 1 hour during which time the pot was agitated every ten minutes. At the completion of 1 hour soaking at room temperature, the smoke detector was removed from the water and allowed to drain into the pot. The water from the pot was then refiltered through a .45u filter. The inside of the pot and the exterior surface of the smoke detector were wipe tested.

3. The pot was rinsed and refilled with clean filtered deionized water. The filter was again analyzed for radioactive contamination. The pot was placed on the hot plate and alowed to come to a boil. The smoke detector was wipe tested on the exterior surface and immersed into the boiling water for 1 hour. The water was not agitated during the 1 hour of boiling.

4. After 1 hour the smoke detector was removed from the boiling water and allowed to drain into the pot. The water from the pot was refiltered through a .45u filter and the filter analyzed for radioactive contamination. The exterior surfaces of the smoke detector and inside of the pot were wipe tested.

5. The printed wiring board assembly was removed from the detector and the inside of the detector housing and the outside and inside of the insulator were wipe tested.

6. The ion source was then examined under a 30X microscope. No discrepanceies were noted.

ENGINEERING SKETCH SHEET

MD-88

NO.

JOB AND USER (DWG. TITLE BLOCK INFORMATION)

CALCULATION OF GAMMA RADIATION EXPOSURE OF PERSON INSTALLING SMOKE DETECTORS

DATE 2/12/85 | PAGE 1 OF 2

BY Jim Haughton

R-1

APPROVED BY · DATE

SQUARE D COMPANY ELECTRICAL EQUIPMENT

IF WE ASSUME THAT AN ELECTRICIAN CAN INSTALL SMOKE DETECTORS IN (2) HOMES PER DAY AND THE MAXIMUM NUMBER OF SMOKE DETECTORS PER HOME IS (6), HE WILL BE HANDLING (12) SMOKE DETECTORS PER DAY. DURING INSTALLATION, HE WILL BE HOLDING EACH SMOKE DETECTOR ABOUT 25cm AWAY FROM HIS FACE FOR ABOUT 4 MINUTES.

EXPOSURE TO HIS FACE:

$$\dot{X}_o = \frac{127.17 \times 10^{-6}}{25^2}$$

$$\dot{X}_o = .203 \times 10^{-6}\ Rh^{-1}$$

$$\dot{X}_{SHIELD} = .931 \times \dot{X}_o$$

$$\dot{X}_{SHIELD} = .189 \times 10^{-6}\ Rh^{-1}$$

∴ EXPOSURE TO HIS FACE PER DAY

$$\dot{X}_{FACE} = .189 \times 10^{-6} \times 4 \times 12$$

$$\dot{X}_{FACE} = 9.07 \times 10^{-6}\ R/DAY$$

IF HE WORKS 6 DAYS PER WEEK, 50 WEEKS PER YEAR

$$\dot{X}_{FACE} = 9.07 \times 10^{-6} \times 6 \times 50$$

$$\underline{\dot{X}_{FACE} = .0027\ REM\ PER\ YEAR}$$

WHICH IS FAR BELOW THE PERMISSIBLE DOSE LEVEL OF .5 REM PER YEAR

ENGINEERING SKETCH SHEET

MD-88

NO.

JOB AND USER (DWG. TITLE BLOCK INFORMATION)

CALCULATION OF GAMMA RADIATION EXPOSURE OF PERSON INSTALLING SMOKE DETECTORS

DATE 8/12/85 PAGE 2 OF 2

BY Jim Hampton

R-1

APPROVED BY DATE

SQUARE D COMPANY ELECTRICAL EQUIPMENT

EXPOSURE TO HIS HANDS = EXPOSURE RATE AT THE OUTSIDE SURFACE OF THE SMOKE DETECTOR

$\dot{X}_{HANDS} = 8.29 \times 10^{-6} Rh^{-1}$ PER CALCULATION of γ EXPOSURE RATE ATTACHMENT B-6

$\therefore$ TOTAL $\dot{X}_{HANDS} = 8.29 \times 10^{-6} \times 4 \times 12$

$\dot{X}_{HANDS} = 397.9 \times 10^{-6}$ R/DAY

IF HE WORKS 6 DAYS/WEEK, 50 WEEKS/YEAR

$\dot{X}_{HANDS} = 397.9 \times 10^{-6} \times 6 \times 50$

$\dot{X}_{HANDS} = .119$ REM/YEAR

WHICH IS BELOW THE PERMISSIBLE DOSE LEVEL OF .5 REM/YEAR

ATTACHMENT B-14

FIRE HAZARD ANALYSIS

The bulk of the completed Smoke Detectors will be stored at the Physical Distribution Center (PDS) in Florence, Kentucky. At PDS mainly Class I materials are stored. Smoke Detectors are pallitized at 240 units per 50 cu ft.

PDS consists of 2 buildings at 178,000 sq ft each. They are protected from fire by a water sprinkler system. The sprinkler system has a 286°F actuation temperature. The sprinkler heads are mounted 18 ft high on 8 ft by 10 ft centers. The sprinkler system is capable of pumping water at the rate of .18 gal/mim/ft^2 (14 gal/min/head).

PDS is a high volume distribution center and may have many of its loading doors open at any one time during normal work hours. This makes it difficult to calculate the number of air changes which would occur during a fire. However, on a randomly chosen day, the number of openings at the check time would allow approximately 3 complete air changes per hour in one building.

PDS has its own emergency squad, however, the City of Florence, Kentucky would fight any fire. The Florence, Kentucky Fire Department has a basic full time force and is rated as a Class VI department by the insurance industry.

The balance of the radioactive sources will be located at the Square D plant in Pinellas Park, Florida. The unassembled sources will be stored in a fire resistant, steel cabinet located in a locked room within a limited access area.

The room and the limited access area will be constructed of fire proof materials and will be protected by a sprinkler system. The sprinkler system will conform to N.F.P.A. standards and all applicable state and federal codes. The building in which the limited access areais located, relies on hand held type ABC fire extinguishers. Any fire, however, would be fought by the City of Pinellas Park Fire Department. The City of Pinellas Park

has 48 full time fire fighters and is rated as Class IV fire department by the insurance industry.

James Hampton
Nov. 9, 1981

/mk

ENGINEERING SKETCH SHEET

MD-88

NO.

