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Institutional Radioactive Wastes - 1977

Final Report

Prepared by T. J. Beck, L. R. Cooley, M. R. McCampbell

Radiation Safety Office
University of Maryland at Baltimore

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ABSTRACT

A followup survey to the 1975 institutional radioactive waste study (3) was conducted to obtain data for the calendar year 1977. The survey population of large medical and academic licensees shipped an estimated 7,771 m^3 of low level radwaste for burial in 1977. Approximately 7% of the waste volume was ascribed to purely medical sources, 79% to sources conducting biological research and 14% to other academic sources. The estimated total activity shipped by the population in 1977 was 1,688 Ci, of which 81% was ^3H. Approximately 540 Ci of ^3H was shipped as depleted tritium targets for neutron generators. Much of the rest was in the form of labeled compounds or labeling reagents used in biological research. The fastest growing waste form produced by the population is waste liquid scintillation vials which have undergone a 60% increase in volume since 1975. The waste volume produced by the population appears to be increasing linearly, at approximately the same rate as low level radwastes in general.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

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I. INTRODUCTION

Most low level radioactive wastes are produced as byproducts of the various phases and fueling requirements in the operation of commercial nuclear power plants. These wastes, their production, and their effects on the environment are the subject of much research and scrutiny by regulatory agencies and public interest groups. It is less well known that a significant portion of the radioactive wastes disposed of in this country are produced by what may be termed as non fuel cycle sources.

In 1975 O'Connell and Holcomb estimated that 39% of the radwaste buried in the commercial low level burial sites were non fuel cycle in origin (1). The source of these wastes are the possessors of some 16,000 licenses for the use of radioactive materials in this country (2). These licensees are a heterogeneous mixture of individuals and institutions primarily in medicine, research and industry.

The University of Maryland, under contract to the USNRC, conducted a survey of a portion of the non fuel cycle sources, specifically the larger medical and academic licensees, obtaining data for the calendar year 1975. This survey showed that these larger institutions shipped approximately one third of the non fuel cycle wastes buried that year, or 11% of the total waste volume including fuel cycle sources (3). Concurrent with the 1975 survey was a separate regional sampling of all licensees in several major metropolitan areas (3). The regional survey, together with the national study, provided data allowing general characterizations of non fuel cycle waste sources.

Data from the 1975 study (3) suggest that a large portion of non fuel cycle licensees use radioactive materials primarily in sealed source form as an integral part of an analytical instrument or irradiator. Other than the occasional disposal of such sources or instruments containing sources, these licensees contribute little to the radioactive waste problem.

Many other licensees use radioactive materials in non sealed source form, which routinely results in the production of wastes. Such wastes result from the contamination of instruments and disposable items, chemical reagents, and biological materials. This latter group of licensees is quite diverse and consists of a wide range of medical, academic, and industrial users. Some typical uses within this group include nuclear medicine, biological research, radiochemical and radiopharmaceutical production, and other research uses.

In nuclear medicine a pharmaceutical "labeled" with a short lived radionuclide is "traced" through various organs of the body for diagnostic or therapeutic effect. Most of the radioactivity used is administered to patients. Wastes produced are typically disposable syringes, vials, test tubes, absorbent papers, gloves and unused radiopharmaceuticals. Generally, the radiocontaminants of these wastes are short lived and volumes of waste are not large.

In biological research the behavior, structure, and kinetics of biochemicals and biological systems are investigated by the use of radiolabeled biochemicals. This is a widespread analytical technique and is probably used by nearly every major laboratory which investigates human, animal, or plant physiology. Wastes produced by such laboratories are often high volume, low activity wastes predominantly contaminated with ^{3}H, ^{14}C, ^{125}I, ^{35}S, ^{32}P, and other physiological species or their analogues such as ^{86}Rb (a potassium analogue). The wastes include a variety of disposable labware and a considerable volume of spent liquid scintillation vials and fluids, since liquid scintillation counting is probably the major method of quantitating these predominantly beta emitting nuclides. From a volume standpoint, it is very likely that radioactive wastes resulting from biological research constitute the most significant single category of non fuel cycle waste production.

Another significant category of waste producers must be the industry which supplies the medical sector with radiopharmaceuticals and the research community with radiochemicals. It is generally true that considering the typical low yields in labeling biochemicals the individual doing the labeling must begin with a considerably large activity to obtain a relatively small quantity of labeled product

(4). Therefore, the labeling process generally results in relatively high activity waste compared to that produced by handling already labeled materials.

Other industries which use non sealed source radioactive materials include luminous dial manufacturers, the producers of instruments which incorporate sealed source components, such as gas chromatographs, x-ray fluorescence analyzers, smoke detectors, level detectors, industrial radiography devices, soil density probes, etc., and the manufacturers of sealed gamma and beta ray sources

Radioactive materials are also used widely in the academic sector in non biological research, such as inorganic chemistry, materials testing, soil analysis, environmental tracing, etc., and in radionuclide producing activities such as neutron activation analysis and research with particle accelerators and small research nuclear reactors.

The large medical and academic institutions surveyed in the 1975 study appear to be the major source of non fuel cycle radwastes. The 1975 survey has engendered a followup survey of the same population to obtain waste data for the calendar year 1977. The purposes of the followup survey were to better delineate specific waste producing segments of the population, to determine the extent of use of certain disposal alternatives and to elicit temporal trends in those wastes shipped for commercial burial. More specific attention has been given to waste characterization, processing and packaging methods, and wastes produced as a result of particle accelerator operation.

2. METHODOLOGY

2.1 The Survey Population

The selection criteria for the survey population were essentially those of the 1975 survey. Members were taken from agreement state and Nuclear Regulatory Commission licensee lists within the following categories:

- Large hospitals with 450 beds or more, excluding mental health and other extended care facilities.

- Schools of medicine (hereafter referred to as medschools).

- Four year colleges and universities with 5000 students or more. Two smaller institutions were also included due to the presence of large research programs. This category is hereafter referred to as colleges.

In general, institutional licenses for the use of radioactive materials require the appointment of a radiation safety officer to insure compliance with the terms of the license. Many members of the survey population appointed an individual "in house" to serve this function, while others shared radiation safety functions with neighboring or affiliated institutions. Still others used the services of a private consultant for radiation safety purposes. These individuals or their offices compiled the data sought in the survey; therefore these surveys were, in effect, samplings of radiation safety programs. In actuality, each institutional member of the study population is a radiation control program which may represent a hospital, a college or a medschool, and frequently functioned for a combination of these. Conversely, a few large institutions maintained two separate radiation control programs on a single campus; for example, one institution had a program for the medschool and a separate one for the rest of the adjoining campus. Program separation, however, was the exception rather than the rule.

The frequent consolidation of radiation control programs presented major difficulties in the categorization of responses. The previous survey showed that it would be extremely difficult for respondents from consolidated programs to categorize data according to whether it came from a hospital, medschool or college. Also, the investigators felt that this categorization would greatly complicate the survey questionnaire and would seriously compromise the response rate. It was decided, in the interests of the response rate, to accept the inherent consolidation of the data and to attempt to classify responses according to the combinations in which they appeared. To this end, the study population was divided into entities.

An entity was defined as a hospital, a college or a medschool. Thus, each institutional member of the population included one or more entities. The combinations of entity types which appeared in the population are shown in Table 2.1. Also shown are the numbers of institutions as well as the total numbers of hospitals, medschools, and colleges in each category.

The 631 institutions in the population included 347 hospitals, 116 medschools and 324 colleges, for a total of 787 population entities.

The geographic distribution of the population is shown by state and U.S. Census Region in Table 2.2.

The study population for the 1975 survey was carefully reviewed to insure conformity with the criteria and assumptions used in the followup survey. Subsequently, the size of the population for the 1975 study was revised to a total of 609 institutions. To facilitate comparisions with the 1977 survey, the 1975 population and the resultant data were resorted according to the categories developed for the 1977 study. This breakdown of the 1975 population is shown in Table 2.3. These revisions necessitated some alterations to the previously reported waste volume estimates (3). The revised 1975 data are reported in Section 5.

Table 2.1 Combinations of Entity Types Within Survey Population

Type of Institution	Number of Institutions	Breakdown of Entities * Hospitals	Medschools	Colleges
Hospital only	264	266	-	-
Medschool only	13	-	13	
College only	252	-	-	254
Hospital and Medschool	36	39	36	-
Medschool and College	26	-	26	-
Hospital, Medschool and College	40	42	41	44
TOTALS	631	347	116	324

*Note that numbers of entities in population exceed the numbers of of institutions due to the consolidation of radiation programs, i.e. an "institution" may represent one or more entities.

1370 203

Table 2.2 Geographic Distribution of Survey Population by State and by U.S. Census Region

Census Region	Number of Institutions	Entities Hosp/Medsch/Coll		
I. New England				
Connecticut	7	5	2	3
Maine	2	1	0	1
Massachusetts	22	9	4	13
New Hampshire	2	0	1	2
Rhode Island	4	1	1	3
Vermont	2	1	1	1
Region Total	39	17	9	23
II. Mid Atlantic				
New Jersey	14	9	1	5
New York	60	39	11	23
Pennsylvania	31	18	6	16
Region Total	105	66	18	44
III. East North Central				
Illinois	36	20	9	17
Indiana	13	6	2	7
Michigan	22	14	3	11
Ohio	32	19	4	13
Wisconsin	14	5	3	9
Region Total	117	64	21	57
IV. West North Central				
Iowa	5	2	1	3
Kansas	10	3	1	7
Minnesota	11	7	3	5
Missouri	15	13	4	8
Nebraska	6	5	2	2
N. Dakota	3	1	1	2
S. Dakota	3	1	1	2
Region Total	53	32	13	29
V. South Atlantic				
Delaware	2	1	0	1
Dist. of Columbia	13	9	3	5
Florida	28	20	2	9
Georgia	14	10	4	8
Maryland	9	5	2	6
N. Carolina	11	5	3	7
S. Carolina	6	4	2	2
Virginia	14	6	2	8
West Virginia	3	2	1	2
Region Total	100	62	19	48

Table 2.2 Continued

Census Region	Number of Institutions	Entities Hosp/	Medsch/	Coll
VI. East South Central				
Alabama	13	9	3	6
Kentucky	9	5	2	6
Mississippi	4	1	1	3
Tennessee	18	12	3	8
Region Total	44	27	9	23
VII. West South Central				
Arkansas	6	4	1	3
Louisiana	19	6	3	11
Oklahoma	12	6	1	6
Texas	46	23	5	21
Region Total	83	29	10	41

Census Region	Number of Institutions	Entities Hosp/	Medsch/	Coll
VII. Mountain				
Arizona	7	5	1	3
Colorado	11	5	1	7
Idaho	2	0	0	2
Montana	2	0	0	2
Nevada	1	0	1	1
New Mexico	1	1	1	1
Utah	4	3	1	3
Wyoming	1	0	0	1
	29	14	5	20
Pacific				
California	46	20	9	29
Hawaii	2	1	1	1
Oregon	6	3	1	6
Washington	7	2	1	3
	61	26	12	39

Table 2.3 Breakdown of Revised 1975 Population*

Type of Institution	Number of Institutions	Breakdown of Entities		
		Hospitals	Medschools	Colleges
Hospital only	247	277	-	-
Medschool only	13	-	13	-
College only	215	-	-	217
Hospital and Medschool	28	30	28	-
Medschool and College	26	-	26	26
Hospital, Medschool and College	48	51	49	52
TOTALS	607	359	116	295

*The numbers of institutions and the breakdown scheme differ somewhat from that previously reported (3); see text Sections 2 and 5.

2.2 Survey Methodology

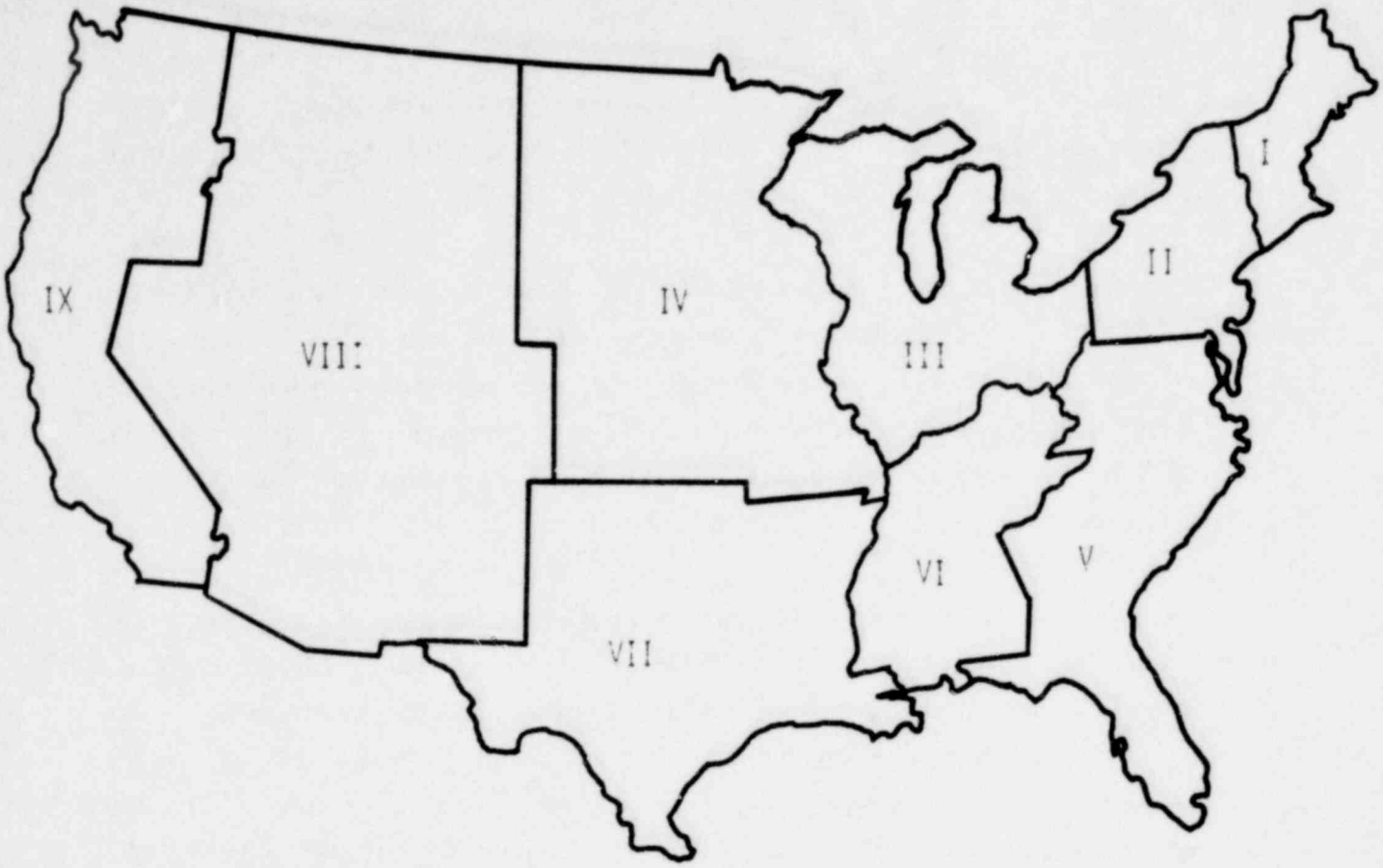
The major portion of the data used in the study was acquired via a mailed questionnaire. Early in the study period a draft survey questionnaire was developed and sent to several individuals in the Nuclear Regulatory Commission and to radiation safety officers of eight large institutions in the study population. The helpful comments of these individuals were incorporated into the questionnaire prior its final printing. The questionnaire and accompanying cover letter are included as Appendix A.

Six hundred and fifty-nine questionnaires were mailed in June, 1978. In September 75 randomly selected institutions who had not yet responded were contacted by telephone to encourage their participation. A second mailing to 200 non-respondents was undertaken at that time.

As questionnaires were returned they were manually transcribed onto coding sheets and simultaneously checked for errors and incongruous responses. Many respondents were recontacted at this time to clarify responses. Data were then keypunched and entered into a master data file where responses were identifiable only by randomly assigned case numbers.

Data entry was completed and analysis begun by mid December, at which time 391 surveys were returned. Of these, 51 were blank or otherwise unusable. An additional 10 surveys have been received since that time, but were not entered in the computer for analysis. Data from these latter cases were included in waste volume extrapolations, although analysis was essentially based on the 340 coded responses. As in the previous survey data was manipulated by the use of the packaged programs of Statistical Package for the Social Sciences (SPSS).

The geographic distribution of the responses is shown in Figure 2.1. Data was received from institutions in 48 states and the District of Columbia; only Alaska and Nevada were not represented.



	USNRC REGIONS	RESPONSES	PERCENT
I	NORTHEAST	24	62%
II	MID ATLANTIC	53	56%
III	EASTERN NORTH CENTRAL	48	41%
IV	WESTERN NORTH CENTRAL	30	57%
V	SOUTHERN ATLANTIC	63	63%
VI	EASTERN SOUTH CENTRAL	24	55%
VII	WESTERN SOUTH CENTRAL	37	45%
VIII	MOUNTAIN	13	60%
IX	PACIFIC	38	62%

FIGURE 2.1 GEOGRAPHIC DISTRIBUTION OF SURVEY RESPONSES BY USNRC REGION

A series of Chi square tests were performed on the responses to determine whether the distributions of responses differed significantly from the total population at an $\alpha = .05$ level of significance.

Geographic biases were tested by allocating the population into U.S. Census regions (5). No significant differences were demonstrated between the distribution of responding institutions and the total population. Additionally, the individual distributions of responding hospitals, colleges or medschools and their respective distributions in the total population did not differ at the stated level of significance.

Respondents were tested for size bias by stratifying the population by number of beds for hospitals, and numbers of full-time students enrolled for colleges; (no appropriate size stratifier was devised for medschools). The strata used for this comparison and the corresponding numbers are shown in Table 2.4. No biases were demonstrated in the responses when compared by these size criteria. The 340 responses accounted for 57% of the hospitals (N = 200), 63% of the medschools (N = 73) and 55% of the colleges (N = 178); these differences in response rate were not significant.

It was concluded that no geographic, size, or type biases were demonstrated in the responses.

Table 2.4 Size Stratification of Responding Hospitals and Colleges

Distribution of Bed Range Among Hospitals			Distribution of Students Among Colleges		
Number of Beds per Hospital	Number of Institutions with Hospitals		Number of Students per College	Number of Institutions with Colleges	
	Surveyed	Responded		Surveyed	Responded
0 - 99	3	3	0 - 2,499	1	1
100 - 199	4	4	2,500 - 4,999	13	8
200 - 299	4	2	5,000 - 7,499	71	32
300 - 399	9	7	7,500 - 9,999	61	34
400 - 499	46	25	10,000 - 12,499	33	22
500 - 599	112	58	12,500 - 14,999	26	12
600 - 699	54	33	15,000 - 17,499	23	15
700 - 799	31	19	17,500 - 19,999	8	5
800 - 899	21	14	20,000 - 22,499	27	13
900 - 999	14	9	22,500 - 24,999	17	8
1,000 or more	43	23	25,000 or more	38	22
TOTAL	341	197		318	172

3. RESULTS

3.1 Responses

The 340 coded responses were broken down by entity combination and compared to the same breakdown of the total population, to obtain response rates for extrapolation. The response rates, computed as the fraction of total entities represented by the responses in each category, are shown in Table 3.1. Except where indicated, waste estimations were based on these response rates.

The separation of the population into individual entities was found to be a useful technique in determining response rates; however, because of the frequent consolidation of responses, certain simplifying assumptions were used in the actual analysis. All responses which included hospitals were assumed to include only one hospital; all responses which included colleges were assumed to include only one; and all responses including medschools were assumed to include only one. Therefore, for the purposes of analysis, the responses were assumed to include 195 hospitals, 172 colleges and 72 medschools, while the actual numbers (used only in the computing of response rates) were 200, 178, and 73, respectively. The consolidations of hospitals and colleges were partially offset by summing the total numbers of beds and students, represented by each response including these entities.

3.2 Analysis

The primary objective of the study was to characterize, as much as possible, the radwastes shipped for commercial burial. It is apparent that the radwastes produced by the study population are indicative of the uses of radioactive material at the individual institution. Further, it is quite obvious that certain activities produce more radwaste than others. To obtain some insight into the relationship between use and waste production, a "wastestream" analytical approach was utilized.

Table 3.1 Breakdown of Coded Survey Responses by Entity

	Number Surveyed	Number Responding	Percent Responding
Hospital	347	200	57.6%
Medschool	116	73	62.9%
College	324	178	54.9%
	787	451	57.3%

For the purposes of this study, wastestream is defined as a general category of use of radioactive materials which results in the continuous or regular discharge of radioactivity into the environment.

The principle purposes of the wastestream analysis were the following:

1. To identify specific sources of radwastes in the population that could be categorized by some common basis.

2. To determine the total amount of radioactivity and principle nuclides available for use and ultimate disposal in each wastestream.

