TRANSPORT OF RADIOACTIVE MATERIAL IN THE UNITED STATES: A REVIEW OF THE CURRENT STATUS

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ABSTRACT

This study is a follow up to previous nationwide surveys of licensed radioactive material transport in the United States sponsored by federal agencies in 1975 and 1985. The John A. Volpe Transportation Systems Center has accumulated data that represent about 82 percent of the known market data based upon the 1985 study. The results indicate a growth in shipments from 2.8 million in 1985 to 18 million in 1999. Based upon survey data, 96.3 percent of the total number of radioactive materials packages shipped in the United States are radiopharmaceutical shipments.

ACKNOWLEDGMENTS

This report could not have been completed without the help of many involved in the nuclear industry in the United States. The John A. Volpe National Transportation Systems Center (Volpe Center) thanks them one and all for their assistance. The Volpe Center would like to note in particular the assistance provided by the Nuclear Energy Institute (NEI). The NEI is a national organization that represents a significant portion of the nuclear industry in the United States. Their willingness to provide assistance to the study was a crucial input into collecting data on the variety of sectors that ship radioactive material. In addition to assisting in the collection of utilities data, the NEI was instrumental in the collection of data on radiopharmaceutical shipments in the United States.

FOREWORD

In 1985, SRI International completed a project for the Sandia National Laboratories designed to create a statistical database of radioactive material shipments in the continental United States. The estimate of shipments in 1985 was based upon a scientific sample of United States Nuclear Regulatory Commission (NRC) and Agreement State licensees and their shipments of radioactive material within the United States. At that time, the NRC and Agreement State lists of radioactive material licensee sites formed a sample frame of approximately 15,000. The John A. Volpe National Transportation Systems Center (Volpe Center) was asked to update the 1985 estimates, and provide the NRC with a new estimate of total radioactive material shipments in the United States.

The NRC directed the use of secondary data sources to develop an estimate; no sampling frame was established for this study and no independent verification or validation of data provided to the Volpe Center was undertaken.

All of the data reported in this document were provided from one of three sources: government, industry trade organizations, or private firms. No independent market research was undertaken.

Due to the cooperation of trade organizations such as the Nuclear Energy Institute and the Council on Radionuclides and Radiopharmaceuticals, the Volpe Center was able to obtain very reliable data describing two of the most significant types of non-governmental shipments of radioactive materials in the United States. Specifically, these are shipments from commercial nuclear power plants and from radiopharmaceutical companies. These data were combined with information provided by other industry and governmental sources to develop an updated estimate.

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EXECUTIVE SUMMARY

Determining the number of radioactive material packages shipped, and the number of shipments made in 1999 were the two principal objectives of this study. This study is a follow up to previous nationwide surveys of licensed radioactive material transport in the United States sponsored by federal agencies in 1975 and 1985. Data from these previous surveys have been employed in, among other things, developing estimates of the safety and potential environmental impacts resulting from transport of radioactive material. Since the completion of the last survey in 1985, the number of radioactive material licensees shippers has increased from approximately 15,000 (Sandia 1985) to 22,000 (NRC 1998). A new study of the movement of radioactive shipments was obviously needed because of the increased use of radioactive materials indicated by the increased number of licensees.

The John A. Volpe National Transportation Systems Center (Volpe Center) has undertaken accounting for the frequency of shipments of radioactive material by using the 1985 SRI study as a basis for estimating shipment growth. There were several challenges in using this approach; (1) changes in the regulatory authority for licenses from 1985 to 1999 resulted in a transfer of authority from the Nuclear Regulatory Commission (NRC) to individual states for nearly one-half of the licenses; (2) the categories used to describe licensee strata in 1985 were not relevant to the current distribution of licensees (thereby inhibiting the Volpe Center's ability to verify that the distribution of licenses was similar to those in 1985); and (3), some data were reported for entire market segments while other data were reported for individuals only, limiting the generalizability of the results.

In spite of these challenges, the Volpe Center has accumulated data from market sectors that represent most (82%) of the original 21 strata (plus Department of Energy data) described in the 1985 SRI study. These data are reported and aggregated in this report, with estimates of reliability. In those cases where pre-existing data sources could not be found or were not available for use in this study, primary data collection efforts were pursued. This study did not acquire the desired data via a formal comprehensive survey; rather, the data were collected by using information provided by others. Many industry and trade associations that were contacted were able to provide data for their particular sectors. Individuals with access to data for sectors where data were not easily accessible were also contacted. The collected data were scaled, where necessary, to create stratum level shipment and package estimates.

The results of the study indicate a substantial growth in the total number of radioactive materials packages shipped (and the number of shipments made) when compared with the 1985 data. The total number of radioactive materials packages shipped in 1999 is estimated to be approximately 18 million. In contrast, the total number of radioactive materials packages shipped in 1985 was estimated to be approximately 2.8 million.

Based upon data provided to the Volpe Center, 96.3 percent of the total number of radioactive materials packages shipped in the United States are radiopharmaceutical shipments. The radiopharmaceutical industry reports that 98 percent of these shipments are made via ground. These estimates were

provided by the radiopharmaceutical industry, based upon a survey and proprietary information available to the industry on market characteristics. As a result, the package estimate represents a highly reliable reflection of nearly 100 percent of the radiopharmaceutical market. When combined with shipments of all other market strata, the number of radioactive material package shipments in these is more than 6 times the 1985 volume (2.81 million versus 18 million).

The Volpe Center attempted to obtain information beyond the number of packages and shipments by mode, including details on shipments such as package and shipment activity and dose rate. Unfortunately, these efforts met with only limited success due to a paucity of available data. However, some shipment details were provided for certain strata, and that information is presented in this report.

1 INTRODUCTION

Radioactive materials are frequently used in common products that are present in nearly every aspect of daily American life. Radioisotopes are used in exit signs and smoke detectors. Some are employed in the manufacturing process to measure thickness or density of products such as coffee filters and radial tires. In addition, they are used in cancer treatments and airport security devices. Since radioisotopes and devices that employ them are used in such a vast variety of circumstances, they are shipped daily to thousands of locations in the United States.