JOB AND USER (DWG. TITLE BLOCK INFORMATION)
CALCULATION OF ALPHA + GAMMA RADIATION
EXPOSURE TO A FIRE FIGHTER DURING A FIRE

DATE 5/6/75 | PAGE 1 OF 5

BY Jim Hampton

R-1

APPROVED BY · DATE

SQUARE D COMPANY
ELECTRICAL EQUIPMENT

TOTAL MAXIMUM INVENTORY OF SMOKE DETECTORS AT P.D.S. WAREHOUSE IN FLORENCE, KENTUCKY = 150,000. IF ALL THE SMOKE DETECTORS ARE STORED IN ONE BUILDING OF 178,000 Sq. feet, WITH AN 18 FOOT High CEILING AND WE ASSUME THAT IN A CATASTROPHIC FIRE ALL 150,000 SMOKE DETECTORS ARE INCINERATED, WE CAN THEN CALCULATE THE AMOUNT OF Am 241 LIBERATED. USING OAK RIDGE NATIONAL LABORATORY TEST RESULTS OF OCTOBER 21, 1969, .31% of Am 241 WILL BE LIBERATED DURING A 1 HOUR FIRE. SINCE EACH SMOKE DETECTOR CONTAINS 1 μCi of Am 241:

TOTAL AMOUNT of Am 241 LIBERATED = $1 \times 150{,}000 \times .0031$

$= 465\ \mu Ci/HR$

IF WE ASSUME THAT THIS TOTAL AMOUNT OF ACTIVITY WILL BE DISTRIBUTED THROUGHOUT THE BUILDING AND THAT THERE WILL BE 3 COMPLETE AIR CHANGES PER HOUR IN THE BUILDING, THEN WE CAN CALCULATE THE TOTAL CONCENTRATION OF Am 241 IN THE AIR DURING THE FIRE.

TOTAL VOLUME OF AIR $= 3 \times 178{,}000 \times 18$

$= 9.612 \times 10^6$ cu ft./HR

$= 9.612 \times 28.32$

$= 272.2 \times 10^6$ LITRES/HR.

TOTAL Volume of AIR $= 272.2 \times 10^9$ ML/HR.

CONCENTRATION OF Am 241 IN AIR DURING FIRE $= \frac{465}{272.2 \times 10^9}$ $\mu Ci/ml$

$\therefore$ Am 241 CONCENTRATION IN AIR $= 1.71 \times 10^{-9}$ $\mu Ci/ml$

DURING A CATASTROPHIC FIRE, WE WOULD EXPECT THE ROOF TO COLLAPSE AND THUS ALLOW MORE AIR TO DILUTE THE CONCENTRATION. ALSO, THE OVERHEAD SPRINKLER SYSTEM WOULD PREVENT MUCH OF THE LIBERATED AMERICIUM FROM BECOMING AIRBORNE PRIOR TO COLLAPSE OF THE ROOF.

IF THE FIRE FIGHTER INHALES 20,000 LITRES OF AIR (10-12 HOURS OF HEAVY BREATHING) DURING THE TOTAL DURATION OF THE FIRE, AND THE CONCENTRATION OF Am 241 IN THE AIR REMAINS AT THE 1.71×10^{-9} $\mu Ci/ml$ level. WE KNOW THAT 50% OF THE Am 241 INHALED WILL BE IMMEDIATELY EXHALED AND THEREFORE HAVE NO EFFECT.

$\therefore$ HIS TOTAL UPTAKE OF Am 241 WILL BE $= .5 \times 1.71 \times 10^{-9} \times 20{,}000 \times 10^3$

$= 17.1 \times 10^{-3}$ μCi

IF WE ASSUME THAT OF THIS TOTAL UPTAKE 50% WILL BE ELIMINATED THROUGH THE LUNGS AND GASTRO-INTESTINAL TRACT AND 50% WILL BE ABSORBED INTO THE BODY AND RETAINED IN THE BONES FOR A PERIOD OF 50 YEARS, THEN HIS INTERNAL DOSE COMMITMENT TO HIS LUNGS WILL BE:

ENGINEERING SKETCH SHEET

MD-88

NO.

JOB AND USER (DWG. TITLE BLOCK INFORMATION)

CALCULATION OF ALPHA & GAMMA RADIATION EXPOSURE TO A FIRE FIGHTER DURING A FIRE

DATE 8/6/85 | PAGE 3 OF 3

BY Jim Langston

APPROVED BY | DATE

R-1

SQUARE D COMPANY ELECTRICAL EQUIPMENT

$$\text{INTERNAL DOSE COMMITMENT} = \frac{2.13 g f_2 E}{m \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

Where $g = .5 \times 17.1 \times 10^{-3} = 8.55 \times 10^{-3}$ μCi

f_2 = FRACTION of TOTAL Body BURDEN (LUNGS + G.I.)

$= .043$

m = TOTAL MASS of LUNGS & G.I.

$= 3000$ gm

$E = 268.7$ MeV d^{-1} Rem Rad^{-1}

(PER "CALCULATION of RADIATION DOSE FROM

$$T_{EFF} = \frac{T_r \cdot T_b}{T_r + T_b}$$

where $T_r = 458$ YEARS

$T_b = 12$ DAYS

$$= \frac{4012080 \times 288}{4012080 + 288}$$

$T_{EFF} = 287.98$ HRS.

$$\lambda_{EFF} = \frac{.693}{287.98}$$

$\lambda_{EFF} = .002406$

$$\text{INTERNAL DOSE COMMITMENT (SOFT ORGANS)} = \frac{2.13 g f_2 E}{m \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

$$\text{Soft ORGAN DOSE} = \frac{2.13(8.55\times10^{-3})\times.043\times 268.7\left(1-e^{-.002406\times 273}\right)}{3000\times.002406}$$

$$= 2.915\times10^{-2}(1-.5)$$

$$= 1.46\times10^{-2}\ \text{REM}$$

$$\text{INTERNAL DOSE COMMITMENT (SKELETON)} = \frac{2.13\,g\,f_2\,E}{m\,\lambda_{Eff}}\left(1-e^{-\lambda_{Eff}T}\right)$$

Where
$g = 8.55\times10^{-3}\ \mu Ci$
f_2 = FRACTION of TOTAL Body BURDEN (SKELETON)
$= .14$
m = MASS of skeleton
$= 1000\ gm$
$E = 273\ MeVd^{-1}\ REM\ RAD^{-1}$
(per Report By I.C.R.P.)

$$T_{Eff} = \frac{T_r \cdot T_b}{T_r + T_b}$$

$T_r = 4012080$ HRS
$T_b = 50$ yrs

$$T_{Eff} = \frac{4012080\times438000}{4012080+438000}$$

$$T_{Eff} = 3.9489\times10^{5}\ \text{HRS}$$

$$\lambda_{Eff} = \frac{.693}{T_{Eff}} \qquad \lambda_{Eff} = \frac{.693}{3.9489\times10^{5}}$$

$$\lambda_{Eff} = 1.754\times10^{-6}$$

ENGINEERING SKETCH SHEET

MD-88

NO.