3. To determine the major waste forms and disposal methods chracteristic of each wastestream.

4. To quantify the volumes, activities and wasteforms shipped as low level radwaste attributable to each wastestream.

Three general wastestreams produced by the 1977 study population are apparent:

1. Medical - which includes:

   a. human use (in vivo) for diagnosis, therapy, and research

   b. non human use (in vitro) i.e. routine clinical radioassays.

2. Bioresearch - which includes:

   a. biochemical, biophysical and physiological investigations using radiolabeled tracer techniques, including in vivo animal research but excluding human use.

3. Non bioresearch - which includes:

   a. use in investigations in non life sciences research such as physics, inorganic chemistry, materials analysis, geology, etc.

   b. production of activation products with charged particle accelerators or research nuclear reactors

   c. instructional or classroom use.

At this point it should be noted that certain characteristics of the responses and the survey design place restrictions on the scope of this analysis. Because many of the respondents contribute to more than one wastestream, it is not possible to partition waste volumes and radioactivities among the three streams with complete certainty. The survey, while it elicited data regarding alternative disposal methods, was designed to quantitate only radwastes shipped for burial. The other data was used primarily to classify responses and to support the analyses.

Table 3.2 shows the breakdown of institutional types by wastestream. As is shown, 38% (128) of the responses contributed to only one wastestream, 55% (188) contributed to two or three wastestreams and 7% (24) were essentially non waste producing. The latter cases were those that received only sealed sources (7 cases) or received no radioactivity in 1977 (17 cases). The assumption that these cases were non waste producing was generally true; however, two cases indicated the disposal of previous accumulations of radwaste, one of which shipped a single 55 gallon drum for burial. None of the non waste producers include either hospitals or medschools.

The remaining analysis is based on the data from the 316 potentially waste producing cases. Because 188 of the responses contribute to more than one wastestream it would be of questionable value to base the entire analysis on the 128 single stream cases. However, if the following assumptions, based on the

Table 3.2 Breakdown of Type of Institution by Wastestream

Wastestream	Number of Institutions
Medical	
Hospitals only	89
Subtotal	89
Bioresearch	
Medschools only	3
Colleges only	21
Medschools and Colleges	2
Subtotal	26
Non Bioresearch	
Colleges only	13
Subtotal	13
Medical and Bioresearch	
Hospitals only	50
Medschools only	2
Hospitals and Medschools	24
Hospitals, Medschools, and Colleges	3
Subtotal	79
Bioresearch and Non Bioresearch	
Colleges only	71
Medschools and Colleges	9
Subtotal	80
Medical, Bioresearch and Non Bioresearch	
Hospitals, Medschools, and Colleges	29
Subtotal	29
No Waste Produced	
Colleges only	24
	24
TOTAL	340

latter group of cases are made, a pattern emerges:

- Hospitals either contribute only to the medical wastestream, or to both the medical and bioresearch wastestream

- Medschools contribute only to the bioresearch wastestream*

- Colleges contribute to the bioresearch wastestream, the non bioresearch wastestream or to both.

The pattern of wastestream input is shown graphically in Figure 3.1. It can be seen that the bioresearch wastestream receives input from the largest numbers of entities of all three types (N = 214), while the medical wastestream is next most frequent with input from all 195 hospitals and 2 medschools. The non bioresearch wastestream receives input from 122 of the 148 potentially waste producing colleges.

3.3 Radionuclide Receipts

The total activity receipts for the major nuclides received by the 316 potential waste producers in 1977 were analyzed to further characterize each wastestream. To select the major nuclides, the activity totals for each of 50 nuclides ranging from ^{3}H to ^{244}Cm were tabulated. Those nuclides meeting the following arbitrary criteria were selected for further analysis:

- Nuclides for which the activity total exceed 0.01% of the total activity of all nuclides received and

- Nuclides which were received by at least 50 respondents.

*The two medschools which contribute to the medical wastestream apparently operate small clinical facilities and were considered to be exceptions to the assumption that the medical wastestream receives input only from hospitals.

WASTESTREAM	SOURCE	NUMBER OF INSTITUTIONS	% INSTITUTIONAL RADWASTE VOLUME
MEDICAL	HOSPITALS	195	7%
	MEDSCHOOLS	2	
	COLLEGES	0	
BIORESEARCH	HOSPITALS	106	79%
	MEDSCHOOLS	72	
	COLLEGES	135	
NON BIORESEARCH	HOSPITALS	0	14%
	MEDSCHOOLS	0	
	COLLEGES	122	

FIGURE 3.1 WASTESTREAM SOURCES DERIVED FROM THE SURVEY RESPONSES

The total activity received by respondents was 59.0 kCi, of which 55.8 kCi (95%) were specified by nuclide. These totals exclude an additional 72.8 kCi of ^{60}Co and ^{137}Cs received by 9 respondents as gamma irradiator sources. A complete listing of the nuclide receipts is included in Appendix C. The nineteen nuclides which met the selection criteria constituted 98% of the activity specified by nuclide, or 93% of the total activity received in 1977. Table 3.3 lists the activity receipt of the 19 selected nuclides. Two of these nuclides, ^{99} Mo and ^{137}Cs, were not included in the final analysis.

The discrepancy between the numbers of respondents indicating receipt of ^{99}Mo (150) and those indicating receipt of ^{99m}Tc (206) cannot be readily attributed to whether the institution receives ^{99m}Tc in "instant" or unit dose form, or in ^{99}Mo - ^{99m}Tc generator form. Although it is apparent that some respondents receive ^{99m}Tc in the instant or unit dose form, the discrepancy of respondents is most likely attributable to the way in which the activities of these nuclides were reported on questionnaires. Many respondents reported only ^{99}Mo generator activity. In those cases, the ^{99m}Tc activity was recorded as the maximum elutable activity of the generator if eluted every 24 hours for 5 days after receipt (parent and daughter are assumed to be in equilibrium with elution efficiency of 100%); i.e.:

$$\text{annual } ^{99m}Tc \text{ activity} = 3.228 \text{ (annual } ^{99}Mo \text{ activity).}$$

In cases where ^{99m}Tc activity was reported as identical to ^{99} Mo activity, the activity computed by the above method was recorded. In the cases where only ^{99m}Tc receipts were listed, the receipt of ^{99}Mo was not automatically assumed because of the possibility that the ^{99m}Tc value was for "instant" or unit dose form.

Thus ^{99} Mo appears to be somewhat underreported. Because this nuclide is only received in significant quantities as an intermediary of ^{99m}Tc it was deleted from further analysis.

Table 3.3 Activity Totals Received by Respondents**

Nuclide	Half Life	N	Activity (mCi) Mean	Total
^{3}H	12.30 y	215	2,889	621,137
^{14}C	5730.00 y	212	89	18,797
^{32}P	14.28 d	240	710	170,412
^{35}S	87.90 d	116	188	21,810
^{45}Ca	165.00 d	106	33	3,520
^{51}Cr	27.80 d	208	204	42,481
^{67}Ga	77.90 h	180	751	135,094
^{75}Se	120.40 d	138	108	14,939
^{86}Rb	18.66 d	54	264	14,229
^{99}Mo	66.70 h	150	82,859	12,428,891*
^{99m}Tc	6.05 h	206	183,260	37,751,354*
^{111}In	2.81 d	105	656	68,906
^{123}I	13.30 h	98	1,466	143,642
^{125}I	60.20 d	231	383	88,565
^{131}I	8.05 d	241	1,058	255,063
^{133}Xe	5.27 d	172	12,081	2,077,905
^{137}Cs	30.00 y	54	14,978	808,834*
^{169}Yb	37.80 d	53	148	7,690
^{201}Tl	74.00 h	102	735	74,958
			TOTAL	54,748,228

*See Section 3.3

**Nuclides for which activity total exceeds .01% of total activity of all nuclides received and which were received by at least 50 respondents.

The ^{137}Cs received by the population was predominantly in the form of sealed sources. Of the 52 responses receiving this nuclide, 48 indicated receipts in sealed source form, representing in excess of 99.9% of the total cesium activity.

Cesium 137 was received by institutions using all three wastestreams. As a sealed source, it is used widely in medicine, biological research and physics research primarily for its gamma emitting properties. This nuclide does appear in the wastes shipped for burial, but predominantly in sealed source form. Because the useful life of this type of a sealed source is likely to be considerably longer than one year (i.e. the period under study), it is probably not useful to use the annual receipts of ^{137}Cs as indicative of the activity available for disposal within the study period. Cesium 137, therefore, was removed from the wastestream analysis.

3.4 Analysis of Wastestreams

The first step in the analysis was to determine the correlation between nuclides received and wastestreams. Prior to doing so, the distributions of activity receipts in the responses were examined for each nuclide. The skewness (third moment) values for each of the 17 nuclides indicated the clustering of values to the left of the mean with extreme values to the right. Z scores were then computed for each nuclide except ^{3}H.* Those values for which the Z scores were outside the 99th percentile were removed and the means recomputed. Extreme values were checked for validity, then excluded from activity means; they are, however, included in activity totals in Table C.1 of Appendix C.

Table 3.4 shows the mean activity received for the 17 nuclides, broken down by the six wastestream combinations (after the exclusion of extreme values). The N values reflect the total number of responses receiving each nuclide in its corresponding wastestream including extreme values and "missing" values (those indicating receipt but not specifying activity).

*The distribution of activity receipt of ^{3}H was apparently bimodal.

Table 3.4 Average Activities of Principal Radionuclides Received by Respondents

(Activity in mCi)

Nuclide	Medical only		Bioresearch only		Non Bioresearch only		Medical & Bioresearch		Bioresearch & Non Bioresearch		Medical, Bioresearch Non Bioresearch	
	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
^{3}H	18	14	20	141	7	178	69	2,238	72	5,009	29	3,687
^{14}C	14	12	20	22	8	93	66	62	75	35	29	103
^{32}P	59	76	13	55	8	99	67	320	64	426	29	1,230
^{35}S	2	51	6	20	3	7	40	129	37	139	26	235
^{45}Ca	2	20	8	10	3	8	38	24	29	17	21	26
^{51}Cr	64	10	3	51	1	<1	74	120	37	79	29	242
^{67}Ga	82	465	-	-	1	10	72	723	-	-	25	955
^{75}Se	55	18	1	<1	-	-	51	21	11	10	20	13
^{86}Rb	-	-	1	53	1	21	18	11	17	16	17	26
^{99m}Tc	88	132,479	-	-	-	-	78	135,272	12	9,505	28	277,152
^{111}In	32	62	-	-	-	-	49	344	2	37	22	44
^{123}I	44	152	-	-	-	-	38	94	2	28	14	207
^{125}I	62	49	8	137	5	35	73	355	56	209	27	739

Table 3.4 Continued

(Activity in mCi)

Nuclide	Medical only		Bioresearch only		Non Bioresearch only		Medical & Bioresearch		Bioresearch & Non Bioresearch		Medical Bioresearch & Non Bioresearch	
	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
^{131}I	89	541	6	12	5	3	78	1,050	35	46	28	1,839
^{133}Xe	76	5,797	-	-	-	-	68	10,190	2	15,005	26	16,547
^{169}Yb	22	42	-	-	-	-	17	28	1	1,600	12	64
^{201}Tl	26	121	-	-	-	-	53	201	3	1	20	181
TOTAL RESPONSES	89		26		13		79		80		29	

NOTE: 'N' designates the number of responses receiving the nuclide as specified, including both "missing" values (i.e. those who indicated receipt of the nuclide but did not supply activity) and extreme values.

Activity means exclude values less than the 0.05 percentile and greater than 99.5 percentile as determined by "Z" score for activity distributions in the entire sample.

An estimate of the unique contribution of each nuclide to the three primary wastestreams was hampered by the fact that only for the medical wastestream, were the numbers (N = 89 hospitals only) to a single stream adequate to characterize that stream. Biological research is conducted by medschools, hospitals, and colleges, most of which were consolidated with responses associated with the medical or non biological wastestreams, or both. Relatively few institutions performed only biological research. A similar situation exists for the non biological wastestream - most of the larger colleges using radionuclides in non bioresearch also conducted bioresearch. Nevertheless, certain inferences could be made by examining the frequencies of receipt and relative activities of each nuclide to establish association with the medical and bioresearch wastestreams.

Nine nuclides, ^{67}Ga, ^{75}Se, ^{99m}Tc, ^{111}In, ^{123}I, ^{131}I, ^{133}Xe, ^{169}Yb and ^{201}Tl, are all gamma emitters used in medical imaging or therapeutics, and were strongly associated with medical use. Carbon 14, ^{35}S, ^{45}Ca, and ^{86}Rb were associated predominantly with the bioresearch wastestream, while ^{32}P, ^{51}Cr and ^{125}I correlated with both bioresearch and medical wastestreams. Tritium is associated with both the bioresearch and the non bioresearch wastestreams.

Table 3.5 shows the estimated total activities for each nuclide broken down by the three wastestreams. The simplifying assumptions used in the construction of Table 3.5 were the following:

1. Nuclides strongly associated with one wastestream were assumed to originate only in that component of a response that indicated that wastestream. For example, an institution including a hospital and a medschool would be associated with both the medical and the bioresearch wastestream. If the response indicated receipt of ^{67}Ga, a "medical" nuclide, the total ^{67}Ga activity of that response was attributed to the medical wastestream.

Table 3.5 Estimates of Total Activity (mCi) Received for Major Nuclides Partitioned Among Wastestreams

Nuclide	Medical			Bioresearch			Non Bioresearch		
	Number	Activity Subtotal	% of Nuclide Activity	Number	Activity Subtotal	% of Nuclide Activity	Number	Activity Subtotal	% of Nuclide Activity
^{3}H	18	249	>1%	190	407,123	65%	15	217,772	35%
^{14}C	14	174	2%	190	10,087	92%	8	747	7%
^{32}P	155	11,819	13%	173	77,048	86%	8	792	1%
^{35}S	2	100	1%	109	16,543	99%	3	20	>1%
^{45}Ca	2	40	2%	96	2,047	97%	3	22	1%
^{51}Cr	167	1,668	9%	143	17,763	91%	1	1	> 1%
^{67}Ga	179	114,072	~100%	-	-	-	1	10	> 1%
^{75}Se	126	2,307	95%	12	110	5%	-	-	-
^{86}Rb	-	-	-	53	973	98%	1	21	2%
^{99m}Tc	197	29,969,607	~100%	12	114,062	>1%	-	-	-
^{111}In	163	19,820	~100%	2	73	>1%	-	-	-
^{123}I	96	13,168	~100%	2	55	>1%	-	-	-
^{125}I	162	24,975	40%	153	36,677	59%	5	174	>1%
^{131}I	195	181,600	99%	41	1,690	1%	5	3	>1%
^{133}Xe	170	1,563,705	98%	2	30,010	2%		-	-
^{169}Yb	51	2,167	58%	-	-	-	1	1,600	42%
^{201}Tl	96	17,436	~100%	-	-	-	3	3	>1%

*With the exception of ^{3}H, annual activity totals were computed using averages determined after excluding extreme values ($3\sigma < X < -3\sigma$)

2. For those nuclides correlating with both bioresearch and medical wastestreams (^{32}P, ^{51}Cr, ^{125}I), the medical component was computed by assuming that all responses indicating receipt of the nuclide, which included a hospital received the average activity of non research hospitals receiving that nuclide. The remaining activity was allocated to the bioresearch wastestream, with the exception of the few responses which fed only the non bio-research wastestream.

   The activity of ^{125}I allocated to the medical wastestream was modified further to include the total activity received by those 11 responses which indicated the receipt of ^{125}I in sealed source form. In these cases, the mean activity value was significantly larger ($p < .001$) than that of those not receiving sealed sources. All 11 responses included hospitals, in which case, the additional activity was assumed to be due to ^{125}I seeds used in brachytherapy.

3. Tritium presented a special case due to the presence of particle accelerators in the population. Many of the institutions with accelerators, most notably with neutron generators, received much larger activities than those without accelerators. The institutions with active neutron generators (8 cases), as determined in the separate accelerator survey (see Appendix B), were all academic institutions associated with both bioresearch and non bioresearch. The non bioresearch component of ^{3}H receipts was taken to be the average activity for these institutions minus the average ^{3}H receipt for those associated with bioresearch, without neutron generators. The remaining ^{3}H receipts were allocated to the bioresearch wastestream. In all other cases associated with bioresearch, the total ^{3}H receipts were allocated to the bioresearch wastestream, whether or not the institution included a hospital. The tritium receipts for the few non research hospitals (18 cases) were assumed to be the entire contribution of this nuclide to the medical wastestream.

Due to the limitations imposed by the data base, the distribution of nuclide activities among the three wastestreams as depicted in Table 3.5, is not definitive. It is, however, a reasonable representation of the relative magnitudes of the principal nuclide species characteristic of the medical and bioresearch wastestreams in general. The non bioresearch wastestream was least well characterized; this "catch all" grouping is considerably more heterogeneous. It should be noted the bulk of the "unspecified" nuclides as well as many of the less frequently received nuclides, was received by the institutions producing non bioresearch waste.

Of the 17 more frequently received nuclides, the one most notably attributable to non bioresearch waste is ^{3}H, associated principally with charged particle accelerators. The medical wastestream is dominated by relatively short lived gamma emitters the bulk of which, ^{99m}Tc, ^{67}Ga, ^{75}Se, ^{51}Cr, ^{111}In, ^{123}I, ^{131}I, ^{133}Xe, ^{169}Yb, and ^{201}Tl are associated with medical nuclear imaging. Iodine 131 and ^{32}P are used widely in therapeutics while ^{125}I, and to a lesser extent, ^{75}Se, ^{3}H, and ^{14}C, as well as several other nuclides are used in clinical in vitro assays.

The generally longer lived beta emitters such as ^{3}H, ^{14}C, ^{32}P, ^{35}S, and ^{45}Ca characterize the bioresearch wastestream. These nuclides are for the most part quantitated by liquid scintillation counting, which explains the association of liquid scintillation wastes with this wastestream. Also common in bioresearch are the gamma emitters ^{86}Rb, ^{125}I, and ^{51}Cr.

3.5 Radwaste Disposal Methods and Waste Forms

Of the 316 cases considered thus far to be potentially waste producing, 22 cases stated that no radwastes were disposed of in 1977. Thirteen of these were relatively small colleges (only) which received relatively small quantities of radioactive materials; a few indicated that insufficient waste had accumulated for disposal during the survey year. No further data was obtained from these cases.

The remaining nine responses were all hospitals (only) which used radioactive materials in medicine; three of which indicated radionuclides also were used in biological research. Two hospitals stated that wastes were "decayed to background," indicating that wastes were probably disposed of in the common refuse. The radionuclides and quantities received by these nine hospitals did not differ significantly from those of the remaining 80 hospitals (only) in the data base. Thus, these 9 cases were treated as waste producers, such that 303 cases were considered to have produced radwastes requiring disposal in 1977; 289 of these cases provided waste form and disposal method data.

Survey respondents were asked to complete a waste type and disposal method matrix (Appendix A, p. 5). The disposal alternatives, some of which are only appropriate for certain waste types, are listed in Table 3.6. For classification purposes, seven waste forms were correlated with these disposal alternatives. These waste forms are listed in Table 3.7.

The following three tables (3.8 - 3.10) show the results of this portion of the analysis, which relates disposal methods and waste forms to the six wastestreams. Table 3.8 displays the numbers and percentages of respondents disposing of various waste forms in each wastestream. In Table 3.9 the frequency of use of each disposal alternative is broken down into the wastestreams. The data from these two tables are summarized in Table 3.10. Table 3.10 lists the percentages of responding institutions who disposed of a given waste form by each of the alternative disposal methods.

The disposal alternatives listed in the study are not exclusive, nor are they necessarily a method of disposal. Many institutions disposed of a given waste form by more than one method. Also, some institutions "disposed" of waste by short-term methods such as transferring waste. The transferring of waste to another institution, an infrequently used alternative, was most common among hospitals. Typically, such hospitals received all radionuclides from a radiopharmacy to which waste was returned.

1370 227

Table 3.6 Radwaste Disposal Alternatives

Alternative	Description
Sewer Disposal	Release of liquid or semisolid radwastes to municipal sewer systems either in a controlled or uncontrolled manner.
Common Refuse	Disposal of radwastes into municipal solid waste systems.
Incineration	Burning of radwaste either in controlled incineration or relatively uncontrolled "open pit" burning.
Shipment for Commerical Burial	Shipment of radwaste to commercial low level waste burial site.
Burial on Site	Burial on land owned by institution.
Transfer	Transfer of radwastes to another institution for disposal.
Evaporation or Distillation	Volume reduction technique for liquid radwastes.
Venting to Atmosphere	Disposal technique for gaseous radwastes.