The United States Department of Transportation (DOT) and the United States Nuclear Regulatory Commission (NRC) strictly regulate radioactive material shipments.[1] For example, these regulations specify the allowable limits for radiation levels during shipment, and the type and robustness of packaging that must be employed to ensure that the material is safe in transport. Due in part to these regulatory standards, and more importantly to the conscientiousness of the industry, incidents involving radioactive material transportation that have resulted in releases of radioactive materials are rare, representing, on average, about 0.112 percent of all reported hazardous materials incidents between 1991 and 2000. In fact, radioactive material transportation has one of the best safety records, historically, of all hazardous materials transportation. See Table 1 for a listing of Hazardous Materials Hazard Classes. During the most recent ten-year period for which data were available (1991 – 2000), the number of reported non-radioactive hazardous material incidents, according to DOT's, Research and Special Programs Administration, has doubled, while the number of radioactive material incidents has remained nearly constant (see Figure 1). Federal regulations require that a written report be filed when any release to the environment of a hazardous material occurs during any phase of transportation.[2] Because of this reporting requirement, every hazardous materials release during transport is, theoretically, reported to the federal government. The number of serious incidents involving all hazardous materials is very small (3 percent of all reported accidents) in comparison with the number of annual reports.[3] As Table 2 shows, the number of radioactive material incidents reports is low and, although the frequency of

[1] 49 CFR Parts 171-178 and 10 CFR Part 71, respectively.

[2] United States DOT / RSPA / Office of Hazardous Materials Safety, January 1990. "Guide for Preparing Hazardous Materials Incidents Reports."

[3] RSPA defines serious incidents as incidents that involve: a fatality or major injury due to a hazardous material; closure of a major transportation artery or facility or evacuation of six or more persons due to the presence of a hazardous material; or a vehicle accident or derailment resulting in the release of a hazardous material.

Table 1 DOT-RSPA Hazard Classes	
Hazard Class No.	**Name of Class**
1	Explosives
2	Flammable Gas
3	Flammable and Combustible Liquid
4	Flammable Solids, Spontaneously Combustible, Dangerous When Wet
5	Oxidizers, Organic Peroxides
6	Poisonous Materials/Infectious Substances
7	Radioactive Material
8	Corrosive Material
9	Miscellaneous Hazardous Material
None	Other Regulated Material: ORM-D

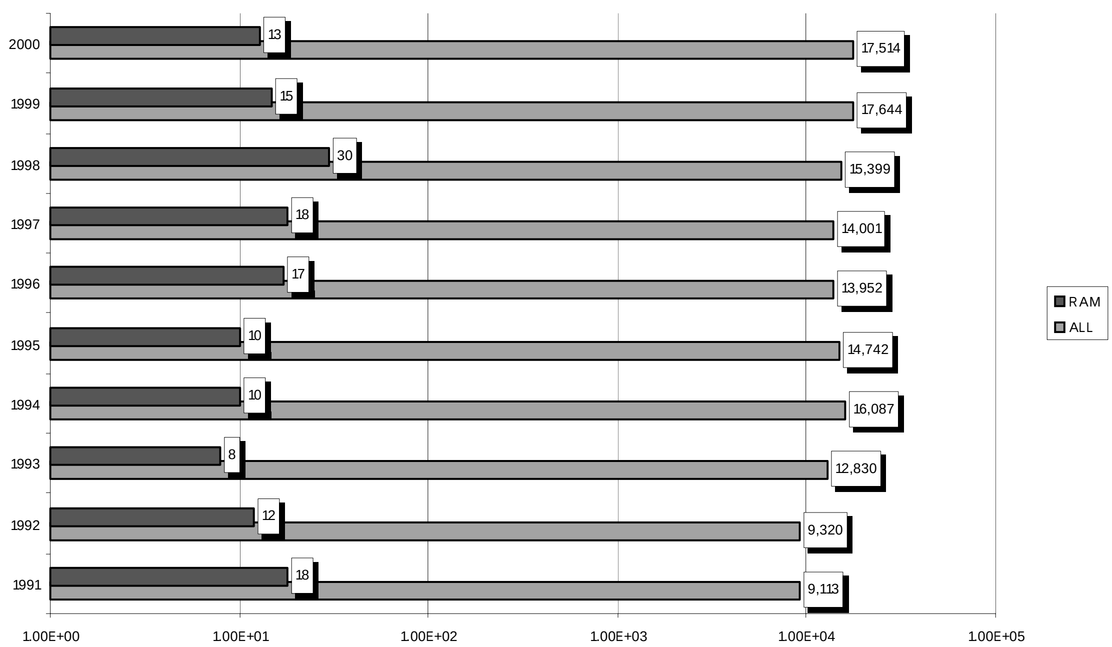

Figure 1 Ten-Year Radioactive Material Incident History

hazardous materials reports has steadily increased over the last decade, the number of radioactive material incident reports has remained nearly constant.

The safety record for radioactive material cannot be fully described, however, because the number of actual radioactive material shipments is not readily available.

Table 2 History of Hazardous Materials Transportation Incidents ALL and Radioactive Material (1991-2000)

	MODE	AIR	HIGHWAY	RAIL	WATER	TOTAL
ALL	1991	299	7,647	1,155	12	9,113
RAM	1991	1	15	1	1	18
ALL	1992	413	7,769	1,130	8	9,320
RAM	1992	3	9	0	0	12
ALL	1993	622	11,080	1,120	8	12,830
RAM	1993	7	1	0	0	8
ALL	1994	929	13,995	1,157	6	16,087
RAM	1994	4	5	0	1	10
ALL	1995	813	12,764	1,153	12	14,742
RAM	1995	3	7	0	0	10
ALL	1996	918	11,916	1,112	6	13,952
RAM	1996	8	8	1	0	17
ALL	1997	1,029	11,864	1,103	5	14,001
RAM	1997	3	9	6	0	18
ALL	1998	1,382	13,017	989	11	15,399
RAM	1998	3	9	18	0	30
ALL	1999	1,583	14,981	1,072	8	17,644
RAM	1999	5	8	2	0	15
ALL	2000	1,420	15,025	1,054	15	17,514
RAM	2000	7	4	2	0	13

Source: United States Department of Transportation, Research and Special Programs Administration, Office of Hazardous Materials Safety.