JOB AND USER (DWG. TITLE BLOCK INFORMATION)

CALCULATION OF ALPHA + GAMMA RADIATION EXPOSURE TO FIRE FIGHTER DURING A FIRE

DATE 2/6/75 | PAGE 5 OF 5

BY Jim Hampton

R-1

APPROVED BY · DATE

SQUARE D COMPANY ELECTRICAL EQUIPMENT

$$\text{INTERNAL DOSE COMMITMENT (SKELETON)} = \frac{2.13 \times 8.55 \times 10^{-3} \times .14 \times 283}{10000 \times 1.7549 \times 10^{-6}} \left(1 - e^{-1.7549 \times 10^{-6} \times 438000}\right)$$

$$= 411.157 \times 10^{-1} (.536)$$

TOTAL DOSE = 22.04 REM

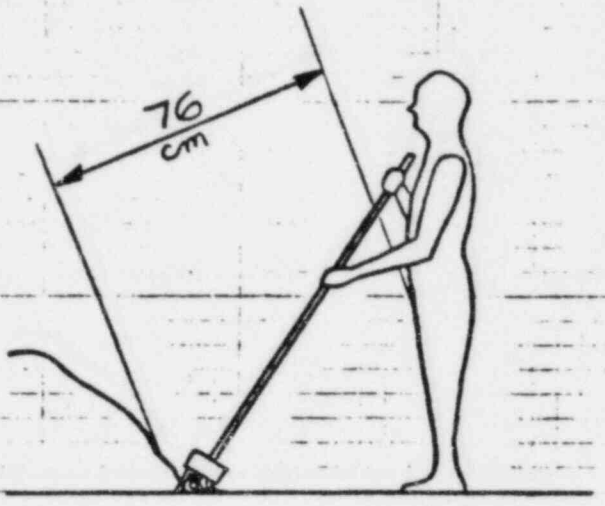
OR, TOTAL DOSE TO SKELETON = .441 REM/YEAR

THE PROBABILITY OF THE FIRE FIGHTER RECEIVING THIS DOSE IS ACTUALLY REMOTE SINCE THE BURNING PLASTIC IN THE HOUSING WOULD REQUIRE THE WEARING OF OXYGEN BREATHING EQUIPMENT; HENCE ELIMINATING ANY INTERNAL RADIATION HAZARD.

BY [illegible] DATE 7-21-11 SUBJECT CALCULATION OF GAMMA RADIATION EXPOSURE OF PERSON CLEANING UP AFTER FIRE SHEET NO. 1 OF 2

CHKD. BY ____ DATE ____ JOB NO. ____

DURING THE CLEAN UP OPERATIONS, THE PERSON SWEEPING THE FLOOR AND SWEEPING ALL THE DEBRIS INTO A HEAP AND THEN LOADING IT INTO DRUMS FOR TRANSPORTATION TO A LICENSED BURIAL SITE, WOULD BE EXPOSED TO THE FOLLOWING RADIATION DOSE.



IF WE ASSUME THAT ONE PERSON CAN SWEEP THE WHOLE AREA IN 16 HOURS, AND THERE WILL BE 150,000 RADIOACTIVE SOURCES SCATTERED ALL OVER THE WAREHOUSE. FURTHER, LET US ASSUME THAT THE AVERAGE DISTANCE OF HIS BODY FROM AN AVERAGE OF APPROXIMATELY 10000 AMERICIUM SOURCES DURING THE TOTAL 16 HOURS IS APPROXIMATELY 76 cm.

$$\text{THEN } \dot{X}_{BODY} = \frac{127.17 \times 10^{-6}}{76^2} \times 10000$$

$$\dot{X}_{BODY} = 220 \times 10^{-6} \text{ Rh}^{-1}$$

$$\therefore \text{TOTAL EXPOSURE} = 220 \times 10^{-6} \times 16$$

$$\therefore \text{TOTAL EXPOSURE } \dot{X}_{BODY} = 3.52 \text{ m REM}$$

WHICH IS FAR BELOW THE PERMISSIBLE DOSE LEVEL OF .5 REM PER § 32.28 "TABLE OF ORGAN DOSES", COLUMN II.

THERE WILL BE PROBABLY MORE THAN 1 PERSON CLEANING UP, AND SO THE LENGTH OF EXPOSURE PER PERSON WILL DECREASE, ALSO IT IS MOST UNLIKELY THAT THE PERSON WILL BE CLOSE TO 10000 ION SOURCES AT ALL TIMES DURING HIS CLEAN UP SHIFT.

BUT EVEN IF HE IS AS CLOSE AS 50 cm TO ALL 67500 ION SOURCES FOR AS LONG AS 2 HOURS. (DURING THE LOADING OF THE DEBRIS INTO THE TRANSPORTATION DRUMS), HIS TOTAL EXPOSURE WOULD ONLY BE:

$$\dot{X}_{BODY} = \frac{127.17 \times 10^{-6}}{50^2} \times 67500 \times 2$$

$$\dot{X}_{BODY} = 6.867 \text{ m REM}$$

ALL OF THE ABOVE CALCULATIONS DO NOT TAKE INTO CONSIDERATION ANY SHIELDING OF THE GAMMA RADIATION DUE TO THE PLASTIC MELTING AROUND THE ION SOURCE OR DUE TO THE SOURCES BEING BURIED IN THE DEBRIS OF THE FIRE.

CHKD. BY _____ DATE _____ RADIATION EXPOSURE OF FIRE JOB NO. _____
CORRECTED 12-6-77 FIGHTER DURING A HOME FIRE

IF WE ASSUME A HOME OF 1200 SQ.FT. WITH AN 8 FT. CEILING CONTAINING A SINGLE SMOKE DETECTOR. IF WE ASSUME THAT IN A CATASTROPHIC FIRE, THE SMOKE DETECTOR WILL BE TOTALLY INCINERATED, AND THAT PER THE OAK RIDGE NATIONAL LABORATORY TEST OF OCTOBER 21, 1969, .31 % OF THE AMERICIUM 241 WILL BE LIBERATED DURING A 1 HOUR FIRE. AS THE SMOKE DETECTOR CONTAINS 1 μCi OF Am 241,

TOTAL AMOUNT OF Am 241 LIBERATED $= 1.0 \times .0031$

$= .0031\ \mu Ci/HR.$

IF WE ASSUME THAT THE GREATEST CONCENTRATION WILL BE IN A ROOM OF 15 FT. x 12 FT., THEN WE CAN CALCULATE THE TOTAL CONCENTRATION OF Am 241 IN THE AIR, IN THIS ROOM, DURING THE FIRE.

TOTAL VOLUME OF AIR $= 15 \times 12 \times 8$ cu FT/HR.

$= 1440$ cu FT./HR.

$= 1440 \times 28.32$ LITRES/HR.

$= 40780.8$ LITRES/HR.

$\therefore$ TOTAL VOLUME OF AIR $= 40.78 \times 10^6$ mL/HR.

$\therefore$ CONCENTRATION OF Am 241 IN AIR DURING FIRE $= \frac{.0031}{40.78 \times 10^6}\ \mu Ci/mL$

Am 241 CONCENTRATION IN AIR $= 7.60 \times 10^{-11}\ \mu Ci/mL$

IF THE FIRE FIGHTER IS IN THIS ROOM FOR 2 HRS. THEN HE WILL HAVE INHALED 3400 LITRES OF AIR (2 HOURS OF HEAVY BREATHING). IF THE CONCENTRATION OF Am 241 IN THE AIR REMAINS AT $7.60 \times 10^{-11}\ \mu Ci/mL$ LEVEL, AND 50% OF THE Am 241 INHALED WILL BE IMMEDIATELY EXHALED, WE CAN CALCULATE HIS TOTAL UPTAKE.