1370 228

Table 3.7 Radwaste Forms Disposed of by Survey Population

Waste Form	Description
L-S Wastes	Waste liquid scintillation vials and fluids, including empty vials.
Organic Liquids	Waste organic liquids other than scintillation fluids.
Aqueous Liquids	Solutions of water soluble radionuclides including laboratory glassware washings.
Biological Wastes	Predominantly animal carcasses and tissues and including animal bedding excreta and labeled culture media.
Patient Excreta	Excreta or materials contaminated with excreta from patients undergoing diagnostic or therapeutic procedures which require the administration of radioactivity.
Gaseous Wastes	With few exceptions, this refers to ^{133}Xe used in human or animal ventilation studies.
Dry Solid Wastes	All dry solid waste materials containing real or suspected levels of radioactivity.

1373 229

Table 3.8 Breakdown of Radwaste Disposed by Responding Institutions

Waste Form	Medical Only		Bioresearch Only		Non Bioresearch Only		Medical & Bioresearch		Bioresearch and Non Bioresearch		Medical Bioresearch and Non Bioresearch		Overall Institutions	
	*N	percent	*N	percent	*N	percent	*N	percent	*N	percent	*N	percent	*N	percent
L - S Wastes	18	23	16	76	6	67	68	89	70	95	29	100	207	72
Other Organics	5	6	7	33	4	44	48	63	50	68	22	76	136	47
Aqueous Liquids	48	60	18	86	8	89	66	87	62	84	26	90	228	79
Biological Wastes	3	4	14	67	4	44	58	76	63	85	29	100	171	59
Patient Excreta	80	100	-	-	-	-	76	100	-	-	29	100	185	65
Gaseous Wastes	52	65	4	19	1	11	63	83	27	36	25	86	172	60
Dry Solid Wastes	68	85	12	57	5	56	69	91	68	92	29	100	251	87

*Missing values, those cases which disposed of radwaste, but did not specify form, were excluded.

Table 3.9 Breakdown by Wastestream Category of Disposal Methods Used by Survey Respondents

Disposal Methods Used	Medical Only		Bioresearch Only		Non Bioresearch Only		Medical and Bioresearch		Bioresearch and Non Bioresearch		Medical Bioresearch and Non Bioresearch		Overall Responses	
	N*	Percent	N*	Percent	N*	Percent	N*	Percent	N*	Percent	N*	Percent	N*	Percent
Release to Sewer	80	100%	16	76%	6	67%	76	100%	43	58%	29	100%	250	87%
Common Refuse	45	56 %	7	33%	2	22%	36	47 %	17	23%	10	34 %	117	40%
Incineration	12	15 %	2	10%	-	-	23	30 %	12	16%	12	41 %	61	21%
Evaporation or Distillation of Liquids	-	-	1	5 %	-	-	4	5 %	14	19%	3	10 %	22	8 %
Venting of Gases	43	54 %	3	14%	-	-	54	71 %	26	35%	22	76 %	148	51%
Commercial Burial	32	40 %	9	43%	5	56%	67	88 %	55	74%	28	97 %	207	72%
Bury on Site	-	-	-	-	-	-	2	3%	16	22%	3	10 %	21	7 %
Transfer to Other Institutions	13	16 %	1	5 %	-	-	5	7%	3	4%	1	3 %	23	8 %

*Missing values, those which disposed of a given waste type, but did not specify disposal method, were excluded.

Table 3.10 Disposal of Radwastes by Survey Respondents *

	DISPOSAL ALTERNATIVES							
Waste Form	Release to Sewer	Common Refuse	Incinerate	Evaporate or Distill	Vent to Atmosphere	Ship for Burial	Bury On Site	Transfer
Full L-S Vials	-	8%	5%	-	-	85%	7%	1%
Empty L-S Vials	-	29%	3%	-	-	71%	8%	1%
L-S Fluids	34%	3%	3%	10%	-	66%	6%	1%
Other Organic Liquids	33%	4%	3%	6%	-	75%	8%	1%
Aqueous Liquids	61%	-	-	2%	-	54%	5%	2%
Biological Wastes	7%	4%	26%	-	-	72%	9%	2%
Patient Excreta	100%	-	1%	-	-	8%	1%	-
Gaseous Wastes	-	10%	-	-	86%	15%	-	1%
Dry Solids	-	25%	12%	-	-	72%	7%	6%

*Numbers are the percentages of responses which disposed of some waste of a given type by the indicated alternative. Many used more than one alternative for a given waste type. These numbers do not reflect volume or other quantity of waste disposed of by any alternative.

The evaporation or distillation of liquid wastes would be more properly considered as a volume reduction technique than as a disposal method. The same, to some extent, also may be said of incineration, for both techniques may leave a contaminated residue. Respondents using such techniques often indicated a second method of disposal for a given wasteform.

Perhaps the most troublesome waste form produced by the institutional population is liquid scintillation wastes (L-S wastes). Liquid scintillation counting is for the most part a biological research technique; it is the principal method used for the quantitation of the beta emitters ^{3}H, ^{14}C, ^{32}P, ^{35}S, and ^{45}Ca generally associated with biological research (see Table 3.6). Most of the L-S waste producers are associated with the bioresearch wastestream. Overall, 72% of the waste producers indicated disposal of L-S wastes. If non research hospitals (who contribute to the medical wastestream only) are excluded, the percentage is 90%.

Some institutions dispose of L-S wastes in the form of vials containing the fluids; others separated the fluids from the vials and disposed of them separately. Most however, did both; the reuse of scintillation vials is apparently quite common.

Eighty-five percent of those who disposed of full L-S vials shipped them for commercial burial. Shipping for burial was also the most common method of disposal for those who separate vials from fluids. Significantly, 34% of those who disposed of L-S fluids emptied them into the sanitary sewer, and it was not uncommon for the empty vials to be thrown into the common refuse. Ten percent of those disposing of L-S fluids used evaporation or distillation as a method of volume reduction. Only a few cases burned vials or fluids in an incinerator.

Organic liquid wastes are generally organic laboratory solvents such as alcohols, adehydes, ketones, organic acids, etc, which were not included as scintillation fluids. As is shown in Table 3.8, these wastes are more commonly associated with the bioresearch wastestream. As with L-S wastes, organic liquids are most commonly shipped for burial, although a third of those disposing of this waste type used sewer disposal to some extent.

Aqueous liquid wastes are commonly associated with all three wastestreams. Most liquid wastes associated with medical uses of radionuclides are aqueous. Eighty-eight percent of non research hospitals who disposed of aqueous liquids dumped them into the sewer, while in the remainder of the population the percentage of institutions disposing of aqueous liquids through the sewer was 64%. Aqueous waste liquids also include the washings from contaminated labware in research facilities. Approximately half of the respondents who disposed of aqueous liquids shipped them for burial.

Biological wastes are for the most part animal carcasses used in biological research. Most were shipped for burial, but signficantly, 26% of those disposing of biological wastes incinerated them (44 cases).

The burning of animal carcasses was the most frequent use of incineration by the 61 institutions incinerating radwastes in some form. Seven percent of those disposing of animal carcasses used a large garbage disposer to grind small animal carcasses for sewer disposal.

Essentially all of the institutions which administered radioactivity in humans were assumed to release contaminated patient excreta to the sewers. Except for some wastes resulting from therapeutic administrations of radioiodine, these releases can be considered to be uncontrolled releases to the sewer system. The use of other disposal methods for patient excreta apparently refers to wastes and contaminated materials collected from patients receiving radioiodine therapy.

Gaseous wastes are produced predominantly by hospitals using ^{133}Xe, and to a lesser extent ^{127}Xe, for ventilation studies.* Most hospitals (86%) using these nuclides vented radioactivity to the atmosphere to some degree. Gas traps, usually filters containing activated charcoal for adsorbtion of the exhaled xenon, which were frequently used, were either disposed of in the common refuse (after decay) or shipped for burial.

*The distribution of the gamma emitting inhaled radionuclide in the lungs is visualized with an external detector as an indicator of lung ventilation.

Dry solids constituted the type of waste most commonly disposed. Overall, the dominant disposal method for dry solids was by shipment for burial (72%). However, if "medical only" wastes are excluded, 84% of the respondents shipped dry solids for burial. "Medical only" wastes were disposed more frequently in the common refuse (57%) than were shipped for burial (41%). Only 16% of the rest of the population disposed of dry solids in the common refuse, almost all of which were from institutions including hospitals.

Medical radwastes, with the exclusion of patient excreta, appear to be composed predominantly of dry solids, aqueous liquids, and gaseous wastes. Ninety-nine percent of the activity associated with the medical wastestream consists of nuclides with half lives of less than seven days. The remaining medical activity consists predominantly of the somewhat longer lived ^{125}I, ^{131}I, ^{169}Yb, ^{51}Cr, and ^{75}Se. Of the medical institutions that produced only medical radwastes, 39% shipped waste for burial in 1977; while 88% of the medical institutions that produced bioresearch wastes, in addition to medical radwastes, shipped wastes for burial.

The disposal alternatives to shipment for burial by non research hospitals appear to be the sanitary sewer for liquid wastes (56% excluding patient excreta) and the common refuse for dry solids (54%).

Bioresearch wastes are largely contaminated with relatively long-lived beta emitters. Seventy-seven percent of the activity associated with the bioresearch wastestream consists of nuclides with half lives longer than seven days, of which ^{3}H dominates. The types of wastes associated with bioresearch are liquid scintillation wastes, aqueous and organic liquids, animal carcasses and dry solids.

Most of the institutions in the bioresearch wastestream (84%) consigned wastes for burial, either on site or by shipment to a commercial burial site. Of these, five percent buried wastes on site, 74% shipped for burial, and 6% disposed of waste by both methods.

The next most common disposal methods were the use of the sanitary sewer for liquids and biologicals (62%), incineration of dry solids and biologicals (27%), and disposal in the common refuse of dry solids and scintillation vials (3%).

3.6 Radwastes Shipped for Burial

Of the 303 institutions considered thus far to be waste producing, 196, or 65%, shipped at least a portion of their radwaste for burial in 1977. Table 3.11 shows the numbers and percentages of respondents shipping waste by wastestream category. The frequency of waste shipment is notably higher in research institutions than in non research hospitals.

3.6.1 Waste Volumes Shipped for Burial

Respondents shipped a total of 5243 m^3(185,160 ft^3) of low level radwaste for commercial burial in 1977. Table 3.12 shows the mean and total volumes shipped of each wastestream category. Again the relatively small average radwaste volume shipped by non research hospitals is apparent. Figure 3.2 shows the relative contribution of the six wastestream categories to the total waste volume shipped for burial in 1977.

3.6.2 Physical Forms of Radwastes Shipped for Burial

Surveyed institutions were asked to specify the relative volume of the following types of wastes shipped for burial:

1. Dry solid wastes

2. Adsorbed or solidified liquids (waste volume includes liquids plus adsorbent or solidifying media)

Table 3.11 Institutions Shipping Waste for Burial in 1977

Wastestream Category	Number Shipping	Percent of Category Shipping Waste
Medical only	31	35%
Bioresearch only	9	35%
Non Bioresearch only	5	56%
Medical and Bioresearch	67	88%
Bioresearch and Non Bioresearch	55	56%
Medical, Bioresearch and Non Bioresearch	28	97%
OVERALL	196	65%

Table 3.12 Waste Volume Shipped for Burial by Respondents in 1977, Broken Down by Wastestream Category

Wastestream Category	Number* Shipping	Volume (m^3)	
		Mean	Total
Medical only	32	2.5	80.1
Bioresearch only	9	13.5	121.9
Non Bioresearch only	5	6.4	32.0
Medical and Bioresearch	67	30.8**	2,643.1
Bioresearch and Non Bioresearch	55	14.2	783.4
Medical, Bioresearch and Non Bioresearch	28	56.4	1,580.1
OVERALL	196	23.7 m^3**	5,240.6 m^3

*Numbers of institutions shipping include 16 "missing cases" that did not specify volume.

** Single extreme value excluded from mean; but included in totals.

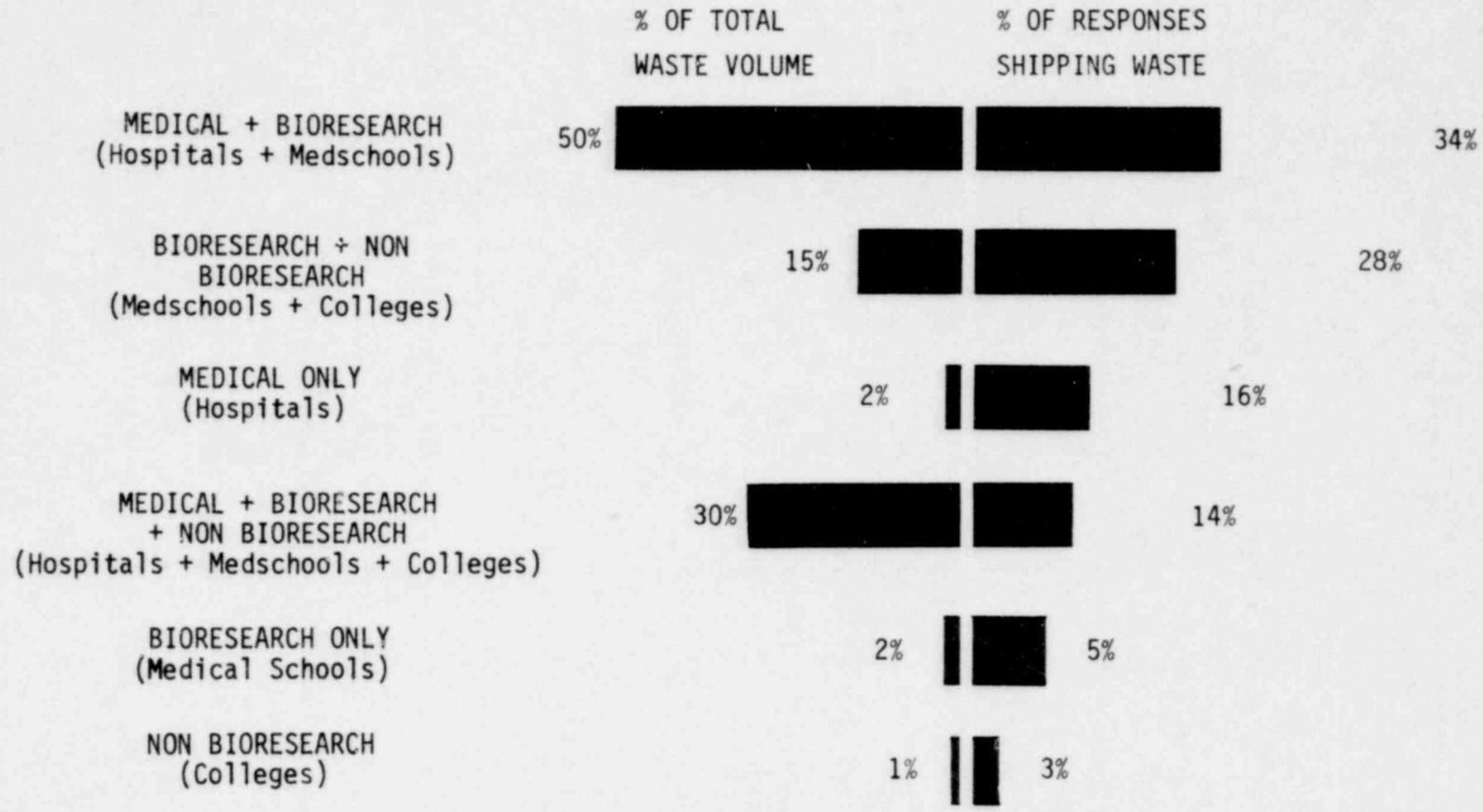


FIGURE 3.2 RELATIVE RADWASTE VOLUMES SHIPPED BY WASTESTREAM CATEGORY

3. Liquid scintillation vials (vials containing liquid scintillation fluids, plus adsorbent media)

4. Biological wastes (predominantly animal carcasses plus any packaging materials).

The radwaste volume, shipped by institutions feeding each of the six wastestreams, is broken down into waste types in Table 3.13.

3.6.3 Allocation of Waste Volumes into Wastestreams

To obtain an estimate of the distribution of radwaste volume into wastestreams, the following assumptions were made:

1. The average waste volume shipped by "medical only" institutions was assumed to be the same as the medical fraction of radwastes shipped by institutions which include a hospital and which also contributed to other than the medical wastestream. For simplicity, the medical fraction was assumed to be only dry solids.

2. The L-S vial and biological waste volumes shipped by institutions feeding into the bioresearch wastestream (as well as one or both other streams) were assumed to be from the bioresearch component.

3. Dry solid and adsorbed liquid wastes, after removal of any existing medical fraction, were evenly divided between the bioresearch and non bioresearch wastestreams : institutions feeding these streams.

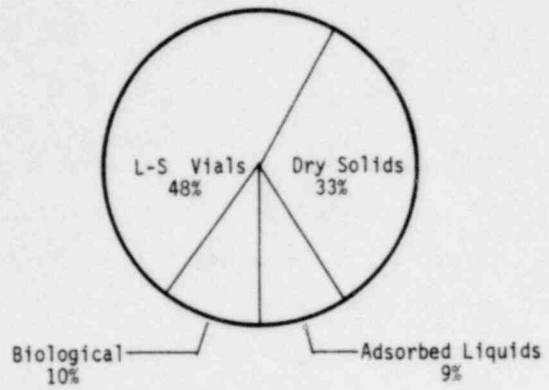
Figure 3.3 employs the assumptions explained above to show the waste volume partitioned into the three wastestreams. The overwhelming bulk of the waste volume is associated with the bioresearch wastestream (79%) and consists of L - S vials (48%), dry solids (33%), biological wastes (10%), and adsorbed liquids (9%). The medical wastestream appears to contribute approximately 7% of the volume of wastes shipped for burial while the remaining 14% is attributed to non biological research.

Table 3.13 Physical Forms of Wastes Shipped for Burial in 1977, Broken Down by Wastestream Category

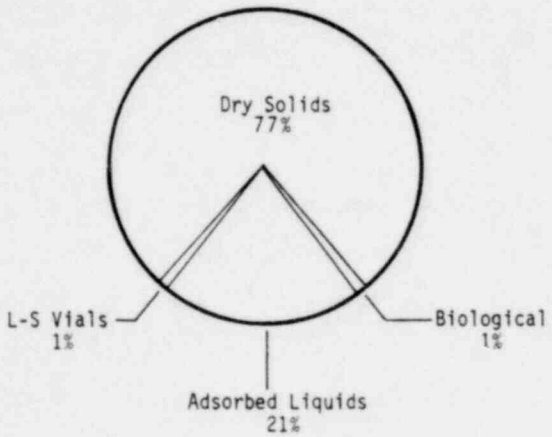
WASTESTREAM CATEGORY	PHYSICAL FORMS OF WASTES: Dry Solids		Liquid Scint. Vials		Adsorbed Liquids		Biological Wastes		Wastestream Totals	
	Number Shipping	*% of WS Volume	Number Shipping	% of WS Volume	Number Shipping	% of WS Volume	Number Shipping	% of WS Volume	Number Shipping	Percent
Medical only	27	45.2	10	17.7	15	10.5	3	26.5	32	100
Bioresearch only	8	22.3	6	16.4	5	38.4	6	23.0	9	100
Non Bioresearch only	5	50.8	3	22.3	1	9.9	3	17.1	5	100
Medical and Bio-research	60	34.5	57	49.5	49	7.0	45	9.1	67	100
Bioresearch and Non Bioresearch	51	49.3	40	32.3	36	12.5	33	5.8	55	100
Medical, Biore-search and Non Bioresearch	28	53.4	26	26.1	22	13.3	26	7.3	28	100
OVERALL	180	42.3	142	38.5	131	10.4	118	8.8	196	100

*WS = Wastestream

BIORESEARCH WASTESTREAM



NON BIORESEARCH WASTESTREAM



MEDICAL WASTESTREAM

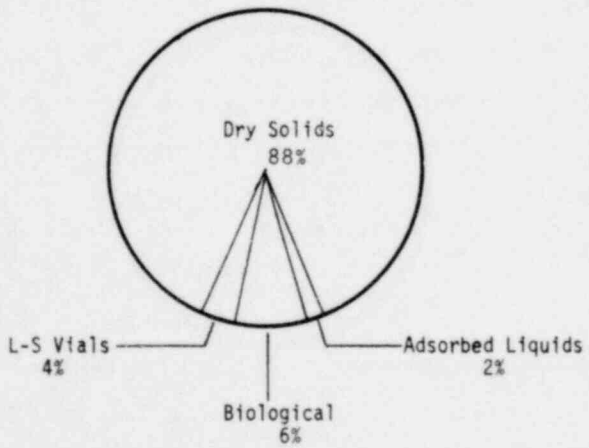


FIGURE 3.3 RELATIVE COMPOSITION OF THE THREE WASTESTREAMS SHIPPED

1370 242

3.7 Radioactivity Shipped for Burial

The total activity reported as shipped for burial by survey respondents was 493 Ci*, 88 Ci of which was reported as sealed sources. The sealed sources shipped for burial by the survey respondants in 1977 are listed by type and activity in Appendix C, Table C.2 (see also Appendix B, "Accelerator Wastes."). Most (99.07%) of the remaining (non sealed source) activity shipped consists of some 31 nuclides, which are also listed in Appendix C, Table C.3.