Without this value, the rate of incidents versus shipments, or the rate of shipments without incident cannot be established. No regulatory requirement for a census of radioactive material shipments exists, either by the DOT or the NRC; therefore the number of radioactive material shipments in the United States must be independently determined.

To fully characterize the safety record of radioactive material shipments, a description of both the volume (quantity) and mode of shipments is required. Shipment of radioactive material occurs in all transportation modes: air, highway, rail, and water. Small quantity shipments are sometimes made by air, while large quantities are shipped by highway or rail. The increased demand for radiopharmaceuticals has had a substantial impact on the number of small quantity shipments; this, along with other changes in the market for radioactive materials, was one of the motivations for a new data collection effort.

In both 1975 and 1985, nationwide surveys of licensed radioactive material transport in the United States were sponsored by federal agencies. Data from these surveys are employed in, among other things, estimates of the safety and potential environmental impacts resulting from transport of radioactive material. Since the performance of the last survey in 1985, the number of radioactive material licensees shippers has increased from approximately 15,000 (Sandia 1985) to 22,000 (NRC 1998). Determining the number of radioactive material packages shipped, and the number of shipments in a year were principal objectives of this study.

1.1 Previous Studies

Two studies conducted within the last 15 years provide a basis for comparison for the current analysis effort. These are the studies conducted for Sandia National Laboratory by SRI (1985) and a study conducted by the Canadian government in 1992. Each provides a critical structure and baseline for estimating what the true number of shipments moved in the United States may be.

<u>1985: Transport of Radioactive Material in the United States</u>

"Transport of Radioactive Material in the United States," details the results of the most recent comprehensive survey of radioactive material shipments. That study sought to provide the NRC with a computer compatible database of radioactive material transportation information. The four-phase project involved an evaluation of data collection instruments and protocols from initial visits with shippers at 30 firms to enlist a scientific sample of industry representatives who would agree, in advance, to "scientifically sample from among their shipment records and provide that data to the contractor."

SRI sampled from 2,800 individual firms. Of those, 518 could not be contacted or declined to cooperate, about 1,369 (49%) turned out to be nonradioactive material shippers and were not asked to complete a survey. Finally, 883 firms were sent data collection forms, of which 263 returned complete shipment data.[4] The ratio of

[4] SRI SANDIA 84-7174, page 9.

respondent licensees to the total number of licensees (263/14,597) may have resulted in some under representation of the universe of shippers.

Based upon their sample of 17,334 packages shipped by respondents during the sampling period (about 1 month), SRI estimated that the total number of packages shipped per year would be 837,000. Applying a population extrapolator, their estimated total number of non-radioactive material packages shipped in the United States annually was 2.79 million.

In their 1985 report, SRI provided a summary of the 1975 Battelle survey of radioactive material shipments. The total number of packages shipped (based upon the 1975 estimate) was about 2.5 million (including U.S. Department of Energy – DOE – shipments, it was about 2.8 million). This signified almost no growth in radioactive material shipments between 1975 and 1985.

<u>The 1992 Canadian Survey of Radioactive Material Shipments</u>

The 1992 Canadian survey represented a departure from the stratified statistical sampling used by Canada to gather data in earlier efforts. Sampling was undertaken by license category, with the sampling rates varying from 1 to 100 percent, depending on the license category. Both telephone contacts and survey forms were used in the effort. Survey information was supplemented with data from other reliable sources whenever possible. The supplemental data appears to have consisted primarily (and perhaps exclusively) of export permit data and reports from licensees.

The information sought from those surveyed included the following: (1) material identity and activity, (2) package and shipment types and numbers, (3) the transport index, (4) mode of transport and distance, (5) origin of shipment, and (6) import/export data. Over 350 licensees were surveyed in 1992. Less than 5 percent of those surveyed could not, would not, or did not cooperate.

The 1992 Canadian survey found that about 883,000 packages were transported in Canada in that year in nearly 740,000 shipments. These figures, it should be noted, exclude an estimated 4.5 million excepted packages.

Approximately 88 percent of the material moved by highway, 10 percent moved by air, 2 percent moved by water, and a minimal percent moved by rail.

2 BACKGROUND: ABOUT THIS STUDY

Radioactive material shipments are made in support of work in nearly every sector of American life. Six general categories are useful for describing shipments in order of volume: medicine, consumer products, industry, agriculture, scientific research, and government.

The John A. Volpe National Transportation Systems Center (Volpe Center) has undertaken an effort to account for the frequency of shipments of radioactive material by using the 1985 SRI study as a basis for estimating shipment growth. There were several challenges in using this approach; (1) changes in the authority for regulating licenses from 1985 to 1999 resulted in a transfer of authority from the NRC to individual states for nearly one-half of the licenses; (2) the categories used to describe licensee strata in 1985 were not relevant to the current distribution of licensees (thereby inhibiting the Volpe Center's ability to verify that the distribution of licenses was similar to those in 1985); and (3) some data were reported for entire market segments while other data were reported for individuals only, limiting the generalizability of the results.

In spite of these limitations, the Volpe Center has accumulated data from market sectors that represent the original 21 strata (plus DOE data) described in the 1985 SRI study. These data are reported and aggregated in this report, with estimates of reliability.

2.1 Relating the 1985 SRI Study to Current Data

In the process of collecting data during the current study, it was sometimes impossible to collect data in subgroups that matched the strata defined in 1985. In some cases, this was because industry groups reported data for several strata rather than one; or the stratifications that appeared in 1985 were no longer relevant. The illustration in Figure 2 shows how these strata were aggregated in the current study. The most important aggregations were of categories 1 (large hospitals), 2 (small hospitals), 7 (medical distributors), and 21 (radiopharmaceuticals) into the single category of radiopharmaceutical shipments. There are several reasons for this new aggregation, which are described in the section on the radiopharmaceutical industry.