∴ HIS TOTAL UPTAKE OF Am 241 WILL BE $= \cdot 5 \times 7.60 \times 10^{-11} \times 3400 \times 10^{3}$

$= \underline{1.292 \times 10^{-4}}\ \mu Ci$

IF WE ASSUME THAT THE CONCENTRATION IN THE REMAINDER OF THE HOME IS AS CALCULATED BELOW:

TOTAL VOLUME OF AIR $= 1200 \times 8 \times 28.32$ LITRES/HR.

$= 2.719 \times 10^{5}$ LITRES/HR.

$\underline{\text{TOTAL VOLUME OF AIR} = 2.719 \times 10^{8}\ mL/HR.}$

∴ CONCENTRATION OF Am 241 IN AIR IN REMAINDER OF HOME $= \dfrac{\cdot 0031}{2.719 \times 10^{8}}\ \mu Ci/mL$

$= \underline{1.14 \times 10^{-11}}\ \mu Ci/mL$

IF HE IS IN THE REMAINDER OF THE HOME FOR 8 HRS. AND HE INHALES 13600 LITRES OF AIR.

HIS TOTAL UPTAKE OF Am 241 WILL BE $= \cdot 5 \times 1.14 \times 10^{-11} \times 13600 \times 10^{3}$

$= \underline{7.75 \times 10^{-5}}\ \mu Ci$

∴ HIS TOTAL UPTAKE OF Am 241 WILL BE $= 1.292 \times 10^{-4} + 7.75 \times 10^{-5}$

$= \underline{2.067 \times 10^{-4}}\ \mu Ci$

IF WE ASSUME THAT OF THIS TOTAL UPTAKE 50% WILL BE ELIMINATED THROUGH THE LUNGS AND GASTRO INTESTINAL TRACT AND 50% WILL BE ABSORBED INTO THE BODY AND RETAINED IN THE BONES FOR A PERIOD OF 50 YEARS. THEN HIS INTERNAL DOSE COMMITMENT WILL BE :

INTERNAL DOSE COMMITMENT (LUNGS & G.I.) $= \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

WHERE $q = .5 \times 2.067 \times 10^{-4} = 1.034 \times 10^{-4}\ \mu Ci$

f_2 = FRACTION OF TOTAL BODY BURDEN (LUNGS & G.I.
$= .043$

m = TOTAL MASS OF LUNGS & G.I.
$= 3000$ gms

$\mathcal{E} = 268.7$ MeV d^{-1} REM RAD^{-1}

$\lambda_{EFF} = .002406$

$\therefore$ INTERNAL DOSE COMMITMENT (LUNGS & G.I) $= \frac{2.13 \times 1.034 \times 10^{-4} \times .043 \times 268.7}{3000 \times .002406} \left(1 - e^{-.002406 \times 288}\right)$

$= 3.526 \times 10^{-4} \left(1 - .5001\right)$

SOFT ORGAN DOSE $= 1.76 \times 10^{-4}$ REM

INTERNAL DOSE COMMITMENT (SKELETON) $= \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

WHERE $q = 1.034 \times 10^{-4}\ \mu Ci$

f_2 = FRACTION OF TOTAL BODY BURDEN (SKELETON)
$= .14$

m = MASS OF SKELETON
$= 10000$ gms.

$\mathcal{E} = 283$ MeV d^{-1} REM RAD^{-1} (PER REPORT BY I.C.R.P.)

$\lambda_{EFF} = 1.7549 \times 10^{-6}$

BY [illegible] DATE 11-29-77
CHKD. BY ____ DATE ____
CORRECTED 12-6-77

SUBJECT CALCULATION OF α & γ RADIATION EXPOSURE OF FIRE FIGHTER DURING A HOME FIRE

SHEET NO. 4 OF 4
JOB NO. ____

INTERNAL DOSE COMMITMENT (SKELETON) $= \frac{2.13\, q\, f_2\, E}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

$= \frac{2.13 \times 1.034 \times 10^{-4} \times .14 \times 283}{10000 \times 1.7549 \times 10^{-6}} \left(1 - e^{-1.7549 \times 10^{-6} \times 438000}\right)$

$= .4972 \quad (1 - .4636387)$

TOTAL DOSE (SKELETON) $= .2667$ REM

OR, TOTAL DOSE (SKELETON) $= 5.33 \times 10^{-3}$ REM / YEAR

INTERNAL DOSE COMMITMENT (LUNGS & G.I.) $= \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

WHERE q = $\cdot 5 \times 2.067 \times 10^{-4} = 1.034 \times 10^{-4}\ \mu Ci$

f_2 = FRACTION OF TOTAL BODY BURDEN (LUNGS & G.I)
= .043

m = TOTAL MASS OF LUNGS & G.I.
= 3000 gms

$\mathcal{E}$ = 268.7 MeV d^{-1} REM RAD^{-1}

λ_{EFF} = .002406

$\therefore$ INTERNAL DOSE COMMITMENT (LUNGS & G.I) $= \frac{2.13 \times 1.034 \times 10^{-4} \times .043 \times 268.7}{3000 \times .002406} \left(1 - e^{-.002406 \times 288}\right)$

$= 3.526 \times 10^{-4} \left(1 - .5001\right)$

SOFT ORGAN DOSE $= 1.76 \times 10^{-4}$ REM

INTERNAL DOSE COMMITMENT (SKELETON) $= \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

WHERE q = $1.034 \times 10^{-4}\ \mu Ci$

f_2 = FRACTION OF TOTAL BODY BURDEN (SKELETON)
= .14

m = MASS OF SKELETON
= 10000 gms.

$\mathcal{E}$ = 283 MeV d^{-1} REM RAD^{-1} (PER REPORT BY I.C.R.P.)

λ_{EFF} = 1.7549×10^{-6}

BY [illegible] DATE 11-29-77
CHKD. BY ____ DATE ____
CORRECTED 12-6-77

SUBJECT CALCULATION OF α & γ RADIATION EXPOSURE OF SPECTATOR WATCHING A HOME FIRE

SHEET NO. 1 OF 2
JOB NO. ____

IF WE ASSUME THE SAME CONDITIONS OF A HOME FIRE AS DESCRIBED IN CALCULATION OF "RADIATION EXPOSURE OF FIRE FIGHTER DURING A HOME FIRE." IF WE ASSUME THAT THE WALLS AND ROOF OF THE HOME COLLAPSE AND THEREBY RELEASING .0031 μCi/HR. OF Am 241 INTO THE ATMOSPHERE, AND IF WE ASSUME THAT A SPECTATOR IS WITHIN 50 FT. OF THE HOME FOR AT LEAST 1 HOUR.