The nuclides selected for analysis from activity receipts (Table 3.4), with the exception of ^{123}I**, constitute 94.33% of the activity specified by nuclide. Cesium 137, (0.27%), ^{99}Mo (3.76%), and ^{60}Co (0.83%) make up the bulk of the remainder.

Z scores were computed on the distibutions of activity shipped for each nuclide, with the exception of ^{3}H, and extreme values ($\bar{x} - 3\sigma < x < \bar{x} + 3\sigma$) were excluded and means were recomputed. These activities are broken down by wastestream category in Table 3.14. Using the same assumptions as in Section 3.3, the activities of each nuclide were allocated into the three wastestream categories. This estimated distribution is shown in Table 3.13.

It should be noted that an attempt to quantitate activities of nuclides shipped for burial with half lives of less than seven days is somewhat dubious in light of their relatively quick rate of dissipation. However, in the interest of estimating the activity concentrations of waste typical of the three waste streams, these activities are included.

*Excluding data from accelerator wastes (Appendix B).

**This short lived nuclide was not listed as shipped in any significant quantities.

Table 3.14 Activity of Principal Nuclides Shipped for Burial (mCi)

	Total Number	Medical only		Bioresearch only		Non Bioresearch only		Medical & Bioresearch		Bioresearch & Non Bioresearch		Medical, Bioresearch & Non Bioresearch	
		N*	Mean	N*	Mean	N*	Mean	N*	Mean	N*	Mean	N*	Mean
^{3}H	157	8	8.9	10	379.5	5	207.1	54	1,948.6	52	1,064.2	28	2,563.0
^{14}C	149	6	1.9	8	43.7	5	64.2	52	64.2	50	59.5	28	87.8
^{32}P	116	11	2.7	4	49.7	3	52.1	47	80.7	25	192.7	26	205.4
^{35}S	85	1	1.0	6	5.5	1	4.6	31	100.0	24	50.3	22	105.0
^{45}Ca	85	-	-	6	4.6	3	1.0	29	16.3	21	13.2	26	18.1
^{51}Cr	115	17	2.5	3	16.8	-	-	49	56.8	20	7.6	26	62.7
^{67}Ga	66	17	31.2	-	-	-	-	34	8.1	1	>0.1	14	53.5
^{75}Se	64	15	1.0	1	>0.1	-	-	31	6.1	5	13.7	12	7.6
^{86}Rb	37	2	>0.1	1	4.7	1	0.1	15	4.3	7	4.5	11	7.0
^{99m}Tc	70	20	432.2	-	-	-	-	31	75.6	6	6.1	13	210.8
^{111}In	41	4	3.0	-	-	-	-	27	2.5	-	-	10	3.8
^{125}I	151	23	4.0	5	160.7	3	20.6	58	280.2	34	101.3	28	305.1
^{131}I	108	22	16.3	3	1.0	1	10.0	49	46.5	14	21.3	19	88.8
^{133}Xe	14	3	>0.1	-	-	-	-	8	66.8	-	-	6	106.1
^{169}Yb	18	6	4.0	-	-	-	-	7	7.8	1	180.0	4	0.8
^{201}Tl	36	6	10.3	-	-	-	-	24	9.3	-	-	6	13.7

* Numbers include missing and extreme values.

** Except for ^{3}H, means were computed after exclusion of extremes ($\bar{x} - 3\sigma < \bar{x} < x + 3\sigma$)

Excluding sealed sources, the total activity shipped for burial by respondents in the three wastestreams is in Table 3.15 If these activity totals are divided by waste volumes for each wastestream (Table 3.12), an estimated waste activity concentration is obtained. The activity concentrations for each wastestream are 64, 63, and 51 nCi/cm^3 for the medical, bioresearch, and non bioresearch wastestreams, respectively. The activity concentrations for wastes originating in the three wastestreams essentially are equal. However, if the activities of the nuclides with half lives of less than seven days are eliminated, the activity concentration of medical wastes drops to 16 nCi/cm^3.

3.8 Waste Processing and Packaging Methods

Information was elicited to determine the extent of use of several volume reduction and packaging methods for the various waste types.

3.8.1 Volume Reduction

Volume reduction techniques include the evaporation or distillation of waste liquids; the incineration of organic liquids, dry solids, and animal carcasses; and the mechanical compaction of dry solids. Twenty-two institutions used evaporation or distillation to reduce the volume of liquid wastes. All 22 institutions distilled or evaporated waste scintillation fluids. These methods were also employed by 8 institutions to reduce other organic liquids and by 5 institutions to reduce aqueous liquids. All 22 institutions were associated with the bioresearch wastestream. Sixty-one institutions of all types incinerated some radwastes, most commonly biological wastes (45 cases), 30 incinerated dry solids, 9 incinerated full scintillation vials, 4 burned empty vials, and 5 burned scintillation fluids. Forty-seven institutions used a mechanical compactor for volume reduction of dry solids. Those who compacted were asked to report their average compaction ratio. The reported ratios indicated volume reduction ranging from 4% to 90%, and the average reduction in volume was 65%. One of the institutions compacting waste was a large research hospital; all of the remainder were responses including academic institutions.

Table 3.15 Estimated Activities (mCi) Shipped for Burial by Respondents Broken Down by Wastestream*

	WASTESTREAM					
	Medical		Bioresearch		Non Bioresearch	
Nuclide	Number Shipping	Activity Subtotal	Number Shipping	Activity Subtotal	Number Shipping	Activity Subtotal
^{3}H	8	72	131	197,650	20	37,887
^{14}C	6	12	138	9,118	5	321
^{32}P	84	226	102	13,951	3	156
^{35}S	1	1	83	6,650	1	5
^{45}Ca	-	-	82	1,247	3	2
^{51}Cr	92	234	98	4,421	-	-
^{67}Ga	65	1,555	-	-	-	-
^{75}Se	58	295	5	69	-	-
^{86}Rb	-	-	34	177	-	-
^{99m}Tc	64	13,720	6	37	-	-
^{111}In	41	118	-	-	-	-
^{125}I	109	434	125	28,698	3	412
^{131}I	90	4,326	17	300	1	10
^{133}Xe	17	1,171	-	-	-	-
^{169}Yb	17	82	-	-	1	180
^{201}Tl	36	367	-	-	-	-
ACTIVITY TOTALS (in mCi)		22,613		262,318		38,973

*Major nuclides only

1370 246

3.8.2 Waste Packaging

Institutions were asked to indicate the method used (if any) for solidification or adsorbtion of liquid wastes shipped for burial. As is shown in Table 3.16, most institutions adsorbed liquid wastes, usually on vermiculite, rather than solidified them. Those who solidified wastes most often used cement or cement silicate. Vermiculite also appears to be the most common packing material for full L-S vials shipped for burial.

The shipment containers most commonly used were 55 gallon steel drums. Seventy-seven percent of the total volume shipped in 1977 was contained in these drums (including "double walled" drums). Other shipping containers frequently used, include 30 gallon steel drums. Table 3.17 displays the relative volumes of the four waste types shipped for burial in the various shipping containers listed.

3.9 Destinations of Institutional Radwastes Shipped for Burial in 1977

Those institutions that shipped waste for burial in 1977 were asked to indicate the commercial burial site where the wastes were shipped. Five sites were in at least limited operation in 1977.

Figure 3.4 shows that nearly 81% of the institutional waste volume was shipped to Barnwell, South Carolina. Most of the institutions on the eastern seaboard and some as far west as Texas, Nebraska, and Colorado shipped waste to the South Carolina site. Figure 3.5 displays the geographic distributions of the institutions shipping to each of the five sites in operation in 1977. The "other sites" referred to in Figure 3.4 are municipal landfills and privately owned burial sites which apparently accepted institutional radwastes under the provisions of 10 CFR 20.304.

Table 3.16 Solidification or Adsorbtion Methods Used for Liquid Wastes Shipped for Burial

Adsorbtion Media	Number Using	Solidification Media	Number Using
Vermiculite	98	Cement	18
Diatomaceous earth	27	Plaster of Paris	6
Adsorbent clays	10	Polymer	1
Other media	7		

Unspecified method - 9

Not solidified or adsorbed - 7

Table 3.17 Waste Volume Packaged for Shipment

Waste Type	55 Gallon Steel Drums		30 Gallon Steel Drums		Double* Drums		Cardboard or Fibreboard Boxes/Drums		Other Metal Cans or Drums		Wooden Crates		Total Percent
	N	% Vol.	N	% Vol.	N	% Vol.	N	% Vol.	N	% Vol.	N	% Vol.	
Dry Solids	133	72.1	27	8.1	3	0.1	23	18.1	11	1.4	3	0.3	100 %
L-S Vials	108	82.6	22	16.8	5	0.1	2	>0.1	3	0.4	-	-	100 %
Adsorbed or Solidified Liquid	63	59.3	25	8.1	30	25.6	5	1.8	4	5.20	-	-	100 %
Biological Wastes	82	65.1	22	16.9	4	4.0	6	12.8	4	1.2	-	-	100 %

*30 Gallon steel drum within a 55 gallon steel drum.

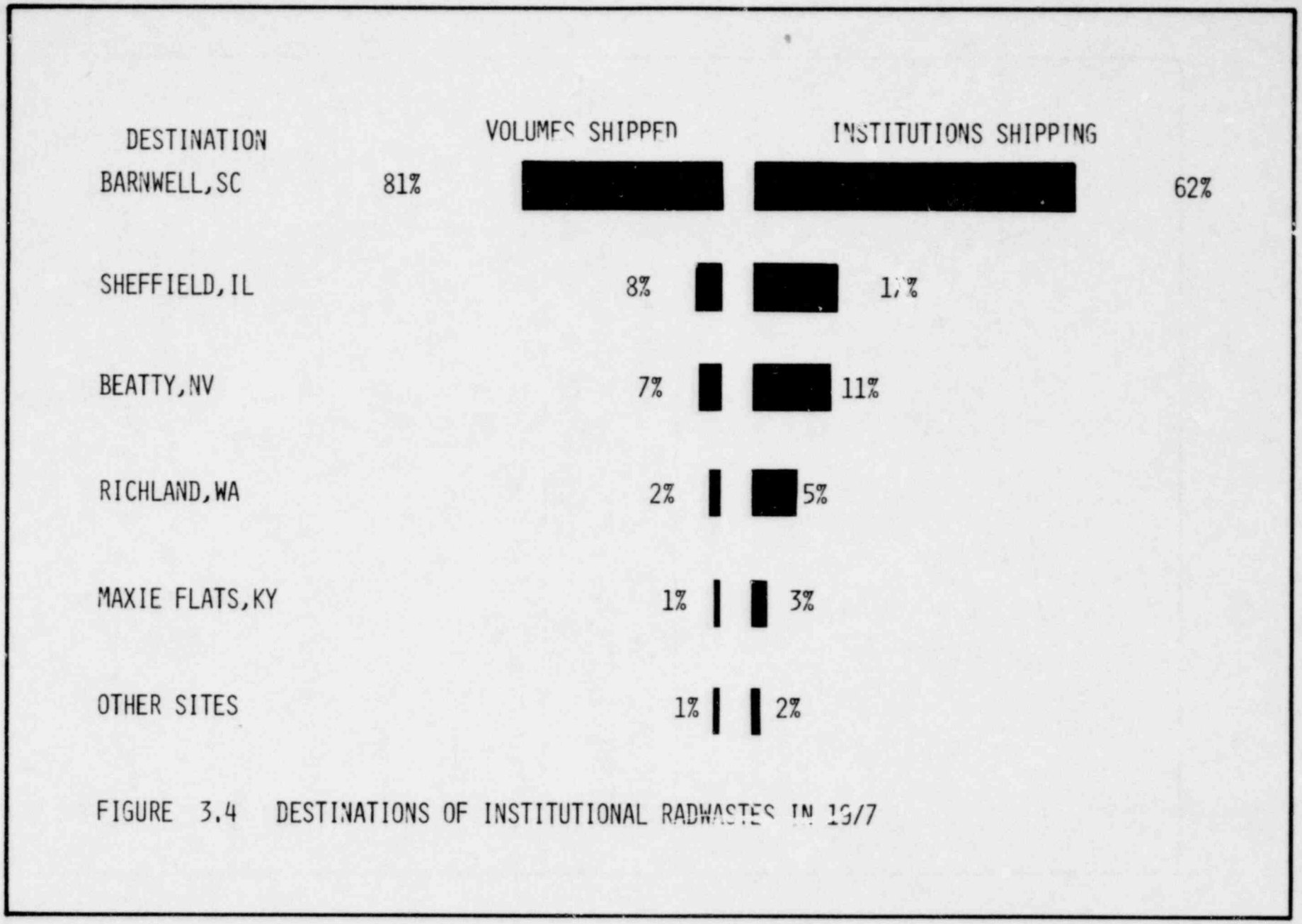


FIGURE 3.4 DESTINATIONS OF INSTITUTIONAL RADWASTES IN 1977

BURIAL SITE DESTINATION	ORIGIN (USNRC REGION / NUMBER SHIPPING)								
	I	II	III	IV	V	VI	VII	VIII	IX
BARNWELL, SC.	17	46	10	2	22	8	11	1	0
BEATTY, NV.	0	0	0	0	0	1	1	3	17
HANFORD, WA.	0	0	0	0	0	0	2	1	6
MAXEY FLATS, KY.	0	2	0	0	0	1	3	0	0
SHEFFIELD, IL.	0	0	23	8	0	0	2	0	0

FIGURE 3.5 GEOGRAPHIC ORIGINS OF RADWASTES SHIPPED TO COMMERCIAL BURIAL SITES IN OPERATION IN 1977

4. DISCUSSION

The uses of radioactive materials by members of the survey population can be grouped into three wastestream categories: medical, bioresearch, and non bioresearch. The medical wastestream results principally from the in vivo and in vitro uses of radionuclides in hospitals; essentially all of the responding hospitals contributed to the medical wastestream. Biological research using radioactive materials, primarily in tracer studies, is conducted at both medical and academic institutions. Fifty-four percent of the hospitals either conducted biological research or were affiliated with an academic institution that did. Additionally, all responding medschools, as well as 78% of the colleges performed biological research with radioactive materials. Non biological research was associated only with colleges; 113 colleges used or produced radionuclides in research in physics, engineering, geology, or other non life science fields.

4.1 The Medical Wastestream

Most of the radioactivity received by institutions in the medical wastestream is administered to patients for diagnostic or therapeutic purposes. A much smaller quantity is used in vitro, i.e.. in routine clinical assay techniques such as radioimmunoassay or other competitive binding assays used to quantitate levels of hormones, circulating proteins, or other biochemical species in the blood, urine, or other body fluids. A typical assay "kit" may contain between 1 and 80 uCi of ^{125}I (most commonly) for between 25 and 150 single determinations (see Appendix D). Each determination generally results in one or more small "counting tube", a pipetting device and a small quantity (~ 1-5 ml) of aqueous liquid as waste. Essentially, all of the responding hospitals (as well as all the schools of medicine) performed routine clinical-type assays.

The major portion of the activity in the medical wastestream is administered to patients and may appear as wastes in either of two ways. First, a variety of syringes, vials, pipettes, reagents, unused radiopharmaceuticals, etc., are

generated in preparation and administration of the radiopharmaceutical. Second, radioactivity enters the environment as it is eliminated from the patient in respiration or excreta. This latter pathway is probably the most significant route by which radioactivity reaches the environment from the medical wastestream. In a presentation to the American Nuclear Society (November 30, 1977), David E. Claridge, et al have modeled the flow of radioactivity from nuclear medicine procedures into the environment and have concluded that most of the radioactivity released from hospitals is via patient excreta to the sewer. Except for the excreta of patients receiving therapeutic doses of ^{131}I in excess of ~ 30 mCi, where urine is usually collected, this pathway can be considered as uncontrolled.

Of the radioactivity comprised by the 17 principal nuclides, 31.9 kCi were received by respondents feeding the medical wastestream (see Table 3.5). All but a small fraction of the activity can be assumed to have been received for the purpose of administration to humans for diagnosis or therapy. By a wide margin, the activity receipts are dominated by ^{99m}Tc, which constitutes 94%, followed by ^{133}Xe, ^{131}I, ^{67}Ga, ^{125}I, ^{111}In, ^{201}Tl, ^{123}I, ^{32}P and others, in descending order.

Less than two thirds (64%) of the responding hospitals shipped wastes for burial in 1977, which contained an estimated total activity of only 22.6 Ci. This averages to only 178 mCi per hospital, per year while in comparison, the average hospital receives total of 160 Ci per year. The differences between these two averages (with the exception of ^{133}Xe*) can be accounted for by physical decay of these largely short lived materials, together with the major component of the activity, which "walks out with the patient." The total medical waste volume shipped for burial in 1977 was 351.3 m^3 (12,406 ft^3) which was shipped by 127 responding hospitals, or an average per hospital equivalent to one and a quarter 55 gallon drums per year.

*These estimates can not be assumed to include the total quantity of ^{133}Xe which is disposed of, due to the short residence time of this nuclide in the body in pulmonary ventilation studies, the most common study with this nuclide. Eight-two percent of the hospitals receiving ^{133}Xe indicated that some gaseous wastes were vented to the atmosphere. No attempt was made, however, to determine the percentage of those who utilized gas traps to minimize the fraction vented to the atmosphere, although it was obvious that many did so. The average annual activity received of ^{133}Xe for all hospitals was 9.2 Ci.

Medical radwastes consist mostly of dry solids (88%), with 4% L-S vials, 2% adsorbed liquids and 6% biological wastes.

The activity contaminating medical wastes is largely short lived, judging from that shipped for burial. Seventy-five percent of the activity consists of nuclides with half lives of less than one week. The remainder is composed mostly of ^{131}I (76%), with ^{125}I* (8%), ^{75}Se (5%), ^{51}Cr (4%), ^{32}P (4%), ^{169}Yb (1%), ^{3}H (1%), and other (1%). Only tritium has a half life longer than a year and this nuclide appears to be infrequently used in medicine. It is extremely unlikely that, if any of the medical wastes buried in 1977 were assayed today, any detectable radioactivity could be found.

It is apparent that hospitals that perform biological research and use the predominantly longer lived radionuclides (54% of responding hospitals), were far more likely either to bury waste on site or to ship for burial than non research hospitals. Only 36% of the latter shipped or buried waste, while 92% of research hospitals did so.

4.2 The Bioresearch Wastestream

The use of radioactive materials in biological research in medical and academic institutions generally involves the use of biochemicals "tagged" with ^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{125}I or ^{131}I, or the use of radioactive isotopes of physiological ions or their analogues such as ^{45}Ca, ^{32}P, ^{86}Rb, ^{22}Na, ^{51}Cr, ^{59}Fe, etc. The most common nuclides used in bioresearch are, in order of use, ^{3}H, ^{14}C, ^{32}P, ^{125}I, ^{51}Cr, ^{35}S, ^{45}Ca, ^{86}Rb and ^{131}I, (see Table 3.5).

*Excluding ^{125}I brachytherapy seeds-sealed sources (see Appendix C, Table C.2).

Except for radiopharmaceutical research and development, most radioactivity used in bioresearch is comprised of relatively long lived isotopes which are more compatible with frequently complex and time consuming analytical techniques. Only 20% of the activity (of the 17 principal nuclides) received by institutions in this wastestream includes nuclides with half lives less than 7days. Of the remaining activity receipts, ^{3}H constitutes 71%; it is followed by ^{32}P (14%), ^{125}I (6%), ^{51}Cr (3%), ^{35}S (3%), and ^{14}C (2%), with the remaining 1% comprised of ^{45}Ca, ^{131}I, ^{86}Rb and ^{75}Se. It is useful to note that, unlike the nuclides which dominate the medical wastestream, most of this activity consists of pure beta emitters.

The activity shipped for burial is also dominated by tritium, constituting 75% of the activity of the principal nuclides. Essentially all the activity shipped by bioresearch sources is composed of nuclides with half lives longer than one week. Besides tritium, the other, abundant nuclides in bioresearch wastes are ^{125}I (11%), ^{32}P (5%), ^{14}C (3%), ^{35}S (3%), ^{51}Cr (2%), and others (1%).

The total waste volume attributed to bioresearch responses was 4,140 m^3 (146,300 ft^3). This waste volume includes dry solids, liquid scintillation vials, adsorbed liquids and biological wastes, the largest component of which (48%) is liquid scintillation vials. Additionally, the data suggests that at least part of the dry solid wastes include emptly scintillation vials; 75% of the 135 bioresearch institutions who disposed of empty L-S vials shipped for burial. The radioactivity content of empty L-S vials is debatable since another 29% simply threw them in the trash. It was not possible, however, to estimate the fraction of dry solid wastes which were empty L-S vials.