Due to a single data source, categories 8 (well-logging), and 9 (radiography) were aggregated; the same source reported data for category 13 (other measuring systems) but not all road gauges. Therefore, this estimate does not report a value specifically for road gauges. Categories 5 (research reactors), 6 (academic), and 15 (R&D) were reported in an aggregate form and also aggregated in the final estimates.

Data from governmental sources (the U.S. Department of Energy) and waste shipment data are aggregate data for the entire reporting year. These are not estimates.

Some data were estimated based solely upon the values reported in the 1985 study as no data source for them could be found; this

Stratum Number	1985 Categories	Consolidation, if any
1	Large Hospitals	Moved to Category 21 - Radiopharmaceuticals
2	Small Hospitals, Clinics	Moved to Category 21 - Radiopharmaceuticals
3	Multiple licenses	Reflected in industry totals where multiple licenses are held.
4	Power reactors	Utilities Data
5	Research reactors	No Change
6	Academic	No Change
7	Medical distribution	Moved to Category 21 - Radiopharmaceuticals
8	Well Logging	Collected with Radiography Data
9	Other measuring systems	Collected with Radiography Data
10	Manufacturing distribution	Collected within other industry categories
11	Excepted quantities	Consumer Products Estimates
12	Waste	Waste Receipts
13	Radiography	Radiography
14	Irradiators (school)	NOT Collected
15	R&D	Collected with Research Reactors
16	Local Govt	No Change
17	Misc	Not collected
18	Source materials	Collected with Neutron Sources
19	Neutron sources	No Change
20	Major shippers ex 21	Not Collected As Separate Category
21	Major radiopharmaceuticals	Reported by CORAR - Industry Survey
22	DOE	Reported by DOE - ETAS

Stratum Number	1999 Categories	Strata Included
1	Utilities	4,18
2	Academic and Research Reactors	5,6,15
3	Radio-pharmaceuticals	1,2,7,21
4	Radiography, well logging	8,9,13
5	Consumer Products	11
6	Waste	12
7	Neutron Sources	19
8	Local Government	16
9	DOE	22
N/A	No longer collected	3,10,14,17,20

Figure 2 Flow Sheet: Data Categories 1985 to Present

was the case for shipments from local governments and category 18 (source materials).

Exempt quantity shipments (which includes most consumer products, such as smoke detectors, etc.) were estimated based upon data collected by the NRC. The result of the aggregation of these estimates is shown in Table 3, Summary of Estimated Packages by Strata.

Table 3 Summary of Estimated Packages by Strata

1985 Stratum Number	1985 Packages	1999 Packages
4. Utilities Power Reactors Fuel Cycle Facilities	85,700	21,699
22. Federal Government (DOE Non-Military)	31,800	40,225
21. Radiopharmaceuticals (Large Hospitals, Small Hospitals, Clinics, Medical Distribution, Major Radiopharmaceuticals)	1,264,710	17,138,756
21a. Research Radiopharmaceutical Shipments	*Not Collected Separately*	160,000
12. Waste	196,000	6,171
5. Research Reactors (Academic, R&D, Irradiator and Other)	41,850	46,035
18. Source Materials	1,310	1,441
19. Neutron Sources	264	390
8. Well Logging, Radiography, Measuring Systems	71,600	395,200
9. Gauges / Measuring Systems (not road gauges)	124,000	10,400
11 Excepted Quantities (Consumer Products)	8,820	143,950
16. Local Government and Civil Defense	27,000	27,000
1 0. Manufacturing Distribution	19,600	Values Reflected in Categories Above
3. Multiple Licenses	486,000	
20. Major Shippers	459,000	
17. Misc	84	
Total Packages	2,817,738	17,991,267

2.2 Distribution of Licensees and Licenses

Licensing of radioactive material in the United States is performed by the NRC and certain states under the Agreement State Program. These states, called Agreement States, maintain and administer independent licensing and inspection programs for radioactive material. Section 274 of the Atomic Energy Act of 1954, as amended, provides a statutory basis under which the NRC relinquishes to the states portions of its regulatory authority to license and regulate byproduct materials (radioisotopes), source materials (uranium and thorium), and certain quantities of special nuclear materials. Under this program, 32 states currently maintain and administer an independent licensing program.

Licensing requirements are risk informed and therefore vary depending upon the number and quantity of source materials used, the handling required for installation and replacement, and the level of radioactivity.

During the 1985 survey period, the analysts were able to construct a sampling frame by looking at license holders (licensees) and using the number in each category to create a 10 percent sample by strata. These strata represented nearly the universe of radioactive material licensees.

Agreement States maintain their own license tracking program, and those states are not required to provide information on the licensees to the NRC. Further, no central repository for information on nuclear materials licensees exists, nor can a universe for a sampling frame be easily constructed.

Most states that maintain their own license program follow protocols similar to the NRC's in terms of reporting, initial license applications, etc. In order to attempt to describe how the licensee distributions might differ between Agreement States and the national level held by the NRC in 1985, a few Agreement States provided information on their current distribution of licensees by category. These distributions were compared with those from the 1985 Agreement States, as listed in Table 4.

Table 4 Total Agreement State Licenses by NRC Region and State							
Region-I		**Region-II**		**Region-III**		**Region-IV**	
Maine	128	Alabama	422	Illinois	735	Arizona	290
Maryland	570	Florida	1,268	Iowa	183	Arkansas	270
Massachusetts	529	Georgia	483	Ohio	704	California	2,085
New Hampshire	85	Kentucky	406			Colorado	333
New York	1,363	Mississippi	325			Kansas	324
Rhode Island	72	North Carolina	608			Louisiana	537
		South Carolina	335			Nebraska	136
		Tennessee	557			Nevada	232
						New Mexico	218
						North	69
						Oklahoma	222
						Oregon	415
						Texas	1,493
						Utah	206
						Washington	409
Total	2,747	Total	4,404	Total	1,622	Total	7,239

Massachusetts, California, and Arkansas, as well as the NRC, provided data on their licensee distributions for this purpose. The distributions from the three states were found to reflect considerable variability; the distribution from the NRC (which is based on 28 non-Agreement States) is believed to more generally represent the current distribution of licensees. The distribution of licensees by category in 1985 was shown in "Table 1 Strata Descriptions" in Transport of Radioactive Material in the United States (Sandia 1985). The NRC distribution was compared with those from 1985, as shown in Table 5. This comparison was made because this study did not employ a sampling methodology, however it is desirable to be able to gauge the accuracy of the current results against the estimates collected in 1985. If the number of licenses and licensees in each of the strata were distributed in somewhat the same manner as they were in 1985, then, it can be argued, the number of packages and shipments in those strata should have a similar distribution. The national distribution of licensees by category helps to define expectations for the number and size of markets and industry groups who ship radioactive material.