TOTAL VOLUME OF AIR $= \frac{2}{3}\pi r^3$ WHERE $r = 50$ FT.

$= \frac{2}{3}\pi \times 50^3$ CU.FT/HR.

$= \frac{2}{3}\pi \times 50^3 \times 28.32$ LITRES/HR.

$= 7.414 \times 10^6$ LITRES/HR.

TOTAL VOLUME OF AIR $= 7.414 \times 10^9$ mL/HR.

$\therefore$ CONCENTRATION OF Am 241 IN AIR $= \frac{.0031}{7.414 \times 10^9}$ μCi/mL

Am 241 CONCENTRATION IN AIR $= 4.18 \times 10^{-13}$ μCi/mL

THIS CONCENTRATION OF Am 241 IN AIR IS TOTALLY INACCURATE AND EXAGGERATED BECAUSE DUE TO THE HOT AIR RISING FROM THE FIRE, THERE WILL BE A STRONG FLOW OF AIR FROM THE SPECTATOR TOWARDS THE FIRE AND THERE WILL BE MANY HUNDREDS OF AIR CHANGES DURING THE HOUR.

IF THE SPECTATOR STAYS FOR 1 HOUR, THEN HE WILL INHALE 1200 LITRES OF AIR (1 HOUR NONOCCUPATIONAL). IF 50% OF THE Am 241 INHALED WILL BE IMMEDIATELY EXHALED, THEN HIS TOTAL UPTAKE WILL BE:

TOTAL UPTAKE $= .5 \times 4.18 \times 10^{-13} \times 1200 \times 10^3$

$= 2.5 \times 10^{-7}$ μCi

IF WE ASSUME THAT OF THIS TOTAL UPTAKE, 50% WILL BE ELIMINATED THROUGH THE LUNGS AND GASTRO INTESTINAL TRACT AND 50% WILL BE ABSORBED INTO THE BODY AND RETAINED IN THE BONES FOR A PERIOD OF 50 YEARS. THEN HIS INTERNAL DOSE COMMITMENT WILL BE :-

$$\text{INTERNAL DOSE COMMITMENT (LUNGS \& G.I)} = \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

WHERE $q = .5 \times 2.5 \times 10^{-7} = 1.25 \times 10^{-7}\ \mu Ci$

$f_2 = .043$

$m = .3000$ gms

$\mathcal{E} = 268.7$ MeV d^{-1} REM RAD^{-1}

$\lambda_{EFF} = .002406$

$$\text{INTERNAL DOSE COMMITMENT (LUNGS \& G.I.)} = \frac{2.13 \times 1.25 \times 10^{-7} \times .043 \times 268.7}{3000 \times .002406} \left(1 - e^{-.002406 \times 288}\right)$$

SOFT ORGAN DOSE $= 2.13 \times 10^{-7}$ REM

$$\text{INTERNAL DOSE COMMITMENT (SKELETON)} = \frac{2.13 \times 1.25 \times 10^{-7} \times .14 \times 283}{10000 \times 1.7549 \times 10^{-6}} \left(1 - e^{-1.7549 \times 10^{-6} \times 438000}\right)$$

TOTAL DOSE (SKELETON) $= 3.22 \times 10^{-4}$ REM

OR, TOTAL DOSE (SKELETON) $= 6.448 \times 10^{-6}$ REM / YEAR

BY [illegible] DATE 7-11-77
CHKD. BY ____ DATE ____
CORRECTED 12-6-77

SUBJECT CALCULATION OF RADIATION DOSE FROM INGESTION OF (1) ION SOURCE.

SHEET NO. 1 OF 3
JOB NO. ____

ATTACHMENT B-14a

$$\text{TOTAL DOSE} = \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

WHERE: q = 1 μCi Am 241 ION SOURCE

f_2 = FRACTION OF TOTAL BODY BURDEN IN G.I. TRACT
= .029

m = TOTAL MASS OF G.I. TRACT.
= 2000 gm

$\mathcal{E} = \mathcal{E}_\alpha + \mathcal{E}_\gamma$

$\mathcal{E}_\alpha$ = E. F. (RBE) n

$\mathcal{E}_\alpha = \left[(5.49 \times .85) + (5.44 \times .13)\right] \times 1 \times 10 \times 5$

$\mathcal{E}_\alpha = (4.6665 + .7072)\ 50$

$\mathcal{E}_\alpha$ = 268.68 MeV d^{-1} rem rad^{-1}

WHERE E = TOTAL ENERGY ABSORBED
F = RATIO OF DISINTEGRATION RATE = 1
RBE = RELATIVE BIOLOGICAL EFFECTIVENESS FACTOR = 10
n = RELATIVE DAMAGE FACTOR = 5

$\mathcal{E}_\gamma = E_\gamma \cdot f_\gamma \left(1 - e^{-\mu a X}\right)$

$\mathcal{E}_\gamma = .060 \times .36 \left(1 - e^{-.0312 \times 30}\right)$

$\mathcal{E}_\gamma = .060 \times .36 \left(1 - .392\right)$

$\mathcal{E}_\gamma$ = .013 MeV d^{-1} rem rad^{-1}

WHERE E_γ = GAMMA RAY ENERGY
f_γ = NO. OF γ PER DISINTEGRATION
μ_a = LINEAR ENERGY ABSORBTION COEFFICIENT = .0312
X = EFFECTIVE RADIUS = 30 cm.

$\therefore \mathcal{E} = 268.68 + .013$

$\mathcal{E}$ = 268.7 MeV d^{-1} rem rad^{-1}

$$T_{EFF} = \frac{T_r \cdot T_b}{T_r + T_b}$$

$$T_{EFF} = \frac{4012080 \times 31}{4012080 + 31}$$

T_{EFF} = 30.999 Hrs.

WHERE T_r = 458 YEARS = 4012080 Hrs.
T_b = 31 Hrs. (NORMAL BIOLOGICAL ELIMINATION RATE)

$$\therefore \lambda_{EFF} = \frac{.693}{T_{EFF}}$$

$$= \frac{.693}{30.999}$$

$$\lambda_{EFF} = .02236$$

IF THE ION SOURCE REMAINS IN THE BODY FOR A MAX. TOTAL OF 96 HRS. BEFORE EXPULSION, AND THE TOTAL ACTIVITY REMOVED IS ONLY 4.9×10^{-3} μ Ci (PER NRD CORP. INVESTIGATION OF MAY 1976), THEN THE TOTAL DOSE TO THE G.I. TRACT WILL BE:

$$\text{TOTAL DOSE} = \frac{2.13\, q\, f_2\, E}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

$$= \frac{2.13 \times 1.0 \times .029 \times 268.7}{2000 \times .02236} \left(1 - e^{-.02236 \times 96}\right)$$

$$= .371 \times (1 - .1169)$$

$$\therefore \text{TOTAL DOSE} = .328 \text{ REM}$$

IF THE TOTAL ACTIVITY REMOVED BY THE GASTRIC ACIDS (4.9×10^{-3} μ Ci) IS ABSORBED INTO THE BODY AND RETAINED IN THE BONES FOR A PERIOD OF 50 YEARS, THEN THE TOTAL DOSE TO THE BONES WILL BE:

$$\text{TOTAL DOSE} = \frac{2.13\, q\, f_2\, E}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