Perhaps the most significant component of bioresearch wastes, and perhaps institutional wastes in general, L-S fluids constitute an estimated 50% of adsorbed liquids in addition to that shipped within vials (3). Apparently, the most common disposal method for L-S fluids is by shipment for burial; 70% of the 155 bioresearch respondents shipped L-S fluids as adsorbed or solidified wastes. The significance of this waste component may be from the chemical rather than the radiological aspect, for activity concentrations are typically quite low (6).

Because L-S fluids appear to be the major identifiable waste liquid, a review from the literature of the major constituents of these counting solutions are in order.

Undoubtedly, the bulk of the liquid volume is the solvent. The major solvents used in scintillation fluids are toluene xylene and 1,4 dioxane, although toluene is the most common (7).

A variety of additives will appear in waste L-S fluids, which are added by manufacturers to increase the solubility of certain samples. Because a large portion of radiolabeled chemicals are soluble only in aqueous solutions, various agents are added to increase the miscibility of aqueous samples in toluene or xylene (dioxane is miscible with water). Triton X-100 (a mixture of polyethoxy alkylphenols), ethoxyethanol, methanol and ethanol are commonly used for this purpose. Labeled tissues or cellular materials are often counted after dissolution in a solubleizer such as perchloric acid, Hyamine hydroxide (p(diisobutylcresoxyethoxyethyl) dimethylbenzyl) ammonium hydroxide) or such commercial solubleizers as Protosol, NCS, Soluene and Bio Solv, all high molecular weight quarternary ammonium bases (7). Alternatively, ^{14}C or tritium labeled tissues or other biological materials are oxidized in a sample oxidizer to $^{14}CO_2$ and HTO, respectively. In such cases, additives such as Hyamine hydroxide, ethanolamine phenethylamine or the commercial tissue solubleizers are often added to increase the absorbency of $^{14}CO_2$ in the counting solution (7).

In addition to additives used to increase sample solubility in toluene, the counting solutions contain a variety of scintillators. Primary scintillators such as PPO (2,5-Diphenyloxazole), PBD (2 Phenyl-5(4-biphenylyl)-1,3,4-Oxadiazole) or butyl PBD (2-(4-t-Butylphenyl)-5-4-biphenylyl) 1,3,4-oxadiazole) and naphthalene are typical in concentrations of 4 - 9 g/l (in toluene) (7). Secondary scintillators such as POPOP, (1,4-Bis-2-(5 phenyloxazolyl) benzene), DMPOPOP (1,4-Bis-2-(4 methyl-5-phenyloxazolyl) benzene, bis MSB (p-Bis(0 - methylstyryl) benzene or PBBO (2-(4-Biphenylyl)-6-phenylbenzoxazole) are present in typical concentrations of approximately 1 g/liter (7). The remaining components of waste scintillation fluids and perhaps of other waste liquids is the labeled biochemical which is being quantitated, often in some biological media such as blood, serum, tissue fluids, tissue homogenates, etc.

The total numbers of combined receipts for tritium, ^{14}C and ^{125}I are listed in Table D.I. The most common nuclide is ^{3}H totalling 86 Ci in 4,084 receipts. Approximately half of the tritium activity (41 Ci) was received in the form of tritiated water, sodium and potassium borohydrides, acetic anhydride and acetic acid, which are used in tritium labeling. The remaining ^{3}H receipts averaged 11.2 mCi per receipt and ranged from one microcurie to a few curies. The labeled tritiated compounds include nucleic acids and derivatives, amino acids, fatty acids, hormones, steroids, drugs, toxins, carcinogens, etc. Tritiated thymidine and methyl thymidine are the most common labeled species received by the two institutions, totaling 529 receipts and 7.18 Ci in ^{3}H. If a specific activity of 50 Ci/mmole is assumed (8), total activity of ^{3}H labeled thymidine represents a mass of only 34 mg. Thus, the relative quantity of labeled chemical species present in typical bioresearch wastes can be expected to be a very small fraction of the total liquid volume. This volume would consist, for the most part, of the solvent containing the radiochemical.

Taking a further example, assume that the tritiated thymidine is being counted in 10 ml of liquid scintillation cocktail. If it is assumed that the 10 ml vial contains an average activity concentration of tritium (6) of 7×10^{-3} uCi/ml, the total mass of thymidine in the vial is .34 ng - an insignificantly small fraction of the approximately 10 g of liquid in the vial.

It is apparent that the labeled compounds that appear in bioresearch waste are extremely varied and complex. Some compounds are quite toxic and others are being studied for their carcinogenicity. It is, however, unlikely unless the compound is of very low specific activity or contains considerable quantity of carrier, that any of the labeled compounds appearing in wastes would be detectable by other than radiometric methods. This is not to suggest that measureable quantities of hazardous materials are not being shipped for burial by biological research institutions, but that radionuclide receipt data suggest that the solvent is likely to be far more significant than the labeled solute.*

*Radiation safety officers at 6 bioresearch institutions were informally asked if wastes from carcinogen research laboratories are shipped as radwaste. Five of the six answered affirmatively. One pointed out that all of the carcinogen laboratories at his institution also used radiolabeled compounds and such wastes were not segregated. No attempt was made to quantitate this aspect of institutional wastes.

Another form of liquid "radwastes" generated in bioresearch are solutions of uranium salts used for the staining of biological specimens for electron microscopy. Undoubtedly, electron microscopy is conducted at most of the major bioresearch centers. It is likely that most use Uranyl salts to some extend, although it was not determined how many consider solutions of these salts as radwaste. At least a few institutions did so, however this aspect of liquid radwastes was not quantitated.

4.3 The Non Bioresearch Wastestream

Even excluding neutron generator targets, aproximately half of the activity shipped as sealed sources as attributed to this wastestream. The kinds of sealed sources shipped included gamma irradiator sources, radionuclide neutron sources and sources from analytical instruments such as density moisture and level guages (see Appendix C, Table C.2 for a listing of sealed sources shipped for burial).

Several of the sealed sources shipped comprised a significant waste volume: one 8.2 Ci ^{137}Cs density guage was shipped in 1.4 m^3; and several others of curie magnitude were shipped in shielded containers of unspecified volumes.

5. TRENDS AND CONCLUSIONS

The study population of large medical and academic institutions shipped an estimated total waste volume of approximately 7,771 m^3 (274,400 ft^3)* for commercial shallow land burial in 1977. This volume constituted approximately 11% of the total volume shipped for burial during the study year, including all low level waste sources **. The fraction of institutional waste shipped in 1975 was also 11% of the total volume for that year, suggesting that growth rates are quite similar.

Data was obtained to determine the rate of growth in wastes shipped by the population. In the current survey, waste volume totals for the years 1976 and 1977 were obtained, while data for the years 1972 to 1975 were taken from the previous survey (3). These latter data were revised to conform to the population breakdown and criteria for the 1977 survey. (The breakdown of the 1975 population, as currently revised, is shown in Table 2.3). The waste volume estimates are listed in Table 5.1 and plotted in Figure 5.1. As is shown in Figure 5.1 the growth rates are quite linear ($r^2 = .96$). The equation of the fitted line is:

$$V = mx + b$$

where V = volume in m^3

$m = 639.74$

x = (year - 1900)

$b = -41{,}621.63$

*Computed after inclusion of uncoded values (see Section 2.)

**W.F. Holcomb, Division of Technical Assessments, U.S. EPA, Washington, D.C. Personal communication to L.R. Cooley, University of Maryland at Baltimore, January 9, 1979.

Table 5.1 Estimated Total Waste Volume Shipped 1972 - 1977

Year	Total Estimated Volume
1972	4,627 m^3
1973	5,148 m^3
1974	5,265 m^3
1975	6,448 m^3
1976	6,977 m^3
1977	7,771 m^3

1370 260

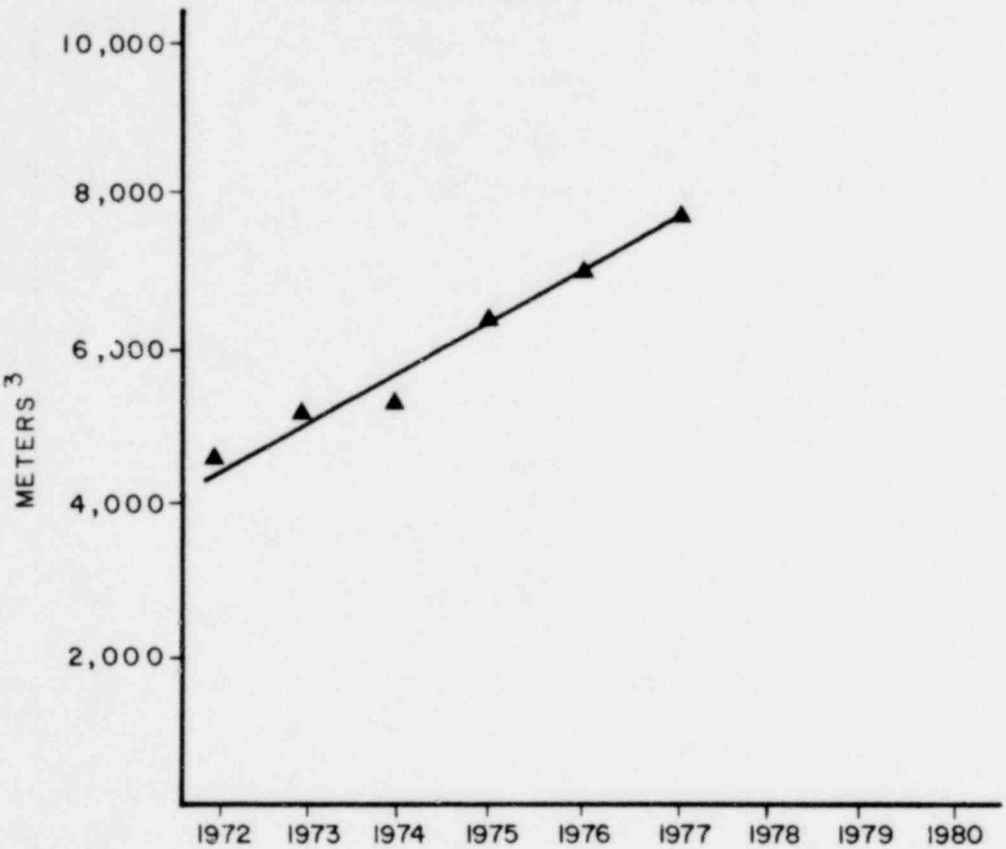


FIGURE 5.1 TOTAL INSTITUTIONAL WASTE VOLUME SHIPPED FOR BURIAL, 1972 - 1977

The 1975 data base was not constructed in such a way to allow a wastestream analysis within the time constraints of this study. Therefore, it would be difficult to show the growth trends in the medical, bioresearch and non bioresearch components of the population. Nevertheless, some indication of the increase in waste volume shipped by bioresearch institutions can be made by looking at the average waste volume shipped by institutions which include medschools; keeping in mind that many of these institutions include other waste producing components, and that medschools do not conduct all the bioresearch in the population.

Figure 5.2 shows the fitted trendline for average volume shipped per institution for those including medschools (r^2 = .988). The equation of the line is:

$$\bar{V}_m = mx + b$$

where $\bar{V}_m$ = average volume shipped by institutions with medschools

x = (year - 1900)

m = 169.14

b = - 11,289

Also shown is the line fitted to average volumes for all institutions in the population (r^2=.976),with one extreme value excluded. The equation of this line is:

$$\bar{V}_t = mx + b$$

$\bar{V}_t$ = average volume shipped by the total population

x = (year - 1900)

m = 31.92

b =-1,612.9

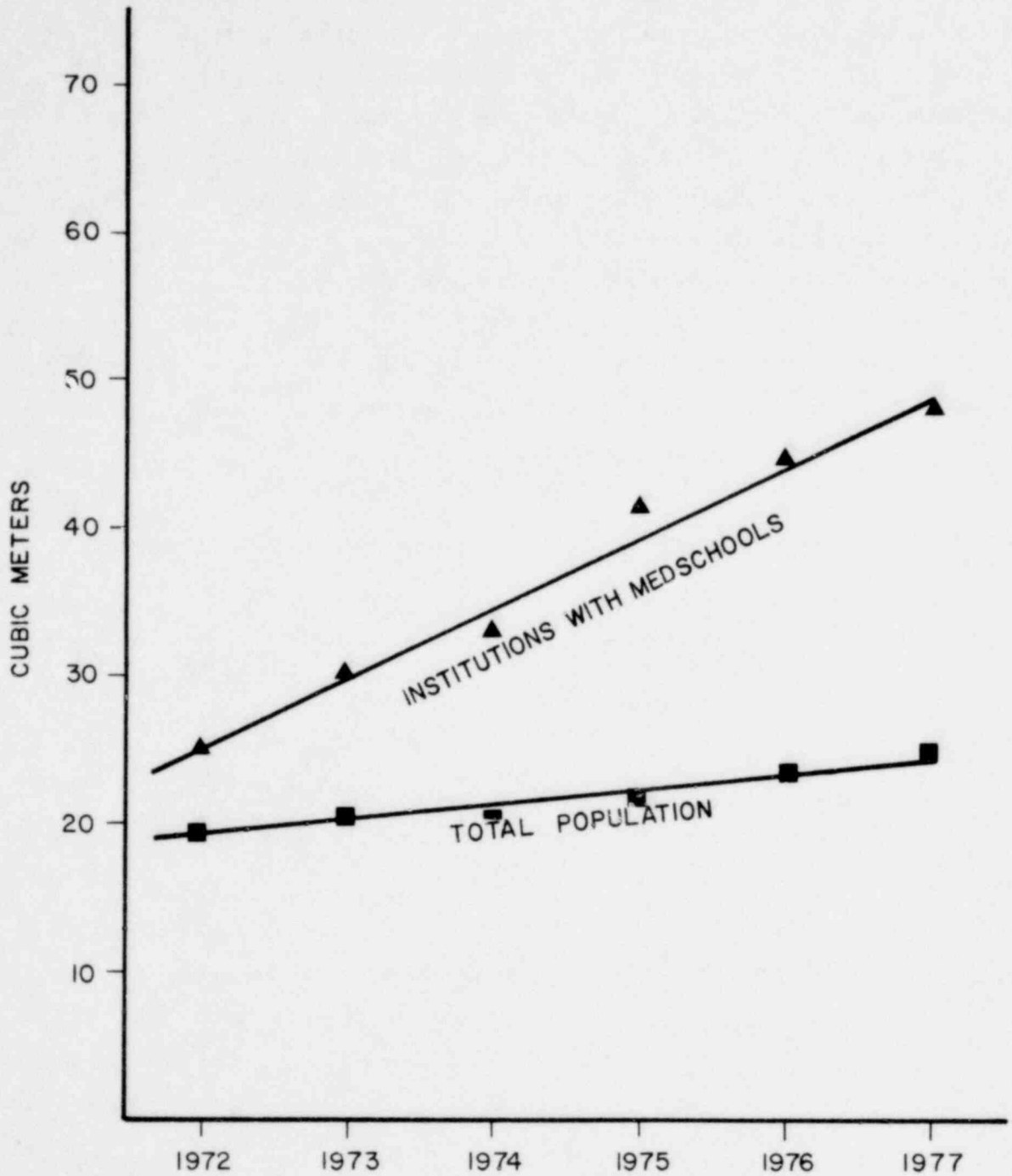


FIGURE 5.2 COMPARISON OF THE AVERAGE PER CAPITA WASTE VOLUME FOR INSTITUTIONS WITH MEDSCHOOLS AND THE TOTAL POPULATION 1972 - 1977

1370 263

These data suggest that the bioresearch wastestream is increasing faster than the population as a whole. Also, because most (79%) of the waste volume appears to be due to bioresearch, it is likely that the greater part of the volume increase is due to this wastestream.

Figure 5.3 shows the breakdown in total waste volumes by physical forms for the sampled years 1975 and 1977. The overall waste volume showed a 21% increase. The largest increase is attributed to the growth in scintillation vial wastes -a 60% increase in volume since 1975. Again, all indicators associate the bulk of scintillation fluid waste to bioresearch. Also shown in Figure 5.3 is an inexplicable decrease in the estimated volume of adsorbed liquids, perhaps resulting from increased restrictions on liquids at the burial sites.

An estimation of the volume of L-S fluids in vials shipped by the population can be made by assuming 3,000 vials per 55 gallon drum and 10 ml of L-S fluid per vial.* This results in a total fluid volume of 431,000 liters shipped in vials. Data from the previous survey (3) suggests that approximately 50% of the adsorbed liquids are L-S fluids. Assuming a ratio of two-to-one of adsorbing or solidifying media to liquid, half of the 783 m^3 of adsorbed liquids results in an additional volume of L-S fluids of 132,000 liters, for a total volume of 563,000 liters of L-S fluids.

Using the same assumptions, the 1975 L-S fluid volume was recomputed to obtain a total fluid volume of 506,000 liters representing a net increase of about 11%. It appears that the increase in numbers of full vials shipped is partially offset by the decrease in adsorbed liquids. Perhaps this may be explained by a relative increase in the use of the sanitary sewer or volume reduction techniques in 1977; 34% of those disposing of L-S fluids dumped at least some into the sewer while 10% used evaporation or distillation for L-S fluids. Unfortunately, because these aspects were not studied in 1975, no comparisons can be made.

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*J.W. Staiger and R.O. Wollan, University of Minnesota, Minneapolis, MN, "University of Minnesota Evaluation of Liquid Scintillation Vial Disposal." Personal communication to R. Andersen, University of Maryland at Baltimore, September 1977.

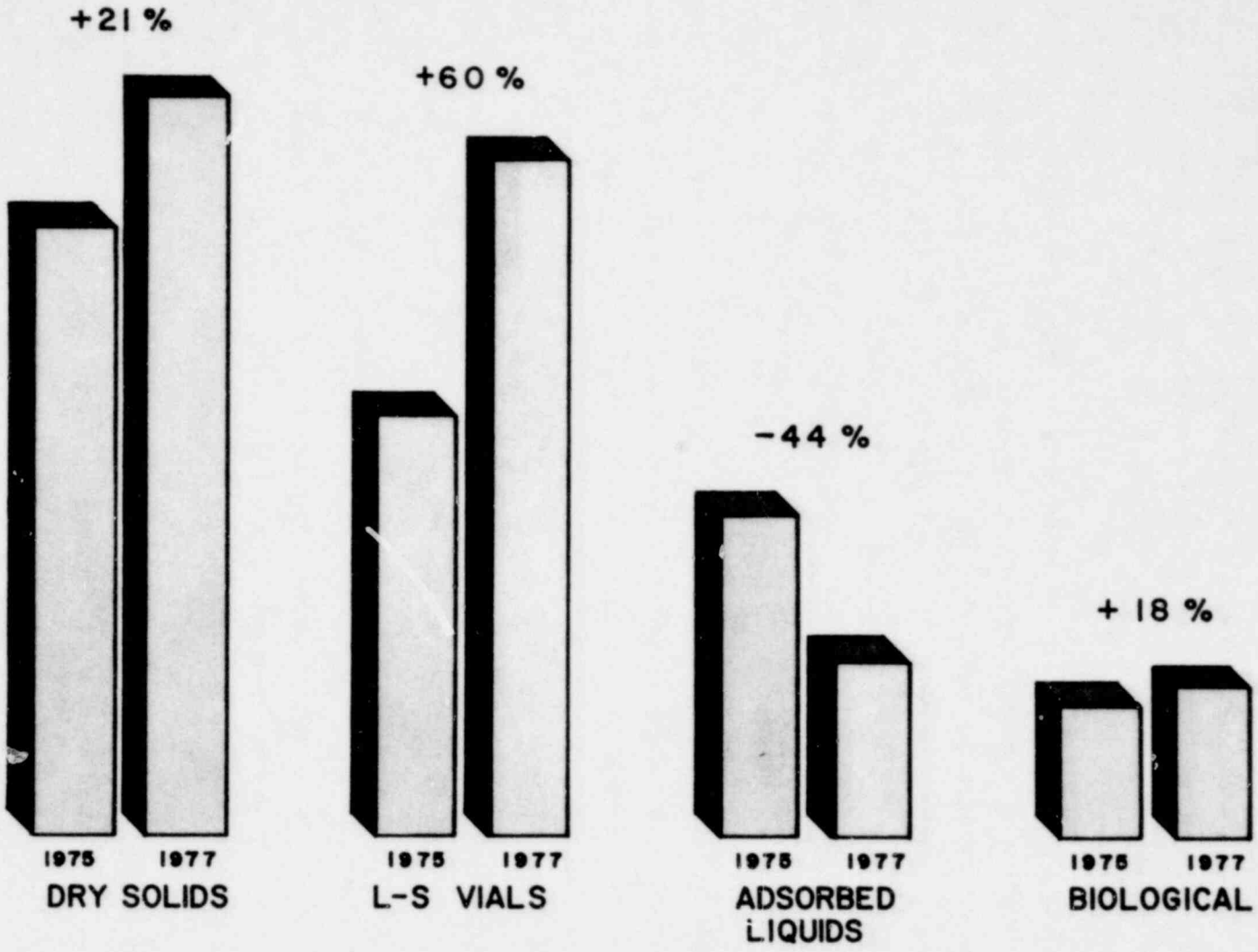

FIGURE 5.3 COMPARISON IN WASTE FORMS SHIPPED FOR BURIAL, 1975 – 1977

The total activity shipped for burial in 1977 by the institutional survey population and the overlapping, but distinct, accelerator population is estimated to total 1,688 Ci.