Table 5 Licensees by Category

(1985) Stratum Number	Description	NRC % Distribution by Category	US % based upon 1985
1	Large Hospitals		3.53%
2	Small Hospitals, clinics	35.91%	24.39%
3	Multiple-licenses	0.00%	3.50%
4	Power reactors	0.00%	0.49%
5	Research reactors	0.00%	0.55%
6	Academic	1.14%	5.51%
7	Medical distrib.(not 21)	0.06%	0.60%
8	Well logging	0.71%	2.03%
9	Other measureing systems	33.56%	39.81%
10	Manufacturing, distribut.	3.86%	2.08%
11	Excepted quantities	2.31%	0.47%
12	Waste	0.20%	0.18%
13	Radiography	2.48%	4.17%
14	Irradiators (school)	2.54%	0.33%
15	R&D	9.52%	2.17%
16	Local gov't and civil defense	0.14%	7.34%
17	Miscellaneous	3.37%	0.71%
18	Source materials	2.38%	0.86%
19	Neutron sources	0.87%	0.19%
20	Major shippers (not 21)	0.00%	0.99%
21	Major radiopharmiculticals	0.95%	0.08%
		100.00%	100.00%

3. METHOD

Although broad surveys were used in previous attempts to gather this data, this form of data acquisition is very expensive, and places a significant burden upon industry. To avoid these problems, the NRC requested that the Volpe Center collect data from available (published) sources, and use information collected or maintained by industry groups. The decision was made to avoid a repeat of the scientific survey undertaken by SRI in 1985, choosing instead to use agency and private industry cooperation to collect information.

The chosen approach was to pursue the data stratum by stratum, beginning with the utilities, followed by the medical industries and continuing through all the strata.

3.1 Data Collection

In those cases where pre-existing data sources could not be found or were not available for use in this study, primary data collection efforts were pursued. Since this study did not employ a data-collection effort such as a survey, the data were collected by using information provided by others in the course of their organizational work. Many industry and trade associations that we contacted were able to provide us with data for their particular sectors. Individuals with access to such data for sectors where data were not easily accessible were contacted, and the collected data were scaled, when necessary, to create stratum level shipment and package estimates.

3.2 Estimate Reliability

Two components of reliability can be discussed with regard to these data; first is the individual reliability of each stratum estimate, and the second is the overall estimate of total package shipments. Illustrated in Table 6 are the sample sizes of sectors from which data have been collected, including those for which estimates were constructed based upon published data. In addition, the relative contribution of each strata to the final estimate of total shipments is shown. Finally, a rough estimate of the possible effect of the under-represented portion of each strata on the fraction of the estimate (and therefore the final total estimate of shipments) is described by multiplying the unreported sample (1-sample size estimate) by the percentage of the total packages estimate represented by that strata. In some cases nearly 100 percent reporting was achieved, therefore, the total estimate is not affected by any potential change in the value reported by the industry. However, in the case of some segments, such as local governments, the estimate had to be constructed from previous values or other public sources.

It is interesting to note that 96 percent of the total number of packages are in the category of radiopharmaceutical shipments. These estimates were provided by the industry, based upon a survey and their information on market characteristics. As a result, we are fairly confident that the package estimate represents about 100 percent of the market. The reliability of this estimate, as well as

Table 6 Reliability Factors by Stratum for the 1999 Estimate					
New Strata	**Description**	**Data Source / Reliability Factor**	**Estimated Percent of Strata Included in Total**	**Percent of Total Shipment Estimate**	**Effect on Reliability of Total Estimate (1-sample size * percent of total estimate)**
1	Utilities	Primary source data by individual site	37.00%	0.14%	7.56%
2	Academic and Research Reactors	Industry source, secondary/published sources	100.00%	0.26%	0.00%
3	Radiopharmaceuticals	Primary source data collected by industry, reported as gross sums	100.00%	96.11%	0.00%
4	Radiography, well logging	Primary source data collected by industry, reported as gross sums	80.00%	2.22%	4.44%
5	Consumer Products	Estimated from available published data	50%*	0.23%	11.50%
6	Waste	Primary source data provided by waste recipient sites	100.00%	0.81%	0.00%
7	Source Materials	Single industry source	10%*	0.03%	0.03%
8	Neutron Sources	Single industry source	10%*	0.01%	0.01%
9	Gauges/ Measuring Systems (not road gauges)	Primary source data collected by industry, reported as gross sums	80.00%	0.0022%	0.04%
10	Local Government	Estimated from available published data	50%*	0.03%	0.02%
11	DOE	Primary source data provided by Department of Energy	100.00%	0.17%	0.00%
			Total	100.00%	23.6%

the other sectors for which 100 percent reporting was available are likewise believed to be very high.

Since the consumer products shipments were not reported as this high level of reliability we have assumed that we may have omitted 50 percent of members of the strata. This translates into a 0.5 factor for missing data, however, when muliplied by the total package estimate contribution of this sector, the potential error resulting from the strata is 11.5 percent. In other words, using this rough estimate of the potential error contribution for this strata, we assume that the total package estimate could be higher (or lower) by 11.5 percent resulting from the error in this individual index. The sum of the calculated errors (using this technique) is 23.6 percent. This error margin is somewhat deceptive since some of the data in each stratum are based upon previously collected market data; therefore this is not an estimate that is likely to be lower by 23.6 percent, instead the estimate of total packages is probably higher (by some value between 0 and 23.6 percent) than the number reported in the final estimate table.