WHERE $q = 4.9 \times 10^{-3}$ μ Ci

f_2 = FRACTION OF TOTAL BODY BURDEN SKELETON
= .14

m = MASS OF SKELETON
= 10000 gms

E = .283 MeV d^{-1} rem rad^{-1} (PER REPORT BY THE INTERNATIONAL COMMISSION ON RADIATION PROTECTION)

$$T_{EFF} = \frac{T_r \cdot T_b}{T_r + T_b}$$

T_r = 4012080 HRS

T_b = 50 YRS = 438000 HRS.

$$T_{EFF} = \frac{4012080 \times 438000}{4012080 + 438000}$$

$$T_{EFF} = 3.9489 \times 10^5 \text{ HRS}$$

BY: J.K. Vennard DATE 11-28-77
CHKD. BY ____ DATE ____
CORRECTED 12-6-77

SUBJECT CALCULATION OF RADIATION DOSE FROM INGESTION OF (1) ION SOURCE

SHEET NO. 3 OF 3
JOB NO. ____

$$\lambda_{EFF} = \frac{.693}{T_{EFF}}$$

$$= \frac{.693}{3.9489 \times 10^5}$$

$$\lambda_{EFF} = 1.7549 \times 10^{-6}$$

$$\therefore \text{TOTAL DOSE} = \frac{2.13 \times 4.9 \times 10^{-3} \times .14 \times 283}{10000 \times 1.7549 \times 10^{-6}} \left(1 - e^{-1.7549 \times 10^{-6} \times 43800}\right)$$

$$= 23.563 \left(1 - .4636387\right)$$

$$\therefore \text{TOTAL DOSE} = 12.638 \text{ REM}$$

OR, TOTAL DOSE TO SKELETON = .253 REM / YEAR.

CHKD. BY _____ DATE _____ RADIATION EXPOSURE OF FIRE JOB NO. _____
CORRECTED 12-6-77 FIGHTER DURING A HOME FIRE

IF WE ASSUME A HOME OF 1200 SQ.FT. WITH AN 8 FT. CEILING CONTAINING A SINGLE SMOKE DETECTOR. IF WE ASSUME THAT IN A CATASTROPHIC FIRE, THE SMOKE DETECTOR WILL BE TOTALLY INCINERATED, AND THAT PER THE OAK RIDGE NATIONAL LABORATORY TEST OF OCTOBER 21, 1969, .31 % OF THE AMERICIUM 241 WILL BE LIBERATED DURING A 1 HOUR FIRE. AS THE SMOKE DETECTOR CONTAINS 1 μCi OF Am 241,

TOTAL AMOUNT OF Am 241 LIBERATED $= 1.0 \times .0031$

$= .0031\ \mu Ci/HR.$

IF WE ASSUME THAT THE GREATEST CONCENTRATION WILL BE IN A ROOM OF 15 FT. × 12 FT., THEN WE CAN CALCULATE THE TOTAL CONCENTRATION OF Am 241 IN THE AIR, IN THIS ROOM, DURING THE FIRE.

TOTAL VOLUME OF AIR $= 15 \times 12 \times 8$ cu FT/HR.

$= 1440$ cu FT./HR.

$= 1440 \times 28.32$ LITRES/HR.

$= 40780.8$ LITRES/HR.

$\therefore$ TOTAL VOLUME OF AIR $= 40.78 \times 10^6$ mL/HR.

$\therefore$ CONCENTRATION OF Am 241 IN AIR DURING FIRE $= \frac{.0031}{40.78 \times 10^6}\ \mu Ci/mL$

Am 241 CONCENTRATION IN AIR $= 7.60 \times 10^{-11}\ \mu Ci/mL$

IF THE FIRE FIGHTER IS IN THIS ROOM FOR 2 HRS. THEN HE WILL HAVE INHALED 3400 LITRES OF AIR (2 HOURS OF HEAVY BREATHING). IF THE CONCENTRATION OF Am 241 IN THE AIR REMAINS AT $7.60 \times 10^{-11}\ \mu Ci/mL$ LEVEL, AND 50% OF THE Am 241 INHALED WILL BE IMMEDIATELY EXHALED, WE CAN CALCULATE HIS TOTAL UPTAKE.

∴ HIS TOTAL UPTAKE OF Am 241 WILL BE $= \cdot 5 \times 7.60 \times 10^{-11} \times 3400 \times 10^{3}$

$= \underline{1.292 \times 10^{-4}}\ \underline{\mu Ci}$

IF WE ASSUME THAT THE CONCENTRATION IN THE REMAINDER OF THE HOME IS AS CALCULATED BELOW:

TOTAL VOLUME OF AIR $= 1200 \times 8 \times 28.32$ LITRES/HR.

$= 2.719 \times 10^{5}$ LITRES/HR.

$\underline{\text{TOTAL VOLUME OF AIR} = 2.719 \times 10^{8}\ \text{mL/HR.}}$

∴ CONCENTRATION OF Am 241 IN AIR IN REMAINDER OF HOME $= \dfrac{\cdot 0031}{2.719 \times 10^{8}}\ \mu Ci/mL$

$= \underline{1.14 \times 10^{-11}}\ \underline{\mu Ci/mL}$

IF HE IS IN THE REMAINDER OF THE HOME FOR 8 HRS. AND HE INHALES 13600 LITRES OF AIR.

HIS TOTAL UPTAKE OF Am 241 WILL BE $= \cdot 5 \times 1.14 \times 10^{-11} \times 13600 \times 10^{3}$

$= \underline{7.75 \times 10^{-5}}\ \underline{\mu Ci}$

∴ HIS TOTAL UPTAKE OF Am 241 WILL BE $= 1.292 \times 10^{-4} + 7.75 \times 10^{-5}$

$= \underline{2.067 \times 10^{-4}}\ \underline{\mu Ci}$

IF WE ASSUME THAT OF THIS TOTAL UPTAKE 50% WILL BE ELIMINATED THROUGH THE LUNGS AND GASTRO INTESTINAL TRACT AND 50% WILL BE ABSORBED INTO THE BODY AND RETAINED IN THE BONES FOR A PERIOD OF 50 YEARS. THEN HIS INTERNAL DOSE COMMITMENT WILL BE :

INTERNAL DOSE COMMITMENT (LUNGS & G.I.) $= \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