The 1977 survey was designed to segregate sealed* from unsealed sources shipped for burial, in order to distinguish between relatively dispersible and non dispersible activity. This allowed a more realistic estimate of average waste activity concentrations. The sealed source portion of the estimated activity total for 1977 is shown in Table 5.2.

The overwhelming majority (95%) of this activity is tritium, most of which is in the form of neutron generator targets (see Appendix B). Most of the remaining 29 Ci of activity consists of energetic gamma emitters ^{137}Cs, ^{226}Ra, ^{192}Ir, ^{60}Co and others which, in all likelihood, were shipped with some biological shielding. Overall, the sealed sources can be considered to occupy a relatively small portion of the total waste volume

The data from the 1975 survey was not separated into sealed and unsealed sources. Nevertheless, a revised estimate of the total activity shipped by the institutional population and the accelerator population can be made. Assuming that the accelerator population produced targets at the same rate in 1975 as determined in 1977, the total activity shipped for burial in 1975 by the two overlapping populations is estimated to be 1,628 Ci. A comparison of the volume and activity data for the two years is displayed in Figure 5.4. Both activity values include a single extreme value of about 400 Ci of ^{3}H.

Excluding these extreme values and the activity due to tritium accelerator targets, the total activities shipped for the years 1975 and 1977 are 667 and 747 Ci, respectively, which represents a net increase in activity shipped of 12%. The waste volume shipped for burial, in comparison, showed an increase of nearly 21% over the same period. This indicates that, on the average, waste activity concentrations are decreasing.

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*See definition of "sealed source" in glossary.

Table 5.2 Estimated Total Activity (Ci) of Major Nuclides Shipped in Sealed Source Form

	Total Activity (Ci) of Nuclide	Percent of Total
^{3}H	552.432	95.0%
^{137}Cs	19.337	3.3%
^{226}Ra	5.734	1.0%
^{192}Ir	2.084	0.4%
^{125}I	0.846	0.1%
^{60}Co	0.443	0.1%
Others	0.908	0.2%
TOTAL	581.784	100.0%

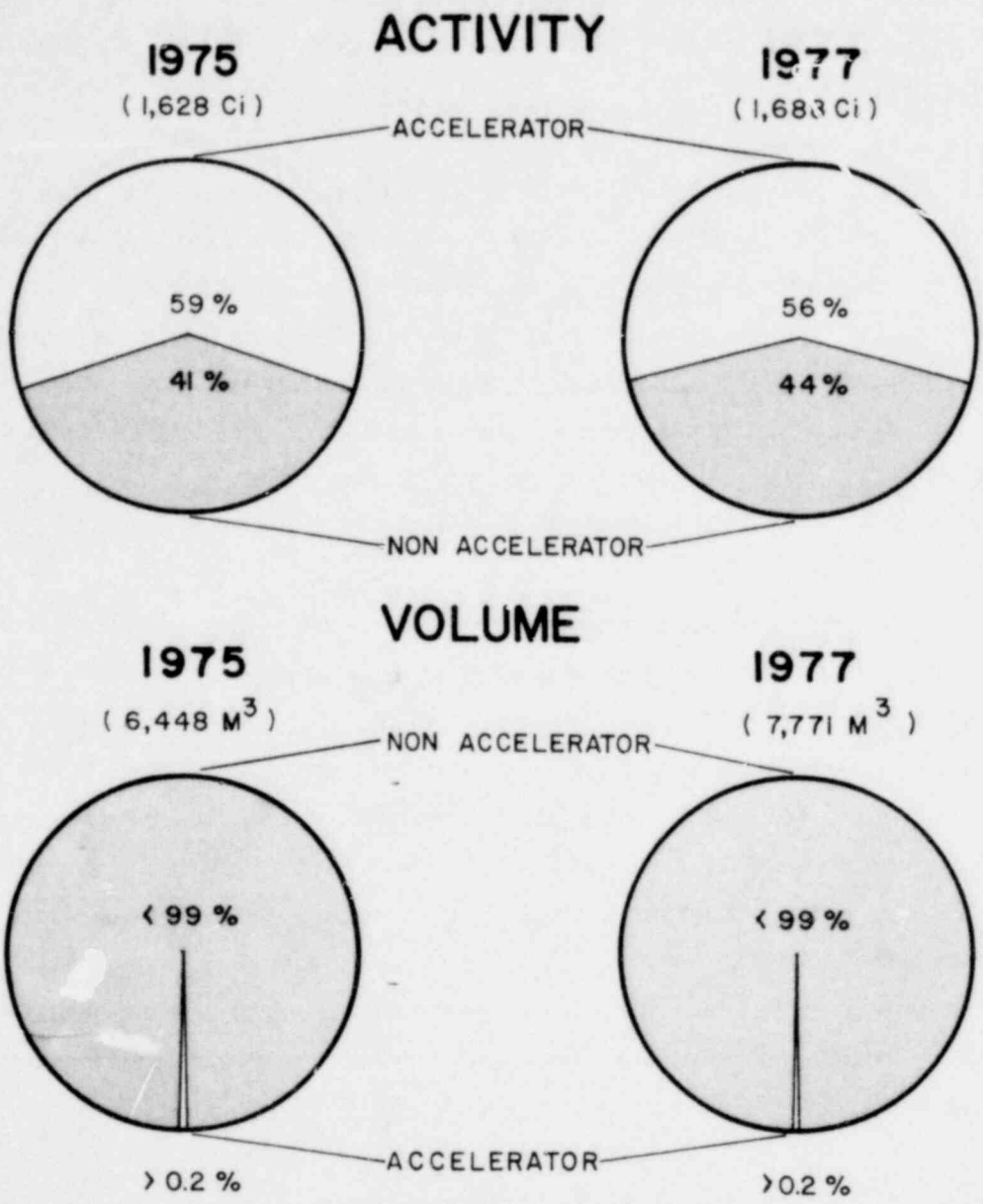

FIGURE 5.4 COMPARISON OF TOTAL INSTITUTIONAL WASTE VOLUME AND ACTIVITY, INCLUDING ACCELERATOR WASTE 1975 - 1977

Of the long lived species contaminating institutional radwaste, ^{3}H is by far the most abundant. An estimated 1,365 Ci of ^{3}H, 81% of the total activity, was shipped by the population in 1977, while a similar total, 1,370 Ci was shipped in 1975.

The total quantity of radioactivity shipped for burial as low level wastes in the United States in 1978 was 886,000 Ci (12). Assuming a similar total activity for 1977, the institutional population shipped 11% of the volume, but only 0.2% of the activity (including accelerator sources). The relative quantity of radioactivity shipped by large institutional sources is further put into perspective when sealed sources and the single extreme tritium value is excluded. The activity from large institutional sources then constitutes an insignificant .08% of the total activity shipped.

Medical wastes are estimated to comprise 6.7% of the volume shipped by the population, or 521 m^3 and are contaminated with an equivalent fraction (7%) of the activity. However, 75% of this activity is of nuclides with half lives less than 7 days (largely ^{99m}Tc) and only 2% with $t_{½}$'s greater than 90 days. After several months, only the latter component is significant, whereupon the average activity concentration of medical wastes would be less than 10^{-9} $\mu Ci/cm^3$ indistinguishable from background. Hence, the higher percentage (64%) of non research hospitals which do not ship waste for burial. Several of the hospitals that did ship, volunteered that they did so to appease the licensing agency or the local municipality, although they realized that the wastes were only nominally radioactive by the time they were actually shipped.

Bioresearch wastes, which comprise the largest fraction of the waste volume shipped for burial (79%), were contaminated with longer lived nuclear species; essentially all with $t_{½}$'s greater than one week. Eighty-two percent was of nuclides with $t_{½}$'s greater than 90 days, the most abundant nuclide being tritium. The mean activity concentration of bioreseach wastes, considering only the component with $t_{½}$'s< 90 days, is 0.035 $\mu Ci/cm^3$.

Non bioresearch wastes were considerably more variable and less well characterized by the wastestream analysis. An estimated 14.3% of the waste volume or 1,111 m^3 was attributed to non bioresearch. This waste component includes wastes produced as a result of particle accelerator operation which was estimated to comprise a total national volume of ~12 m^3.

Another component of non bioresearch wastes is that resulting from the operation of a research fission reactor, or subcritical assembly. Although 29 responding institutions possessed one or more of these facilities, no attempt was made to characterize or quantitate this waste fraction.

Of the sealed sources shipped, 96% of the activity was attributable to non bioresearch. Besides ^3H targets, these included irradiator and calibration sources, Mossbauer sources, Ra-Be and Am-Be neutron sources, level guages, moisture guages, etc.

It appears that large medical and academic institutions alone are using up 11% of the nation's scarce low level burial site capacity, not including the contributions of medical and academic sources not meeting the survey criteria. Whether or not the major part of these wastes can be considered to be significantly radioactive, is debatable. Indeed, some of the wastes from these sources are unarguably radioactive, particularly the sealed sources (or materials considered as such) for this report; however, the volume occupied by most of the activity is insignificant. Certainly, the vast majority of the wastes from purely medical sources constitute no long term radiological hazard. Most of this activity would be undectable if assayed prior to burial. The most significant fraction of the waste volume derives from those many medical and academic institutions which use radioactivity in biological research. These institutions use primarily the biologically compatible nuclides such as ^3H, ^{14}C, ^{32}P and ^{125}I, as an essential research tool for the investigation of biochemical pathways in plants, animals and humans. These techniques are by definition, dilution techniques, which tend to produce large volumes of very low activity radwastes. Bioresearch sources appear to appear to be shipping more radwaste per institution every year, although evidence suggests

that the activity concentrations of these wastes are decreasing. This is corroborated by the proliferation of pre labeled biochemical species available to the bioresearch investigator from commercial vendors, precluding the necessity of purchases of large quantities of radioactivity to produce a small amount of labeled material. The use of prelabeled materials generally results in lower average activity concentrations in radwastes.

Many institutions polled in the survey are actively seeking alternative disposal methods for their burgeoning radwaste problems. These institutions, like our own, are faced with conflicting federal guidelines which require the consideration of a drum of waste materials as radioactive when in many cases the radiolabeled material entered the institution as an "exempt" quantity. The problem of liquid scintillation wastes is particulary thorny. Further restrictions on liquid scintillation wastes could render the use of an extremely valuable research tool, prohibitively expensive. Already waste disposal costs constitute a significant fraction of the ballooning costs experienced by biological researchers (who are federally sponsored for the most part). The consideration of more restrictive disposal criteria (i.e. better solidification media, double packing of animal carcasses, etc.) serve only to drive up disposal costs, ultimately borne by the taxpayer, with no perceptible impact on the public health.

The data in this report suggest that far less restrictive disposal alternatives are in order for medical and academic radwastes. Certainly the occasional sealed source or vial of tritiated water or other concentrated long lived waste material should be shipped for burial, but these constitute a very small part of the volume. Little, if any of purely medical wastes should be shipped. After a suitable period of decay, such wastes could be relegated to the municipal refuse system (as is frequently done). Biological research wastes, the major part of the problem, require the most attention. Perhaps in certain areas the bulk of the waste liquids could be poured into the sewer system. The use of regional or institutional incineration also shows great promise. Consideration of disposal alternatives for bioresearch wastes should be treated as a unique problem with particular attention to the economic effects on the research that generated the waste. The hazards of such wastes should be considered uniquely, with all their chemical, biological and

radiological components, but separate from the very different problems of wastes from fuel cycle sources.

6. SUMMARY

A followup study to the 1975 institutional radioactive wastes study was conducted for calendar 1977 focusing on the following topics: population size and character; waste volumes, characteristics, activities and processing methods; and radioactive wastes resulting from the use of particle accelerators.

Data was obtained primarily by means of a mailed survey questionnaire. Other sources of data include personal contact with individuals in the participating institutional radiation protection programs, regulatory agencies, commercial waste processing companies, and current literature.

6.1 Changes in the Study Population

The study population was independently identified using the same criteria as in the 1975 survey. Some members were deleted and others added resulting in a net population increase of 2.2%, with no significant alteration in the types of institutions represented. There was, however, an apparent increase in the sharing and consolidation of radiation control functions among institutions.

6.2 Waste Production in the Study Population

Data regarding the uses of radioactivity together with the types and quantities of nuclides received by population members in the study year, were used to categorize the population members into wastestreams. The three resulting wastestreams were the medical, bioresearch and non bioresearch.

The medical wastestream results from the use of radioactivity in medicine for diagnostic and therapeutic purposes. Most of the activity used in this stream is administered to patients and is subject to essentially uncontrolled release,

primarily via patient excreta to the sewer system. The wastes produced via controlled methods generally consist of a variety of dry solids and relatively small quantities of aqueous liquids. Most of the radioactivity used in this stream consists of nuclides with $t_{1/2}$'s less than one week, predominantly ^{99m}Tc. Approximately 62% of the hospitals shipped radwaste for burial in 1977, totalling an estimated volume of 521 m^3 of medical wastes (excluding the bioresearch component from hospitals performing research). Medical wastes shipped for burial appear to be the least significant component of institutional radwastes comprising less than 7% of the total volume and with average activity concentrations of $< 10^{-9}$ $\mu Ci/cm^9$ after exclusion of activity of nuclides with $t_{1/2}$'s <90 days.

The largest component of institutional radwastes is that produced by institutions conducting biological research with radioactive materials. Sixty-three percent of the institutions in the survey performed bioresearch, including 55% of the hospitals, all of the medschools and 73% of the colleges in the study. These institutions produced an estimated 6,139 m^3 of bioresearch wastes or 79% of the total institutional volume shipped in 1977. The most common nuclides associated with bioresearch wastes are ^3H, ^{125}I, ^{32}P, ^{14}C, ^{35}S, and ^{51}Cr of which ^3H is dominant. Considering only nuclides with half lives greater than 90 days, average activity concentrations in bioresearch wastes are estimated to be ~ .035 $\mu Ci/cm^3$. Data from two large bioresearch institutions suggests that most of the activity of the common nuclides ^3H, ^{125}I and ^{14}C are used in the form of labeled biochemicals or labeling reagents used to produce radiolabeled biochemicals. The quantitation of the beta emitting nuclides (^3H, ^{14}C, ^{32}P, ^{35}S) is for the most part, by liquid scintillation counting, which results in a considerable volume of waste liquid scintillation vials and fluids. An estimated 48% of the bioresearch wastes was comprised of liquid scintillation vials, a waste component which has seen a 60% growth in volume since 1975. The remaining components of bioresearch wastes are dry solids (33%), biological wastes - mostly carcasses of research animals (10%), and adsorbed liquids (9%).

1370 274

The rate of growth in bioresearch wastes appears to be faster than that of the total institutional population as evidenced by the growth in the average waste volume shipped per institution by medschools and other institutions including medschools (see Figure 5.2). These data also suggest that the bulk of the growth rate in institutional waste volume is due to the bioresearch component.

Institutional radwastes not attributable to medical or biological research uses were classified as non bioresearch wastes. The sources of these radwastes, all of which were colleges, shipped an estimated 1,111 m^3 of radwastes for burial in 1977. Wastes included in this category include those resulting from the operation of a research nuclear reactor or particle accelerator and those resulting from the use of radioactive materials in physics, engineering, geology and other non life sciences. Radwastes in this category were least well categorized but included most of the sealed source activity and much of the activity of the less common nuclides (see Appendix C) shipped for burial by the survey population.

6.3 Accelerator Radwastes

In a subsidiary effort, the radwastes produced by particle accelerator facilities at all medical and academic institutions in the United States was investigated. One hundred and thirty-seven institutions possessed a total of 185 particle accelerators (this population was restricted predominantly to those capable of accelerating positive charged particles). These facilities included Cockroft-Walton neutron generators, cyclotrons, Van de Graaff generators and others. The total waste volume estimated as shipped for burial from these facilities in 1977 was minimal - 11.8 m^3. The most significant aspect of accelerator radwastes is the spent tritium targets from neutron generators. These totalled an estimated 541 Ci of activity in some 300 targets shipped for burial in the study year. An additional ~ 400 Ci of ^3H was shipped for burial by a single atypical Van de Graaff facility using a gaseous ^3H target in neutron shielding studies.

6.4 Overview

These surveys have shown that a relatively static population of large medical and academic institutions produce a significant fraction of the total low level waste volume shipped for shallow land burial in this country.

Moreover, the rate of growth in waste volume shipped by the population is at present matching that of the waste producing population as a whole. This waste volume increase is a per capita increase, very little can be attributed to a growth in the number of waste producing institutions. Evidence suggests that the most active waste producing segment of the biological research laboratories account for the bulk of the waste volume increase. The increase in waste volume was accompanied by a slower increase in total activity shipped, suggesting that average waste activity concentrations are decreasing.

One-third of the estimated total activity shipped by the population in 1977 was in the form of sealed sources, and an additional quarter came from a single respondent. Thus, 56% of the activity shipped by the population contaminated a negligable fraction of the waste volume. The 747 Ci which contaminated most of the waste volume represents less than a tenth of one percent of the total activity shipped by all low level radwaste sources (12).

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(2) License Data Sources: 1) Agreement State Licensee lists (1977) obtained from individual state departments of radiological health and, 2) NRC Non Agreement State licensee list (1977) obtained from the Public Document Room of the NRC.

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(4) "The Stability of Labeled Organic Compounds," reprinted by permission of The Radiochemical Center, Amersham, Buck, England, in: Handbook of Radioactive Nuclides, Yen Wang, editor, The Chemical Rubber Company, Cleveland, Ohio, 1969. Available at public technical libraries.

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APPENDIX A

INSTITUTIONAL RADIOACTIVE WASTE SURVEY 1977

UNIVERSITY OF MARYLAND
Radiation Safety Office
Baltimore, Maryland 21201
(301) 528-6281

GENERAL INSTRUCTIONS

1. The information given in this survey will be keypunched directly from this form. Please **print clearly in ink.** Mark the appropriate boxes with an "X".
2. If possible, all quantitative data should be taken directly from receipt and shipment records. If this is not practical, please estimate answers as accurately as possible.
3. Please explain or specify answers (where requested) as completely as possible. If additional space is needed, please use the "Additional Comments" section on the last page of this questionnaire.
4. Disregard the coding numbers in parentheses and next to the answer blocks. They are for keypunching purposes only.
5. When you have completed this questionnaire, please return it in the enclosed, stamped, self-addressed envelope.

THANK YOU VERY MUCH FOR YOUR COOPERATION

1370 280

UNIVERSITY OF MARYLAND
660 W. REDWOOD STREET
BALTIMORE, MARYLAND 21201

INSTITUTIONAL RADIOACTIVE WASTE STUDY
RADIATION SAFETY OFFICE
(301) 528-6281, 3548

Dear Radiation Safety Officer:

Many medical and academic institutions today are faced with the problem of disposal of radioactive wastes generated in clinical and research activities. This problem is further complicated by rapidly rising disposal costs and increasingly restrictive regulations. It has long been felt by many individuals in the institutional community that their radioactive wastes differ significantly from those produced in the nuclear fuel cycle and therefore different disposal modalities are needed. Data gathered in a recently completed study of institutional radioactive wastes conducted by the University of Maryland under contract to the Nuclear Regulatory Commission thus far support this hypothesis.

We have been asked to conduct a followup survey to further corroborate these data, to validate growth trends, and to define more specifically characteristics of the wastes and the population that produced them. It is our belief that these studies will ultimately result in more specific regulatory guidelines, and less costly disposal alternatives.

A primary objective of this study is to determine volumes and characteristics of institutional wastes buried in the commercial shallow land burial sites. We also are interested in determining what disposal alternatives and waste processing methods are being used by members of the institutional population. If you have any comments regarding disposal alternatives, please include them on the last page of the survey questionnaire.

In response to helpful comments of several respondents of the previous study, we have simplified the questionnaire somewhat. We hope that you will be encouraged to complete it and return it to us in the enclosed envelope as soon as it is conveniently possible.

As with the 1975 study, every precaution will be taken to maintain the confidentiality of any data you supply. If you have any questions regarding the study, please call us at (301) 528-6281, leave your number and a convenient time to reach you, and we will return your call on our WATS line.