4 STRATUM DATA for 1999

4.1 Commercial Nuclear Power Plants

The data included shipments reported by 29 reactor sites; 13 single and 16 multiple reactor sites. These 29 sites represent 44 percent of all operating reactor sites. In total, 9,644 packages were shipped in 3,276 shipments from these facilities. To estimate the total number of packages and shipments from utilities for this time period, these values were scaled up by a factor of approximately 2.25. The data reflect 13 of 29 single reactor sites (approximately 45 percent) and 16 of 36 multi-reactor sites (approximately 44 percent). Since the volume of shipments is most likely to be related to the number of reactors at the site, our inflation factor reflects the ratio (1/0.44) of the fraction of each type of the sites reporting. This factor (2.25) when multiplied by the reported values results in 21,699 shipments and 7,371 shipments, respectively. See Table 7 below. The distribution of packages by mode of shipment as illustrated in Figure 3 is very similar to the distribution of shipments by mode, as illustrated in Figure 4. Based upon the data reported by 29 reactor sites, about 91 percent of shipments were made via highway (Figure 3) carrying 96 percent of all packages shipped (Figure 4). See also Tables 8 and 9.

Table 7 Reactor Sites

Total number of	**Single**	**Multi-**	**# of Reactors at**
Region 1	8	9	18
Region 2	6	13	28
Region 3	9	8	16
Region 4	6	6	13
	29	36	75
Total reporting	13	16	
Fraction reporting	0.448	0.444	Ratio = 2.25