WHERE $q = .5 \times 2.067 \times 10^{-4} = 1.034 \times 10^{-4}\ \mu Ci$

f_2 = FRACTION OF TOTAL BODY BURDEN (LUNGS & G.I.)
$= .043$

m = TOTAL MASS OF LUNGS & G.I.
$= 3000$ gms

$\mathcal{E} = 268.7$ MeV d^{-1} REM RAD^{-1}

$\lambda_{EFF} = .002406$

$\therefore$ INTERNAL DOSE COMMITMENT (LUNGS & G.I) $= \frac{2.13 \times 1.034 \times 10^{-4} \times .043 \times 268.7}{3000 \times .002406} \left(1 - e^{-.002406 \times 288}\right)$

$= 3.526 \times 10^{-4} \left(1 - .5001\right)$

SOFT ORGAN DOSE $= 1.76 \times 10^{-4}$ REM

INTERNAL DOSE COMMITMENT (SKELETON) $= \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

WHERE $q = 1.034 \times 10^{-4}\ \mu Ci$

f_2 = FRACTION OF TOTAL BODY BURDEN (SKELETON)
$= .14$

m = MASS OF SKELETON
$= 10000$ gms.

$\mathcal{E} = 283$ MeV d^{-1} REM RAD^{-1} (PER REPORT BY I.C.R.P.)

$\lambda_{EFF} = 1.7549 \times 10^{-6}$

BY W. Lemmon DATE 11-29-77
CHKD. BY ____ DATE ____
CORRECTED 12-6-77

SUBJECT CALCULATION OF α & γ RADIATION EXPOSURE OF FIRE FIGHTER DURING A HOME FIRE

SHEET NO. 4 OF 4
JOB NO. ____

INTERNAL DOSE COMMITMENT (SKELETON) $= \frac{2.13\, q\, f_2\, E}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

$= \frac{2.13 \times 1.034 \times 10^{-4} \times .14 \times 283}{10000 \times 1.7549 \times 10^{-6}} \left(1 - e^{-1.7549 \times 10^{-6} \times 438000}\right)$

$= .4972 \quad (1 - .4636387)$

TOTAL DOSE (SKELETON) $= .2667$ REM

OR, TOTAL DOSE (SKELETON) $= 5.33 \times 10^{-3}$ REM / YEAR

INTERNAL DOSE COMMITMENT (LUNGS & G.I.) $= \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

WHERE $q = .5 \times 2.067 \times 10^{-4} = 1.034 \times 10^{-4}\ \mu Ci$

f_2 = FRACTION OF TOTAL BODY BURDEN (LUNGS & G.I)
$= .043$

m = TOTAL MASS OF LUNGS & G.I.
$= 3000$ gms

$\mathcal{E} = 268.7$ MeV d^{-1} REM RAD^{-1}

$\lambda_{EFF} = .002406$

$\therefore$ INTERNAL DOSE COMMITMENT (LUNGS & G.I) $= \frac{2.13 \times 1.034 \times 10^{-4} \times .043 \times 268.7}{3000 \times .002406} \left(1 - e^{-.002406 \times 288}\right)$

$= 3.526 \times 10^{-4} \left(1 - .5001\right)$

SOFT ORGAN DOSE $= 1.76 \times 10^{-4}$ REM

INTERNAL DOSE COMMITMENT (SKELETON) $= \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$

WHERE $q = 1.034 \times 10^{-4}\ \mu Ci$

f_2 = FRACTION OF TOTAL BODY BURDEN (SKELETON)
$= .14$

m = MASS OF SKELETON
$= 10000$ gms.

$\mathcal{E} = 283$ MeV d^{-1} REM RAD^{-1} (PER REPORT BY I.C.R.P.)

$\lambda_{EFF} = 1.7549 \times 10^{-6}$

BY [illegible] DATE 11-29-77
CHKD. BY ____ DATE ____
CORRECTED 12-6-77

SUBJECT CALCULATION OF α & γ RADIATION EXPOSURE OF SPECTATOR WATCHING A HOME FIRE

SHEET NO. 1 OF 2
JOB NO. ____

IF WE ASSUME THE SAME CONDITIONS OF A HOME FIRE AS DESCRIBED IN CALCULATION OF "RADIATION EXPOSURE OF FIRE FIGHTER DURING A HOME FIRE." IF WE ASSUME THAT THE WALLS AND ROOF OF THE HOME COLLAPSE AND THEREBY RELEASING .0031 μCi/HR. OF Am 241 INTO THE ATMOSPHERE, AND IF WE ASSUME THAT A SPECTATOR IS WITHIN 50 FT. OF THE HOME FOR AT LEAST 1 HOUR.

TOTAL VOLUME OF AIR $= \frac{2}{3}\pi r^3$ WHERE $r = 50$ FT.

$= \frac{2}{3}\pi \times 50^3$ CU.FT/HR.

$= \frac{2}{3}\pi \times 50^3 \times 28.32$ LITRES/HR.

$= 7.414 \times 10^6$ LITRES/HR.

TOTAL VOLUME OF AIR $= 7.414 \times 10^9$ mL/HR.

∴ CONCENTRATION OF Am 241 IN AIR $= \frac{.0031}{7.414 \times 10^9}$ μCi/mL

Am 241 CONCENTRATION IN AIR $= 4.18 \times 10^{-13}$ μCi/mL

THIS CONCENTRATION OF Am 241 IN AIR IS TOTALLY INACCURATE AND EXAGGERATED BECAUSE DUE TO THE HOT AIR RISING FROM THE FIRE, THERE WILL BE A STRONG FLOW OF AIR FROM THE SPECTATOR TOWARDS THE FIRE AND THERE WILL BE MANY HUNDREDS OF AIR CHANGES DURING THE HOUR.

IF THE SPECTATOR STAYS FOR 1 HOUR, THEN HE WILL INHALE 1200 LITRES OF AIR (1 HOUR NONOCCUPATIONAL). IF 50% OF THE Am 241 INHALED WILL BE IMMEDIATELY EXHALED, THEN HIS TOTAL UPTAKE WILL BE:

TOTAL UPTAKE $= .5 \times 4.18 \times 10^{-13} \times 1200 \times 10^3$

$= 2.5 \times 10^{-7}$ μCi

BY [illegible] DATE 11-29-77
CHKD. BY _____ DATE _____
CORRECTED 12-6-77

SUBJECT CALCULATION OF α & β RADIATION EXPOSURE OF SPECTATOR WATCHING A HOME FIRE

SHEET NO. 2 OF 2
JOB NO. _____

IF WE ASSUME THAT OF THIS TOTAL UPTAKE, 50% WILL BE ELIMINATED THROUGH THE LUNGS AND GASTRO INTESTINAL TRACT AND 50% WILL BE ABSORBED INTO THE BODY AND RETAINED IN THE BONES FOR A PERIOD OF 50 YEARS. THEN HIS INTERNAL DOSE COMMITMENT WILL BE :-

$$\text{INTERNAL DOSE COMMITMENT (LUNGS \& G.I)} = \frac{2.13\, q\, f_2\, \mathcal{E}}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