If you elect not to participate, please return the blank questionnaire in the envelope provided to preclude the expense of contacting you further.

We greatly appreciate your cooperation in this project.

Sincerely,

Thomas J. Beck
Project Director

1370 281

NOTE

All data furnished to the University of Maryland in this survey is **Strictly Confidential.**

After initial verification, the data will be entered into the computer and referenced by a randomly assigned code number. This will be done to protect the anonymity of the respondents.

☐ We have a limited number of copies of the 1975 institutional radioactive waste study which we will supply to survey participants. If you would like a copy, please check the box to the left.

Please note any address corrections below:

NAME: _____

TITLE: _____

INSTITUTION: _____

ADDRESS: _____
(number & street)

_____
City State Zip Code

TELEPHONE: (_____)_____
area code telephone

1370 282

I. GENERAL INSTITUTIONAL INFORMATION

A. Check **each category** below which applies to your institution:

- ☐ Hospital
- ☐ Nuclear Pharmacy
- ☐ School of Medicine
- ☐ School of Dentistry
- ☐ School of Pharmacy
- ☐ School of Veterinary Medicine
- ☐ School of Agriculture
- ☐ Undergraduate School(s)
- ☐ Graduate School(s)
- ☐ Department of Nuclear Engineering

B. Check **each use** of radioactive materials performed at your institution in 1977 (excluding the use of sealed sources*):

- ☐ Use in humans (please specify):
  - ☐ Diagnostic
  - ☐ Therapeutic
  - ☐ Research
- ☐ Biological or medical research (other than human use)
- ☐ Routine clinical assay (including radioimmunoassay)
- ☐ Physical, chemical, geological, or engineering research
- ☐ Other (please specify: _____

_____

*Note: For purposes of this survey, by sealed sources we mean: radioactive materials permanently sealed, encapsulated or affixed (e.g. electroplated) in a nondispersable form.

C. Please indicate below if any of the following **facilities** were in operation at your institution in 1977:

☐ Nuclear Reactor

☐ Neutron generator(s) (e.g. Cockroft-Walton or similar principle devices)
How many? _____

☐ Cyclotron or synchrotron

☐ Other particle accelerator; please specify below, but do not include electron accelerators (i.e. betatrons, clinical linear accelerators, etc.)

_____

_____

SKIP QUESTION "D" (below) IF NONE OF "C" (above) WAS CHECKED

D. Did the operation of the reactor or accelerator result in the production of **radioactive wastes** requiring disposal in 1977?

☐ Yes* ☐ No

*Please exclude this waste data from the remainder of the questionnaire; however, if this is **not** possible, check the box below:

☐ Reactor/accelerator data is included

II. RECEIPT OF RADIOACTIVE MATERIALS

A. Did your institution **receive** radioactive materials in 1977?

☐ Yes ☐ No If NO, you have completed this questionnaire

B. Did your institution receive any of the following in 1977?

☐ **Only** sealed sources (see note on previous page)

☐ **Only** unsealed sources

☐ **Both** sealed and unsealed sources

1370 284

C. RADIONUCLIDES RECEIVED IN 1977

Instructions

1. Check each **nuclide** you received in 1977.
2. List **total activity received** in 1977 for each checked nuclide.
3. Check which activity totals include **sealed sources** (see definition, page 1).

✓ If Received in 1977		Total Activity in 1977 (mCi)	✓ If Sealed Sources Included	✓ If Received in 1977		Total Activity in 1977 (mCi)	✓ If Sealed Sources Included
^{3}H	☐		☐	^{123}I	☐		☐
^{14}C	☐		☐	^{125}I	☐		☐
^{22}Na	☐		☐	^{131}I	☐		☐
^{24}Na	☐		☐	^{127}Xe	☐		☐
^{32}P	☐		☐	^{133}Xe	☐		☐
^{35}S	☐		☐	^{198}Au	☐		☐
^{42}K	☐		☐	^{201}Tl	☐		☐
^{45}Ca	☐		☐			(others, please specify)	
^{51}Cr	☐		☐	_____			☐
^{59}Fe	☐		☐	_____			☐
^{57}Co	☐		☐	_____			☐
^{58}Co	☐		☐	_____			☐
^{67}Ga	☐		☐	_____			☐
^{68}Ga	☐		☐	_____			☐
^{75}Se	☐		☐	_____			☐
^{86}Rb	☐		☐	_____			☐
^{99m}Tc	☐		☐	_____			☐
^{111}In	☐		☐	_____			☐
^{113}Sn	☐		☐	_____			☐

III. DISPOSAL OF RADIOACTIVE MATERIALS — 1977

A. Did your institution **dispose** of radioactive materials (by any method) in 1977?

☐ Yes

☐ No

If NO, you have completed this questicnnaire.

If YES, go on to next page.

B. Radioactive Waste Categorization by Disposal Method.

Instructions

1. Check each **type** of radioactive waste you disposed of in 1977
2. Check the **disposal method or methods** used for each type of waste in 1977

CHECK WASTE TYPES DISPOSED OF IN 1977	CHECK DISPOSAL METHODS USED FOR EACH TYPE OF WASTE							
	Release to Sewer	Dispose in Common Refuse	Incinerate	Evaporate or Distill	Vent to Atmosphere	Ship for Burial	Bury On-Site	Other (specify below)
☐ Scintillation fluids (not in vials)	☐	☐	☐	☐		☐	☐	☐
☐ Empty scintillation vials		☐	☐			☐	☐	☐
☐ Scintillation vials containing fluids		☐	☐	☐		☐	☐	☐
☐ Other organic liquids	☐	☐	☐	☐		☐	☐	☐
☐ Aqueous liquids	☐			☐		☐	☐	☐
☐ Animal carcasses or other biological wastes	☐	☐	☐	☐		☐	☐	☐
☐ Patient excreta	☐	☐	☐			☐	☐	☐
☐ Gaseous wastes		☐	☐		☐	☐	☐	☐
☐ Dry, solid wastes		☐	☐			☐	☐	☐
☐ Other radioactive wastes (specify below)	☐	☐	☐	☐	☐	☐	☐	☐

C. Did you **ship** radioactive wastes for burial in 1977?

☐ Yes

☐ No If NO, you have completed this questionnaire

D. Please indicate **destination** (burial site) for radioactive wastes shipped for burial by your institution in 1977.

☐ Sheffield, Illinois

☐ Maxie Flats, Kentucky

☐ Beatty, Nevada

☐ Barnwell, South Carolina

☐ Richland, Washington

☐ Other: _____

IV. PROCESSING OF WASTES PRIOR TO SHIPMENT FOR BURIAL

A. Do you mechanically **compact** dry wastes before shipment?

☐ Yes

☐ No

If **YES,** what is your estimated compaction ratio? _____ (uncompacted volume) to _____ (compacted volume)

B. Which of the following methods do you use for the **preparation** of waste liquids for shipment?

☐ **Adsorption** (please specify)

- ☐ on vermiculite
- ☐ on microcel
- ☐ on diatomaceous earth
- ☐ other adsorption method: _____

☐ **Solidification** (please specify)

- ☐ in cement
- ☐ in polymer (urea formaldehyde or similar media)
- ☐ in plaster of paris
- ☐ other method of solidification: _____

☐ **Other Preparation Method(s):** _____

_____

V. RADIONUCLIDES SHIPPED FOR BURIAL IN 1977

A. Did you ship for burial any **sealed sources** in 1977 (e.g. flood sources, calibration sources, brachytherapy sources, gas chromatography foils, etc.)?

☐ Yes* ☐ No

*If YES, please specify below by type, activity and nuclide

Type of Source(s)	Nuclide	Total Activity

B. Radionuclides **Shipped** in 1977

Instructions

1. Check each **nuclide** you shipped for burial in 1977.
2. List **total activity shipped** in 1977 for each checked nuclide.*
3. Check which activity totals include **sealed sources** (see def. p. 1).

✓ If Received in 1977		Total Activity in 1977 (mCi)	✓ If Sealed Sources Included	✓ If Received in 1977		Total Activity in 1977 (mCi)	✓ If Sealed Sources Included
^{3}H	☐		☐	^{113}Sn	☐		☐
^{14}C	☐		☐	^{125}I	☐		☐
^{22}Na	☐		☐	^{131}I	☐		☐
^{32}P	☐		☐	^{201}Tl	☐		☐
^{35}S	☐		☐			(others, please specify)	
^{45}Ca	☐		☐				☐
^{51}Cr	☐		☐				☐
^{60}Co	☐		☐				☐
^{67}Ga	☐		☐				☐
^{75}Se	☐		☐				☐
^{86}Rb	☐		☐				☐
^{99m}Tc	☐		☐				☐
^{111}In	☐		☐				☐

*Estimate if necessary

VI. VOLUMES, PHYSICAL FORMS, AND COSTS OF RADIOACTIVE WASTES SHIPPED FOR BURIAL IN 1977

A. Please indicate the **total volume** (in cubic feet) of radioactive wastes shipped by your institution in:

1977 _____ cu. ft. 1976 _____ cu. ft.

B. **Physical forms** of radioactive wastes shipped:

INSTRUCTIONS

1. For each type of waste shipped in 1977, list the **number of containers** shipped of each kind.
2. For kinds of containers **not given,** please specify number and volume (in cu. ft.) of each.
3. If you **mix** waste types in a single container, check here ☐ and estimate number of containers of each form, as if unmixed.

	55 gal Steel Drums (7.35 cu. ft.)	30 gal Steel Drums (4.01 cu. ft.)	Double Steel Drums (7.35 cu. ft.)	Other Containers (please specify below)
Dry Solids				
Liquid Scintillation Vials Containing Fluids				
Solidified or Absorbed Liquids				
Animal Carcasses or Other Biological Wastes				
Other Types of Radioactive Wastes (please specify below)				

_____

_____

* 30 gal drum within 55 gal drum—total waste volume 7.35 cu. ft.

1370 290

C. Excluding labor expenses, what were the **total costs** of radioactive waste disposal for your institution in 1977?

$ _____

ADDITIONAL COMMENTS

If you have any comments concerning this survey or institutional radioactive waste management in general, please use the space provided below.

Thank you very much for your cooperation.

Thomas Beck, Leland Cooley,
Ralph Andersen and Margaret McCampbell
Institutional Radioactive Waste Study
University of Maryland

APPENDIX B

RADWASTE PRODUCTION BY PARTICLE ACCELERATORS

During the course of the 1975 survey, it became apparent that the existence of charged particle accelerators may have a significant effect on radwaste production in the survey population. To investigate this question, a separate effort concurrent with the followup survey was undertaken.

B.1 Introduction

Mundis et al* suggest that there are as many as 1200 particle accelerators in the U.S. including megavoltage medical accelerators, Cockroft-Walton neutron generators, Van de Graaff generators, cyclotrons, synchrotrons, synchrocyclotrons, etc. Radwaste produced by these facilities could be expected to fall into two general categories:

1. Induced radioactivity in the beam target, accelerator structure, beam stops, target coolant and the local environment of the accelerator, and any materials contaminated with induced radioactivity, such as cleaning solutions, paper, gloves, glassware, etc. (9).

2. Expended tritium targets used for neutron generation by d - t reaction; usually associated with Cockroft-Walton type, 400 keV deuteron accelerators (9, 10).

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*R.L. Mundis, M.J. Kitka, G.J. Marmer, J.H. Opelka, J.M. Peterson, and B. Siskind, "Health Physics Considerations in Accelerator Decommissioning and Disposal," presented at: Health Physics Society's Twelfth Annual Midyear Topical Symposium, Williamsburg, Virginia, February 12-15, 1979.

Although the accelerator structure, components and room shielding may become activated to some extent during its operation, it is unlikely that much of this material would be considered as waste prior to the decommissioning of the facility. The problem of waste generation as a result of accelerator decommissioning is being addressed elsewhere by Mundis et al. In this effort, however, the investigators were concerned only with radwastes routinely produced and requiring disposal during the useful life of the facility.

The investigators decided to select a survey population consisting of medical or academic institutions possessing accelerators with a high probability of waste production. The study population was confined predominantly to positive particle or negative ion accelerations, although with the exception of synchrotrons and electron linacs operating above 50 MeV, electron accelerators (including essentially all medical accelerators) were excluded.

The survey population was identified by a combination of two methods. First, respondents to the institutional survey indicated whether they had an accelerator (page 2, Appendix A). Additionally, a search of the high energy physics and nuclear physics literature revealed other accelerator facilities. A population of 137 institutions was identified possessing a total of 185 accelerators. Table B.1 shows the numbers and types of facilities in the population.

B.2 Survey Methodology

Those institutions which responded to the institutional survey and indicated the presence of an accelerator were asked whether the operation of the facility resulted in the production of radwaste in 1977. Most of those that answered affirmatively were contacted by telephone to obtain specific waste data. Additionally, many of those identified by other methods were also telephoned.

*R.L. Andersen, University of Colorado at Boulder, personal communication to T.J. Beck, University of Maryland at Baltimore, March, 1979.

Table B.1 Particle Accelerators
at Medical and Academic Institutions

Accelerator Type	Number of Units
Neutron generators*	90
Van De Graaff generators:	
single stage	46
tandem	16
Cyclotrons	20
Synchrotrons **	3
Synchrocyclotrons	3
Linear accelerators**	4
Others	2
	185

* Cockroft-Walton type

** electron accelerators (> 50 MeV)

1370 295

B.3 Results

B.3.1 Neutron Generators

Seventy-eight institutions were identified as possessing a total of 90 Cockroft-Walton type deuteron accelerators used for 14 MeV neutron production. As expected, the only radwastes produced by these were in the form of expended tritium targets.

Data was obtained for 71 machines (79%), of which 27 produced waste targets in 1977. Of the 44 remaining, 35 produced no waste and 9 were either inactive or decommissioned.

The specific activity per waste target as reported ranged from 1 to 5 Ci and averaged 1.8 Ci of ^{3}H. On the average, each of the 27 machines expended 8 targets in 1977 (range: 1 - 15 targets). A total of 252 targets, including a 10-year accumulation of 45 targets at one institution, were disposed of by the responding facilities. The total tritium activity disposed of was approximately 452 Ci, of which approximately 14 Ci were buried on site at one institution; the remainder was shipped for burial.

The waste volume associated with the targets can be considered to be negligible; however, for a conservative estimate, assuming 0.25 ft^{3} per target, the total reported volume shipped for burial by respondents would be ~61 ft^{3} or 1.73 m^{3}.

B.3.2 Van de Graaff Generators

Forty-nine institutions were identified with a total of 62 Van de Graaff (VdG) generators, 16 of which were tandem (2 stage) devices while the remainder were single stage.

Data was obtained for 34 single stage and 15 tandem VdG generators. Ony two (6%) of the single stage VdG produced radwaste while 5 (33%) of the somewhat higher energy tandem VdG's, produced radwaste in 1977. Information from the survey indicated that 7 of the single stage and none of the tandem devices had been decommissioned. The only waste produced by the single stage VdG's was approximately 1 cubic foot each of ^{3}H contaminated cooling oil. The radwastes produced by the tandem VdG's generally consisted of a few cubic feet of cleaning materials or activated components, none of which was assayed to determine nuclide contaminants. One, however, had been used in neutron shielding research, and utilized a 900 Ci gaseous ^{3}H target. The resultant wastes included a tritium gas trap and tritium contaminated cooling oil, coolant pumps and other components; the volume of which could not be determined, but the tritium activity disposed of was 300-500 Ci. All of the waste at this facility was shipped for burial. Excluding that produced by the latter case, the total waste volume disposed by responding VdG facilities was 13 ft^3 (0.38 m^3), all of which was shipped for burial.

B.3.3 Cyclotrons

Twenty cyclotrons were identified in the population, 8 of which were used at least in part for radiopharmaceutical production. Sixteen facilities were contacted for waste data, twelve (75%) stated that radwastes were produced in 1977. One of these shipped approximately 150 ft^3 of waste consisting mostly of cleaning materials and cleaning solvents (ethanol) adsorbed on vermiculite.

The remaining eleven produced on the average 6.5 ft^3 of cleaning materials or activated components during the survey period. As with the wastes produced by the tandem VdG generators, none were assayed prior to disposal, although two indicated the presence of ^{3}H in their waste. The total volume of waste disposed of by cyclotron facilities was 215 ft^3 (6.08 m^3) of which 6.5 ft^3 was buried on site at one institution and the remainder shipped for commercial burial.

B.3.4 Other Accelerator Facilities

The remaining 12 accelerators included 3 synchrotrons, 3 synchrocylotrons, 4 linear accelerators and two plasma beam devices used in fusion research. One of the synchrotrons, two synchrocyclotrons*, three linacs and both of the plasma devices provided waste data. Of these, five produced radwaste. The electron synchrotron shipped a single drum of activated target assemblies. All three linacs shipped some radwaste, generally consisting of activated components and cleaning materials totaling three 55 gallon drums (22 ft^3 or 0.62 m^3). The plasma beam facilities both shipped a small quantity of waste consisting of activated target assemblies for a total waste volume of 8 ft^3 (0.24 m^3). None of the waste produced by these facilities was assayed before disposal.

B.4 Discussion

From an activity standpoint the most significant waste produced by the accelerator population consists of tritium targets. Such targets, usually used with a Cockroft-Walton deuteron accelerator, have a useful life of between one and several hours depending on the beam current (10). Typical targets consist of tritium adsorbed on a titanium substrate with a backing of copper. Targets are usually a few centimeters in diameter with an initial total activity from 1 - 8 Ci of ^3H (11).

If the response data for neutron generators is extrapolated to the total population, an estimated 308 targets with 555 Ci of activity were disposed of in 1977. If the activity of the gaseous ^3H source used with the tandem VdG is included, the total ^3H activity is approximately 1 kilocurie in a relatively small volume of perhaps 75 cubic feet (2.13 m^3) or more. A summary of the neutron generator target data is included in Table B.2.

*one was decommissioned

Table B. 2 Neutron Generator Targets Disposed in 1977

GENERATOR DATA	
Number of generators	90
Average number of targets per generator	8
Estimated total number of targets	308

WASTE DATA	
Percent producing waste	38%
Average ^{3}H activity per target	1.8 Ci
Estimated ^{3}H total activity	555 Ci

	Shipped for Burial	Burial on Site
Total activity	541 Ci	14 Ci
Estimated total volume*	75 ft^3	2 ft^3

*Assumes 0.25 ft^3 per target

Radwaste production by single stage Van de Graaffs was essentially nil. The two stage VdG's produced an estimated 11.5 ft^3 of waste designated for burial. Cyclotrons and electron accelerators such as synchrotrons and linacs produced on the average of one 55 gallon drum of waste per year. The same is also true of the two beam plasma devices surveyed. The total estimated waste volume from these sources is approximately 333 ft^3 (9.44 m^3) of waste. Radwaste produced by tandem VdG's, cyclotrons, synchrotrons, etc., generally consist of contaminated target coolant and coolant pumps; activated target assemblies, beam stops, and other small components; and cleaning solutions and material. None of these facilities assayed waste for nuclide content before disposal, although several stated that wastes were in the picocurie range, others stated that external dose rates were up to 20 mR/hr. The significant nuclides present in these wastes are likely to be those commonly activated in the usual materials near the beam port such as water or oil coolant, copper, iron, stainless steel, aluminum and concrete. The principal nuclides activated in such components are ^{7}Be, ^{22}Na, ^{51}Cr, ^{54}Mn, ^{57}Co, ^{58}Co, ^{60}Co, ^{59}Fe, ^{55}Fe and ^{65}Zn all of which have half lives longer than 2 weeks (9) although the controlling γ emitters in wastes would be ^{22}Na, ^{54}Mn and ^{60}Co*. The phenomenon of ^{3}H production in coolant water from oxygen spallation (star production) also may be significant for facilities accelerating protons into the GeV range (9).

Table B.3 summarizes the volume estimate for radwaste produced by the accelerator population. The estimated total volume of waste shipped for burial by these accelerator facilities is essentially quite small (416 ft^3 or 11.8 m^3), although this estimate can be considered to be conservative. Of the activity present in these wastes, the most significant portion is, in all likelihood, ^{3}H. An estimated 1 kCi was shipped for burial as tritium targets from neutron generation, half of which consisted of trapped tritium gas and contaminated components from a single facility using a gaseous ^{3}H target for neutron shielding research.

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*Mundis, et al (see Section B.1)

Table B.3 Accelerator Radwaste Volume

Type of Accelerator	Total ** Number	Producing Waste	Average Volume (m^3)	Total Waste Volume Produced ** (m^3)
Neutron generators	90	38%	.057	2.180*
Van de Graaff				
single stage	46	6%	.028	.085
tandem	16	27%	.082	.350
Cyclotrons	20	75%	.184	7.745
Synchrotrons	3	100%	.208	.624
Synchrocyclotrons	3	-	-	-
Linear accelerators	4	100%	.208	.833
Others	2	100%	.119	.238

Total volume produced	12.055 m^3 (425.6 ft^3)
Volume buried on site	.241 m^3 (8.5 ft^3)
Total volume shipped for burial	11.814 m^3 (417.2 ft^3)

*Assumes .007 m^3/target (i.e. .25 ft^3/target)

**Total values are for the total population of accelerators. Volumes are projected to the total population from response data.