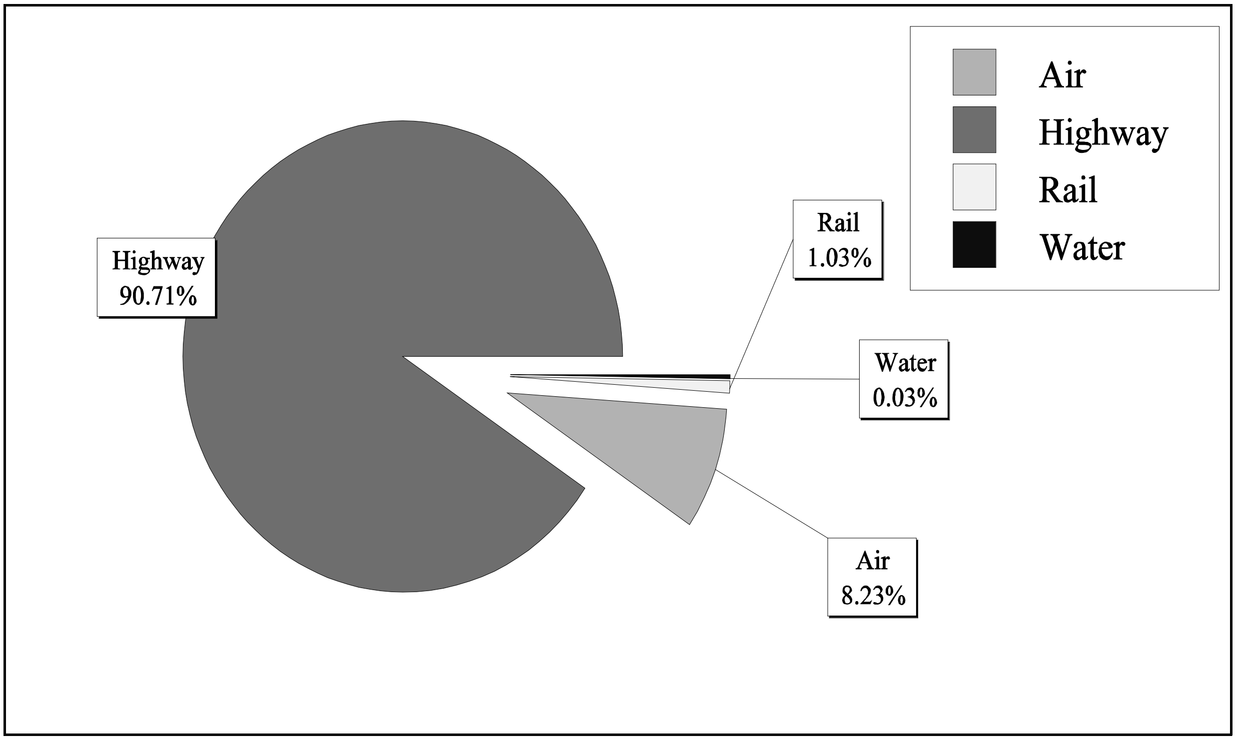

Figure 3 Utilities Shipments by Mode

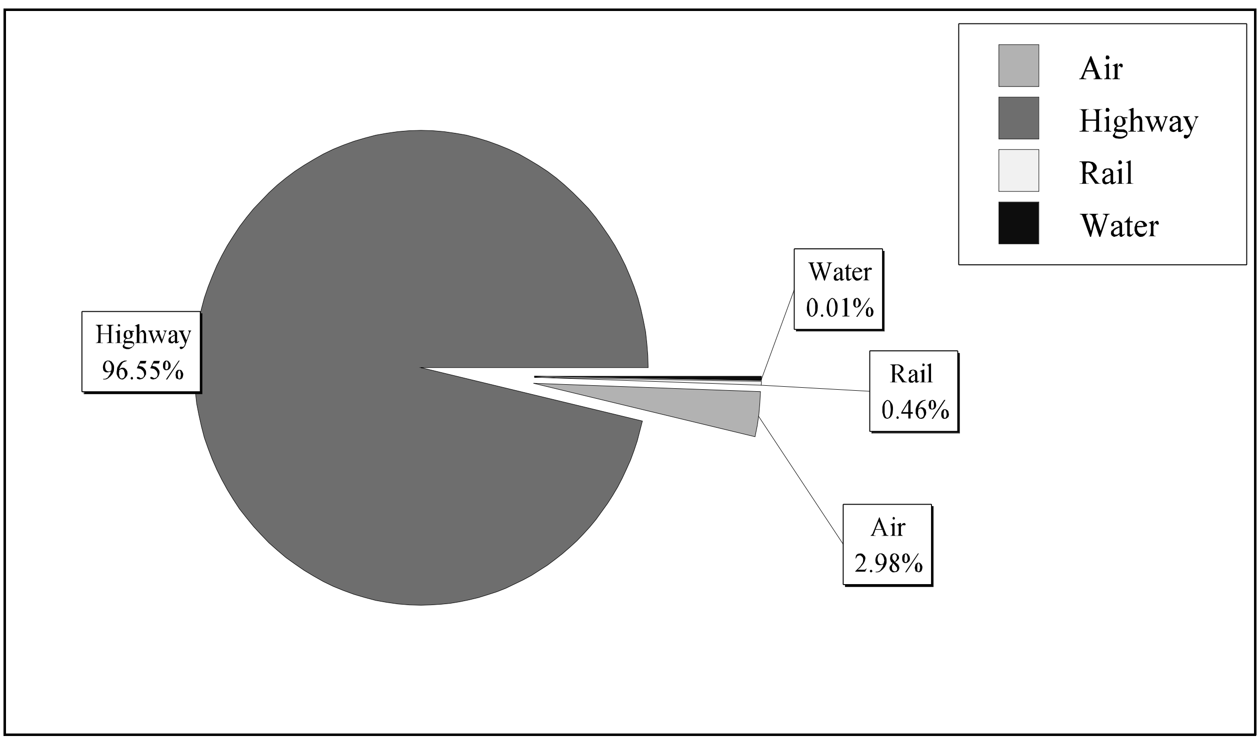

Figure 4 Distribution of Packages by Mode, Utilities Shipments

Table 8 Utility Shipments by Mode (1999)					
Mode	**Total # of Packages**	**Total # of Shipments**	**Total Activity TBq (Ci)**	**Total -TI / Package Dose Rate mSv/hr (mrem/hr)**	**Approximate Packages per Shipment**
Air	287	264	2.44 E-4 (6.6 E-3)	0.013 (1.3)	1
Highway	9,312	2,911	5.55 E-5 (1.5 E-3)	0.013 (1.3)	3
Rail	44	33	4.07 E-5 (1.1 E-3)	0.015 (1.5)	1
Water	1	1	5.55 E-5 (1.5 E-3)	0 (0)	1

Table 8 provides detail by mode on the numbers of shipments and the numbers of packages that the utility industry ships. As can be seen in the table, shipments by air, rail, and water generally consist of a single package. Shipments by highway, on the other hand, generally consist of approximately three packages.

4.2 Fuel Cycle Facilities

The domestic fuel cycle facilities are undergoing considerable change. Currently there are a few mines and mills that are operating. There is only one operating conversion facility and one operating enrichment plant. There are four operating fabrication facilities that support the commercial sector and two fabrication facilities that support the Naval Nuclear program. The primary mode of transportation of radioactive material to or from these facilities is by highway.

For 1999, data are available for the enrichment plants. In 1999, there were two plants in operation. This datum can be found in Table 9, Utility Data Summary from Fuel Cycle Facilities. The distribution of shipments by mode of transportation is very similar to the distribution of shipments from utilities as illustrated in Figure 5.

Table 9 Utility Data Summary from Fuel Cycle Facilities			
Shipments From Fuel Cycle Facilities	**Truck**	**Rail**	**Air**
Uranium Hexafluoride, non-fissile (U depleted)	414	109	0
Uranium Hexafluoride, fissile (enriched to 5%)	1233	64	0
Residue, Uranium Hexafluoride, non-fissile (U natural)	802	0	0
Residue, Uranium Hexafluoride, fissile	0	0	0
Radioactive Material LSA n.o.s. (Low Level Waste)	125	0	0
Miscellaneous waste	73	0	0
Miscellaneous Radioactive sample shipments	107	0	85
Total Outbound Shipments	2754	173	85