WHERE $q = .5 \times 2.5 \times 10^{-7} = 1.25 \times 10^{-7}\ \mu Ci$

$f_2 = .043$

$m = .3000$ gms

$\mathcal{E} = 268.7$ MeV d^{-1} REM RAD^{-1}

$\lambda_{EFF} = .002406$

$$\text{INTERNAL DOSE COMMITMENT (LUNGS \& G.I.)} = \frac{2.13 \times 1.25 \times 10^{-7} \times .043 \times 268.7}{3000 \times .002406} \left(1 - e^{-.002406 \times 288}\right)$$

SOFT ORGAN DOSE $= 2.13 \times 10^{-7}$ REM

$$\text{INTERNAL DOSE COMMITMENT (SKELETON)} = \frac{2.13 \times 1.25 \times 10^{-7} \times .14 \times 283}{10000 \times 1.7549 \times 10^{-6}} \left(1 - e^{-1.7549 \times 10^{-6} \times 438000}\right)$$

TOTAL DOSE (SKELETON) $= 3.22 \times 10^{-4}$ REM

OR, TOTAL DOSE (SKELETON) $= 6.448 \times 10^{-6}$ REM / YEAR

BY [illegible] DATE 7-11-77
CHKD. BY ____ DATE ____
CORRECTED 12-6-77

SUBJECT CALCULATION OF RADIATION DOSE FROM INGESTION OF (1) ION SOURCE.

SHEET NO. 1 OF 3
JOB NO. ____

ATTACHMENT B-14a

$$\text{TOTAL DOSE} = \frac{2.13\, q f_2 E}{m \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

WHERE: q = 1 μCi Am 241 ION SOURCE

f_2 = FRACTION OF TOTAL BODY BURDEN IN G.I. TRACT
= .029

m = TOTAL MASS OF G.I. TRACT.
= 2000 gm

$E = E_\alpha + E_\gamma$

$E_\alpha = E.F.(RBE)n$

$E_\alpha = \left[(5.49 \times .85) + (5.44 \times .13)\right] \times 1 \times 10 \times 5$

$E_\alpha = (4.6665 + .7072)\ 50$

$E_\alpha = 268.68$ MeV d^{-1} rem rad^{-1}

WHERE E = TOTAL ENERGY ABSORBED
F = RATIO OF DISINTEGRATION RATE = 1
RBE = RELATIVE BIOLOGICAL EFFECTIVENESS FACTOR = 10
n = RELATIVE DAMAGE FACTOR = 5

$E_\gamma = E_\gamma \cdot f_\gamma \left(1 - e^{-\mu a X}\right)$

$E_\gamma = .060 \times .36 \left(1 - e^{-.0312 \times 30}\right)$

$E_\gamma = .060 \times .36 \left(1 - .392\right)$

$E_\gamma = .013$ MeV d^{-1} rem rad^{-1}

WHERE E_γ = GAMMA RAY ENERGY
f_γ = NO. OF γ PER DISINTEGRATION
μa = LINEAR ENERGY ABSORBTION COEFFICIENT = .0312
X = EFFECTIVE RADIUS = 30 cm.

$\therefore E = 268.68 + .013$

$E = 268.7$ MeV d^{-1} rem rad^{-1}

$$T_{EFF} = \frac{T_r \cdot T_b}{T_r + T_b}$$

$$T_{EFF} = \frac{4012080 \times 31}{4012080 + 31}$$

$T_{EFF} = 30.999$ Hrs.

WHERE T_r = 458 YEARS
= 4012080 Hrs.

T_b = 31 Hrs. (NORMAL BIOLOGICAL ELIMINATION RATE)

$$\therefore \lambda_{EFF} = \frac{.693}{T_{EFF}}$$

$$= \frac{.693}{30.999}$$

$$\lambda_{EFF} = .02236$$

IF THE ION SOURCE REMAINS IN THE BODY FOR A MAX. TOTAL OF 96 HRS BEFORE EXPULSION, AND THE TOTAL ACTIVITY REMOVED IS ONLY 4.9×10^{-3} μ Ci (PER NRD CORP. INVESTIGATION OF MAY 1976), THEN THE TOTAL DOSE TO THE G.I. TRACT WILL BE:

$$\text{TOTAL DOSE} = \frac{2.13\, q\, f_2\, E}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

$$= \frac{2.13 \times 1.0 \times .029 \times 268.7}{2000 \times .02236} \left(1 - e^{-.02236 \times 96}\right)$$

$$= .371 \times (1 - .1169)$$

$$\therefore \text{TOTAL DOSE} = .328 \text{ REM}$$

IF THE TOTAL ACTIVITY REMOVED BY THE GASTRIC ACIDS (4.9×10^{-3} μ Ci) IS ABSORBED INTO THE BODY AND RETAINED IN THE BONES FOR A PERIOD OF 50 YEARS, THEN THE TOTAL DOSE TO THE BONES WILL BE:

$$\text{TOTAL DOSE} = \frac{2.13\, q\, f_2\, E}{m\, \lambda_{EFF}} \left(1 - e^{-\lambda_{EFF} T}\right)$$

WHERE $q = 4.9 \times 10^{-3}$ μ Ci

f_2 = FRACTION OF TOTAL BODY BURDEN SKELETON
$= .14$

m = MASS OF SKELETON
$= 10000$ gms

$E = .283$ MeV d^{-1} rem rad^{-1} (PER REPORT BY THE INTERNATIONAL COMMISSION ON RADIATION PROTECTION)

$$T_{EFF} = \frac{T_r \cdot T_b}{T_r + T_b}$$

$T_r = 4012080$ HRS

$T_b = 50$ YRS $= 438000$ HRS.

$$T_{EFF} = \frac{4012080 \times 438000}{4012080 + 438000}$$

$$T_{EFF} = 3.9489 \times 10^5 \text{ HRS}$$

BY J.K. Vennard DATE 11-28-77 SUBJECT CALCULATION OF RADIATION DOSE FROM INGESTION OF (1) ION SOURCE SHEET NO. 3 OF 3

CHKD. BY ..... DATE ..... JOB NO. .....

CORRECTED 12-6-77

$$\lambda_{EFF} = \frac{.693}{T_{EFF}}$$

$$= \frac{.693}{3.9489 \times 10^5}$$

$$\lambda_{EFF} = 1.7549 \times 10^{-6}$$

$$\therefore \text{TOTAL DOSE} = \frac{2.13 \times 4.9 \times 10^{-3} \times .14 \times 283}{10000 \times 1.7549 \times 10^{-6}} \left(1 - e^{-1.7549 \times 10^{-6} \times 43800}\right)$$

$$= 23.563 \left(1 - .4636387\right)$$

$$\therefore \text{TOTAL DOSE} = 12.638 \text{ REM}$$

OR, TOTAL DOSE TO SKELETON = .253 REM / YEAR.