APPENDIX C

Radionuclide Receipt and Shipment Data

In this appendix are listed the mean and total activity values for both receipts and shipments. All nuclides quantified in the survey are listed.

Some responses listed the receipt or shipment of a nuclide but did not specify activity. Those few cases were considered to have received the mean value for that nuclide; thus, totals include such "missing" values. Activity receipts include both sealed and unsealed sources while shipments are listed separately.

Note that these tables only include data from survey responses and are not projected to the entire population. Also, the sealed source data in Table C.2 includes only that data from the major survey. Additional data from the accelerator study (Appendix B) was gathered separately from a slightly different (overlapping) population.

C.1 Radionuclides Received

Nuclide	Number of Receipts	Activity (mCi)		Percent of Total Receipt**
		Mean	Total (incl. missing)	
^{3}H	215	2,889.009	621,136.94	1.11 %
^{14}C	212	88.664	18,796.77	0.03 %
^{22}Na	86	12.300	1,057.80	-
^{24}Na	36	846.271	30,465.76	0.05 %
^{32}P	240	710.054	170,412.96	0.30 %
^{33}P	17	16.847	286.40	-
^{35}S	116	118.010	21,809.16	0.04 %
^{36}Cl	37	.724	26.79	-
^{42}K	34	85.413	2,904.04	0.01 %
^{45}Ca	106	33.207	3,519.94	0.01 %
^{47}Ca	10	15.847	158.47	-
^{46}Sc	24	6.882	165.17	-
^{51}Cr	208	204.236	42,481.09	0.08 %
^{55}Fe	23	14.155	325.68	-
^{59}Fe	122	7.570	923.54	-
^{57}Co	211	11.712	2,471.23	-
^{58}Co	55	22.558	1,240.69	-
^{60}Co *	38	24,106.884	916,061.59	1.63 %
^{63}Ni	26	13.054	399.40	-
^{65}Zn	30	3.237	97.11	-
^{67}Ga	180	750.521	135,093.78	0.24 %
^{68}Ga	9	83.933	755.40	-
^{75}Se	138	108.234	14,936.29	0.03 %
^{86}Rb	54	263.507	14,229.40	0.03 %
^{85}Sr	52	9.710	504.92	-

C.1 Continued

Nuclide	Number of Receipts	Activity (mCi)		Percent of Total Receipt**
		Mean	(incl. missing)	
^{90}Sr	19	1,326.944	25,211.94	0.04 %
^{95}Nb	14	5.077	71.08	-
^{99}Mo ***	150	82,859.270	12,428,891.00	22.26 %
^{99m}Tc ***	206	183,259.600	37,751,478.00	67.63 %
^{109}Cd	22	5.328	117.22	-
^{111}In	105	656.244	68,905.62	0.12 %
^{113}Sn	23	13.371	307.53	-
^{123}I	98	1,465.731	143,641.64	0.26 %
^{125}	231	383.400	88,565.40	0.16 %
^{131}I	241	1,058.354	255,063.31	0.46 %
^{127}Xe	15	2,192.817	32,892.26	0.06 %
^{133}Xe	172	12,080.840	2,077,904.50	3.72 %
^{137}Cs *	54	14,978.400	808,833.00	1.45 %
^{133}Ba	18	0.946	17.03	-
^{141}Ce	42	131.449	5,520.86	0.01 %
^{153}Gd	6	252.867	1,517.20	-
^{169}Yb	52	147.865	7,689.00	0.01 %
^{192}Ir	27	655.176	17,689.76	0.03 %
^{198}Au	37	775.538	26,694.91	0.05 %
^{137}Hg	6	50.083	300.50	-
^{203}Hg	25	12.660	316.50	-
^{201}Tl	102	734.886	74,958.35	0.13 %
^{222}Rn	13	49.185	51.41	-
^{241}Am	24	261.671	6,289.10	0.01 %
^{244}Cm	7	2.771	19.40	-
Other	95	33,005.900	3,135.560.50	

C.1 Continued

SUMMARY:

Total Activity.....58,959,457 mCi

Total Accounted for.....55,823,897 mCi (94.68%)

*Activity totals exclude the following irradiator loads > 999 Ci

^{60}Co N = 6 $\bar{x}$ = 10.100 kCi

^{137}Cs N = 5 $\bar{x}$ = 4.054 kCi

**Percent of receipts excluding "others".

***See Section 3.3 for a detailed discussion of the receipts of ^{99m}Tc, ^{99}Mo, and ^{137}Cs.

1370 305

APPENDIX C. CONTINUED

C.2 Sealed Sources Shipped for Burial

Nuclide	Number of Responses	Total Activity (mCi)	Type of Source
^{3}H	7	6,550.50	Electron capture detectors for gas chromatographs
	5	65,000.00	Neutron generator targets**
^{14}C	1	0.01	β reference source
^{22}Na	2	0.10	γ detector calibration sources
^{57}Co	2	10.00	Mossbauer sources
	8	7.30	Flood sources for γ camera calibration
	4	1.02	Miscellaneous γ detector calibration sources
^{60}Co	1	200.00	γ irradiator source
	1	50.00	Exposure meter calibration source
	3	4.07	γ detector calibration sources
^{63}Ni	2	33.00	Electron capture detectors for gas chromatographs
^{65}Zn	1	0.01	γ detector calibration source
^{90}Sr	3	40.00	β reference sources
	1	50.00	Medical applicator

APPENDIX C. CONTINUED

C.2 Continued

Nuclide	Number of Responses	Total Activity (mCi)	Type of Source
^{110}Ag	1	100.00	Unspecified
^{125}I	5	335.00	Brachytherapy sources
	1	150.00	Bone mineral analyzer source
^{137}Cs	1	2,000.00	Level guage
	1	15.00	Moisture guage
	1	100.00	Brachytherapy sources
	2	550.00	Soil density guages
	2	210.00	Exposure meter calibration sources
	1	8,200.00	γ irradiator sources
	4	5.00	γ detector calibration sources
^{152}Eu	1	125.00	Unspecified
^{154}Eu	1	100.00	Unspecified
^{192}Ir	7	1,194.00	Brachytherapy sources
^{210}Po	1	0.02	Static eliminator
	1	2.50	Unspecified
^{226}Ra	11	3,261.10	Brachytherapy sources
	1	0.02	Electron capture detector for gas chromatograph
	2	15.01	Ra-Be neutron sources
	1	4.50	Ra-Be soil density guage
	1	5.00	Ra-Be moisture guage

APPENDIX C. CONTINUED

C.2 Continued

Nuclide	Number of Responses	Total Activity (mCi)	Type of Source
^{241}Am	1	50.00	Am-Be neutron source
^{252}Cf	1	1.00	Unspecified
Misc	1	0.02	Unspecified
TOTAL	90*	88,369.18	

*78 respondents shipped sealed sources

**For complete data on neutron generators, see Appendix B.

APPENDIX C CONTINUED

C.3 Radionuclides in Non Sealed Source Form Shipped for Burial

Nuclide	Number of Shipments	Activity (mCi)		Percent of Total Shipped**
		Mean	Total (incl. missing)	
^{3}H	157	1,504.146	236,150.922	58.88 %
^{14}C	149	90.525	13,488.225	3.36 %
^{22}Na	62	3.331	206.522	0.05 %
^{32}P	116	213.178	24,728.648	6.17 %
^{33}P	4	4.596	18.384	-
^{35}S	85	148.814	12,649.190	3.15 %
^{36}Cl	26	0.520	13.520	-
^{45}Ca	85	24.014	2,041.190	0.51 %
^{46}Sc	16	7.991	127.856	0.03 %
^{51}Cr	115	86.242	9,917.830	2.47 %
^{54}Mn	16	0.503	8.048	-
^{59}Fe	43	6.237	268.191	0.07 %
^{57}Co	50	4.232	211.600	0.05 %
^{60}Co	31	107.765	3,340.715	0.83 %
^{67}Ga	66	35.135	2,318.910	0.58 %
^{75}Se	64	14.823	948.672	0.74 %
^{86}Rb	37	6.117	226.329	0.06 %
^{85}Sr	40	7.736	309.440	0.08 %
^{90}Sr	16	35.815	573.040	0.14 %
^{95}Nb	10	13.527	135.720	0.03 %
^{99}Mo	18	837.786	15,080.148	3.76 %
^{99m}Tc	70	284.331	19,903.170	4.96 %
^{111}In	41	4.378	179.498	0.04 %
^{113}Sn	16	12.134	194.144	0.05 %
^{125}I	151	317.098	47,881.798	11.94 %

APPENDIX C CONTINUED

C.3 Continued

Nuclide	Number of Shipments	Activity (mCi)		Percent of Total Shipped**
		Mean	Total (incl. missing)	
^{131}I	108	61.296	6,619.968	1.65
^{133}Xe	17	79.821	1,356.957	0.34
^{137}Cs	25	44.035	1,100.875	0.27
^{141}Ce	26	6.744	175.344	0.04
^{169}Yb	18	17.527	315.486	0.08
^{201}Tl	36	15.692	564.912	0.14
Others	90	41.783	3,760.470	-

TOTAL ACTIVITY 404,816 mCi

Total excluding "others" 401,055 mCi (99.07%)

* Numbers include missing values

** Percent of total activity excluding "others"

APPENDIX D

ANALYSIS OF COMMON RADIOLABELED CHEMICAL COMPOUNDS USED IN BIOLOGICAL RESEARCH

Radionuclide receipt records for the year 1977 were obtained from two of the largest institutions in the study. One includes a hospital, medschool and college while the other is a moderately large hospital with a very large biological research program. The former puts waste into all three wastestreams, although the non bioresearch component is miniscule. The latter is associated with both medical and bioresearch wastestreams. However, radwaste production in both institutions is dominated by bioresearch waste. The receipt records of the two institutions were combined for analysis.

The most frequently received nuclides were ^{3}H, ^{14}C and ^{125}I, which are the most common species used for the labeling of research biochemicals (8). The summarized receipts for these three nuclides are listed in Table D.1. Tritiated compounds are by far the most common, totalling 4,084 receipts and 86.2 Ci of activity. The number of receipts of ^{14}C and ^{125}I totalled 2,597 and 2,666, respectively.

A summary listing of the numbers of receipts and total activities of some of the major labeled compounds are listed in Table D.2. Approximately half of the tritium activity (41.5 Ci) consists of tritium labeling reagents, such as tritiated water, sodium and potassium borohydride, acetic anhydride and acetic acid. These, however, only account for 2 % of the total number of receipts. A similar situation exists for ^{125}I where 93% of the activity is in the form of sodium iodide or Bolton-Hunter reagent; which constitute 36% of the total receipts.

Most of the tritium receipts and essentially all of the ^{14}C receipts are in the form of complex labeled biochemicals such as nucleic acids, amino acids, proteins, carbohydrates, hormones, drugs, carcinogens and toxins, common examples of which are listed in Tabie D.2. These compounds are generally received in

activities of between one microcurie and a few millicuries for ^{3}H and usually less than a mCi for ^{14}C.

Typical quantities received of the more common labeled biochemicals range between a few μ moles and a few hundred mmoles. Because specific activities of ^{14}C labeled compounds tend to be lower than tritium labeled compounds, larger (molar) quantities of the former are usually received (8).

Excluding the receipts of compounds used for iodinations (NaI and Bolton-Hunter reagent), the receipts of ^{125}I are dominated by radioassay kits used either for research purposes (such as cAMP and cGMP assays) or routine clinical (in vitro) diagnostics. Some of the latter include assays for Hepatitis antigen, T-3 and T-4 assays, Follicle Stimulating Hormone, etc. Some of the more common assays are also listed in Table D.2. Typically, these assay kits contain a total activity between 1 and 10 μCi of ^{125}I.

Table D.1 Labeled Compounds Received by Two Institutions

Nuclide	Number of Receipts	Total Activity (mCi)
^{3}H	4,084	86,207.57
^{14}C	2,597	1,402.82
^{125}I	2,666	6,91[illegible].31

Table D.2 Compounds Most Commonly Received

	Isotope	Number of Receipts	Total Activity (mCi) of Receipts
AMINO ACIDS			
Amino acid mixture, L-amino acids	^{3}H	65	382.750
	^{14}C	53	39.511
Amino butyric, aminoisobutyric acids	^{3}H	16	21.750
	^{14}C	18	6.150
Alanine, L-alanine	^{3}H	17	13.500
	^{14}C	1	1.600
Arginine, L-arginine	^{3}H	16	33.500
	^{14}C	9	1.050
Aspargine, L-aspargine, aspartic acid, L-aspartic acid	^{3}H	13	14.750
	^{14}C	28	11.050
Glutamine, L-glutamine, glutamic acid, DL-glutamic acid, L-glutamic acid	^{3}H	121	229.500
	^{14}C	147	11.475
Histidine, L-histidine	^{14}C	14	12.100
Leucine, L-leucine, isoleucine, L-isoleucine	^{3}H	305	1,457.750
	^{14}C	46	45.350
Lysine, L-lysine	^{3}H	34	146.000
	^{14}C	38	39.400
Methionine, L-methionine, methionine methyl, L-methionine methyl, methyl methionine	^{3}H	108	892.250
	^{14}C	50	7.910
Ornithine, DL-ornithine, L-ornithine	^{14}C	49	12.100
Phenylalanine, L-phenylalanine, dihydroxyphenylalanine	^{3}H	43	117.500
	^{14}C	11	2.100
Serine, L-serine	^{3}H	6	11.000
Tryptophan, L-tryptophan	^{3}H	15	38.250
	^{14}C	7	0.210

D.2 Continued

	Isotope	Number of Receipts	Total Activity (mCi) of Receipts
Tyrosine, L-tyrosine	^{3}H	21	73.000
	^{14}C	15	5.100
Valine, L-valine	^{3}H	11	43.500
	^{14}C	18	3.250
NUCLEIC ACIDS AND DERIVATIVES			
Adenosine, deoxyadenosine	^{3}H	50	589.510
AMP, cAMP, ADP, ATP, dATP, ScAMP	^{3}H	161	557.078
	^{14}C	13	0.270
Polyadenylate	^{3}H	20	0.790
Adenine	^{3}H	14	48.500
	^{14}C	19	6.400
Cytidine, deoxycytidine	^{3}H	31	206.010
CMP, CTP, dCTP, dCMP, SCMP	^{3}H	93	976.250
	^{14}C	10	21.250
	^{125}I	14	19.000
Polycytidylate	^{3}H	10	0.130
Guanosine, deoxyguanosine	^{3}H	20	30.000
GMP, GDP, GTP, cGMP, ScGMP	^{3}H	107	546.263
	^{14}C	1	0.005
Polyguanidylate	^{3}H	3	0.030
Thymidine, thymidine methyl	^{3}H	529	7,180.820
	^{14}C	88	25.670
TTP, DTP, dTTP	^{3}H	124	3,789.500
	^{14}C	35	437.250
Uridine, deoxyuridine	^{3}H	379	4,425.900
	^{14}C	65	6.400
Polyuridylate	^{3}H	25	0.940

D.2 Continued

	Isotope	Number of Receipts	Total Activity (mCi) of Receipts
UTP	^{3}H	62	180.000
DNA, DNA components and markers	^{3}H	24	0.051
RNA, RNA markers	^{3}H	19	0.016
S-adenosyl-L-methionine	^{3}H	95	229.100
	^{14}C	60	5.050
HORMONES, STEROIDS, AND LIPIDS			
Acetyl Coenzyme A, Coenzyme A acetyl, Coenzyme A	^{3}H	2	0.300
	^{14}C	60	3.260
Butyric acid	^{14}C	15	4.150
Estradiol, estriol, estrone	^{3}H	45	3.300
	^{14}C	13	0.390
Cholesterol	^{3}H	13	9.500
Cholic acid, cholic chloride	^{3}H	23	73.500
Corticosterone	^{3}H	11	2.750
Dexamethasone	^{3}H	20	18.750
Dihydroxytestosterone, testosterone	^{3}H	45	45.050
Hydrocortisone, hydroxycortisone	^{3}H	12	5.500
Oleic acid	^{3}H	5	25.000
Pregnenalone	^{3}H	13	8.250
Prostaglandins	^{3}H	54	5.260

D.2 Continued

	Isotope	Number of Receipts	Total Activity (mCi) of Receipts
DRUGS AND CARCINOGENS(68) (69)			
Benzopyrene, benzanthracene, benzo(a)pyrene	^{3}H	2[a]	838.400
Diazepam	^{3}H	10	2.500
Imipramine	^{14}C	13	1.670
Methotrexate	^{3}H	16	17.250
RADIOASSAY KITS			
Hepatitis associated antigen assay	^{125}I	414	42.926
Carcino embrionic antigen assay	^{125}I	50	5.500
Angiotensin, Angiotensin I, Angiotensin II assays	^{125}I	30	1.295
T-3 assay	^{125}I	43	7.574
T-4 assay	^{125}I	61	3.425
cAMP, ScAMP assay	^{125}I	61	0.442
cGMP, ScGMP assay	^{125}I	136	10.969
Human follicle stimulating hormone assay	^{125}I	21	6.635
Human thyroid stimulating hormone assay	^{125}I	50	4.010
Human chorionic gonadotropin	^{125}I	40	39.268
Rat leutinizing hormone	^{125}I	14	1.252

D.2 Continued

	Isotope	Number of Receipts	Total Activity (mCi) of Receipts
LABELING AGENTS			
Tritiated water	^{3}H	5	30,100.000
Sodium borohydride	^{3}H	59	9,405.000
Potassium borohydride	^{3}H	4	400.000
Acetic anhydride	^{3}H	13	985.000
Acetic acid	^{3}H	12	560.000
Bolton-Hunter Reagent	^{125}I	77	120.000
Sodium Iodide	^{125}I	881	6,285.150

GLOSSARY

BIORESEARCH WASTESTREAM - One of three wastestreams identified for analytical purposes in the 1977 institutional radioactive waste study. This wastestream is characterized by waste resulting from the non human use of radioactive materials in biochemical, biophysical, and physiological investigations using radiolabeled tracer techniques .

COLLEGE - The term used by the authors when referring to any four-year college or university.

ENTITY - The term used by the authors to distinguish reference to a hospital, medschool, or college from an institution, which may include more than one of these.

INSTITUTION - The term used by the authors referring to an administrative facility. An institution may be a single entity (e.g. a hospital) or it may include more than one entity (e.g. a hospital and a medschool).

L-S - Acronym for liquid scintillation.

MEDICAL WASTESTREAM - One of three wastestreams identified for analytical purposes in the 1977 institutional radioactive waste survey. This wastestream is characterized by waste produced from the use of radioactive materials for in vivo diagnosis, therapy, and research; and from in vitro use such as routine clinical assays.

MEDSCHOOL - The term used by the authors, referring to schools of medicine.

NON BIORESEARCH WASTESTREAM - One of three wastestreams identified for analytical purposes in the 1977 institutional radioactive waste study. This wastestream is characterized by waste resulting from the use of radioactive materials in investigations of non life sciences such as physics, inorganic

chemistry, materials analysis, geology, etc.; and including production of activation products with charged particle accelerators or research nuclear reactors.

RADIATION CONTROL PROGRAM - The term used by the authors when referring to the administrative entities from which data was obtained to the 1977 institutional radioactive waste survey. This term is inclusive of such titles as "Radiation Protection Program," " Radiation Safety Office, " "Environmental Protection Office," etc.

RADWASTE - radioactive waste.

SEALED SOURCE - Radioactive materials permanently sealed, encapsulated or affixed (e.g. electroplated) in a nondispersible form.

WASTESTREAM - A general category of use of radioactive materials which results in continuous or regular discharge of radioactive materials into the environment.

Z SCORES - Used to normalize several distributions, assumed to be Gaussian, for the purpose of rejection or "flagging" of extreme values.

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16. ABSTRACT (200 words or less)

A followup survey to the 1975 institutional radioactive waste study (3) was conducted to obtain data for the calendar year 1977. The survey population of large medical and academic licensees shipped an estimated 7,771 m^3 of low level radwaste for burial in 1977. Approximately 7% of the waste volume was ascribed to purely medical sources, 79% to sources conducting biological research and 14% to other academic sources. The estimated total activity shipped by the population in 1977 was 1,688 Ci, of which 81% was ^3H. Approximately 540 Ci of ^3H was shipped as depleted tritium targets for neutron generators. Much of the rest was in the form of labeled compounds or labeling reagents used in biological research. The fastest growing waste form produced by the population is waste liquid scintillation vials which have undergone a 60% increase in volume since 1975. The waste volume produced by the population appears to be increasing linearly, at approximately the same rate as low level radwastes in general.

17. KEY WORDS AND DOCUMENT ANALYSIS

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