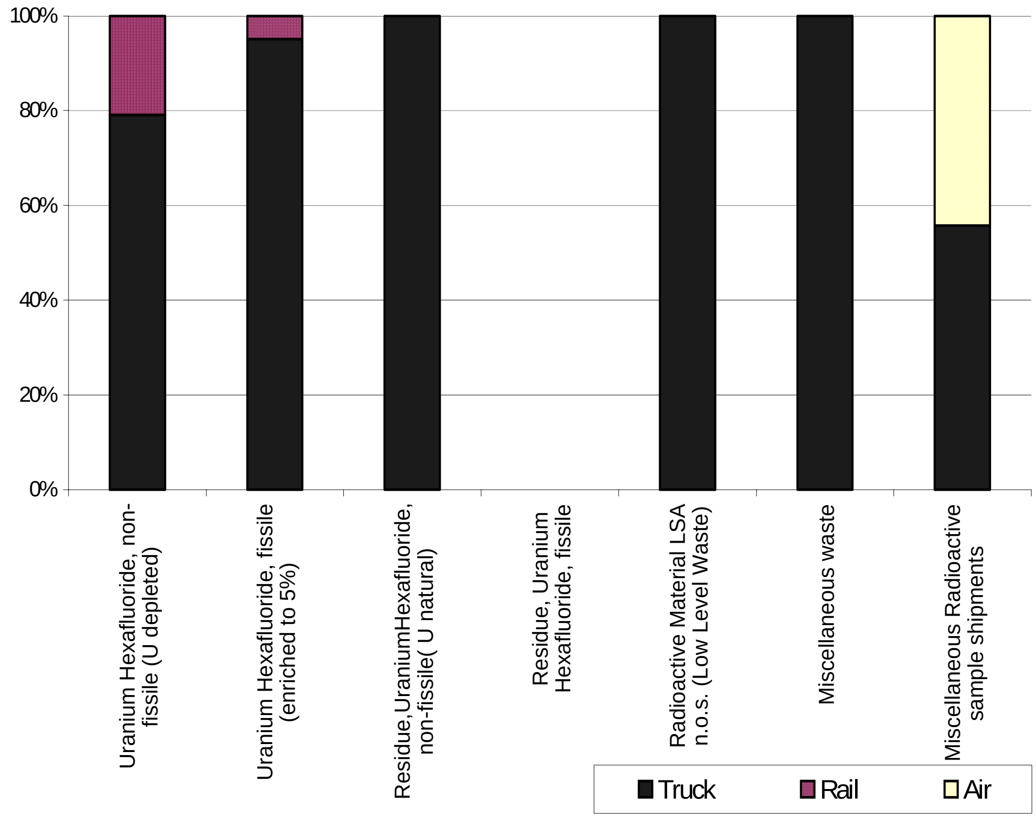

Figure 5 Fuel Cycle Facility Shipments (1999) Provided by NEI

4.3 Radiopharmaceutical Shipments

The Council on Radionuclides and Radiopharmaceuticals (CORAR) provided the estimate of total radiopharmaceutical shipments in the United States reported in this study. "CORAR is a national nonprofit association of United States and Canadian companies that manufacture, develop, and distribute radiopharmaceuticals, radionuclides, radiochemicals, and other radioactive products primarily used in medicine and life science research. CORAR members have dedicated significant resources to the research, development, manufacture, and distribution of radioactive products for medical research and clinical use. Over 98 percent of nuclear medicine procedures in the United States are performed with products manufactured by CORAR members."[5] The estimate of total shipments provided in Table 10 includes shipments from manufacturers directly to hospitals, manufacturers to central radiopharmacies, from central radiopharmacies to hospitals, and return shipments of residual radiopharmaceuticals from hospitals to manufacturers. They do not reflect intra-hospital shipments, or radiochemicals for life science and other research applications. The number of these shipments is not estimable from data provided by CORAR for this study.

In comparison with the estimate of the number of radiopharmaceutical shipments in the 1985 survey, the total number of shipments has increased by a factor of over 13. The total estimated packages reportedly shipped in 1985 were approximately 1.3 million. Most of these packages were assumed to have been shipped individually. The estimate provided by CORAR to the Volpe Center for total shipments in 1999 is approximately 17.1 million (not including research-related radionuclide shipments made by the radiopharmaceutical industry). Due to the enormous difference between the 1985 and 1999 estimates (Table 10), the Volpe Center asked that CORAR provide an explanation for what has happened in the industry that resulted in this large increase. To avoid revealing any sensitive information about the industry, including market research studies that provided some of the basis for the current estimate, CORAR's explanation is primarily based upon trends in the number of treatments provided to patients, and the fact that central radiopharmacies (as opposed to hospital pharmacies) presently provide individual doses for treatments. In the past, most individual treatments were provided by hospitals, while central radiopharmacies provided the source materials to individual hospitals from which these doses were made.

Radiopharmacies and doses from radiopharmacies are relatively new; in 1978, the number of companies in the field was approximately 10 and the number of procedures delivered annually was approximately 6.2 million.[6] At that time, CORAR estimates that only about 5 percent of those doses were delivered by central radiopharmacies, the rest being delivered by local hospitals, clinics, etc.

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[5] CORAR's members include Berlex Laboratories, Inc., Bracco Diagnostics, Inc., Bristol-Myers Squibb, Corixa Corporation, DuPont Pharmaceuticals Co., Mallinckrodt, Inc., MDS Nordion, PerkinElmer, Life Science Products, Inc., Nycomed, Amersham and Syncor Pharmaceuticals, Inc. *http://www.corar.org.*

[6] CORAR 1989 "Market Measures Trend Data."

By 1985, the number of radiopharmacies had increased to about 153, and the number of doses delivered increased to approximately 7.2 million.

All three of these indicators continued on an upward trend through the 1980s and 1990s. The number of radiopharmacies increased to 167 in 1991[7] and 299 in 2000, the number of doses delivered by radiopharmacies increased from 30 percent of all doses delivered in 1985 to 55 percent in 1988, 64 percent of all doses (approximately 6.5 million) in 1991, and 74 percent of all doses in 2000[8] (approximately 10 million). Most shipments made by radiopharmacies are single-dose shipments, although some multiple package shipments were reported. For every dose-related shipment, one return shipment is generated, therefore the CORAR estimate of approximately 8.7 million outgoing and 8.4 million return shipments is consistent with the market research data on dose delivery for the same time period.

CORAR provided estimates of the number of shipments by mode; over 98 percent of shipments reported for 1999 were by ground transportation (Table 11).

The data provided in Tables 10 and 11 are therefore assumed to be highly reliable estimates of the total shipments of radiopharmaceuticals in the United States. Most of the packages shipped from radiopharmaceuticals are transported by highway, and are likewise returned by the ground mode.

CORAR also provided estimates of shipments for nonresearch materials by isotope and activity; these data are summarized in Table 12. The total activity of radiopharmaceutical isotopes in 1999 is described in Table 12. Ninety-two percent of the total activity results from shipments of Mo-99 and Tc-99m.

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[7] Frost and Sullivan, 1992. "The United States Market for Radiopharmaceuticals" – Fall 1992 – Report A2532, reported with permission from CORAR.
[8] Bio-Tech Systems, Inc. "The United States Market for Diagnostic Radiopharmaceuticals" Report 120 reported with permission from CORAR.

Table 10 Summary of Reported Radiopharmaceutical Shipments 1999		
Number of Packages	**52 weeks**	**Percent**
Limited Quantity	2,704	0.02%
White I[9]	6,985,596	40.76%
Yellow II	1,613,533	9.41%
Yellow III	140,972	0.82%
LSQ[10] returns	8,395,951	48.99%
Totals	17,138,7566	100%

Table 11 Summary of Reported Radiopharmaceutical Shipments 1999 by Mode		
Mode	**52 weeks**	**Percent**
Ground	16,806,996	98.06%
Air	331,760	1.94%
Total	17,138,756	100%

Table 12 Summary of Reported Nonresearch Radiopharmaceutical Shipments (1999) by Percent of Total Activity		
Radionuclides	Activity TBq (Ci)	Percent of Total
Mo-99	31,314.21 (846,330)	65.18%
Tc-99m	12,888.543 (348,339)	26.83%
Xe-133	1,230.916 (33,268)	2.56%
Tl-201	1,005.882 (27,186)	2.09%
I-131	487.697 (13,181)	1.02%
P-32	401.894 (10,862)	0.84%
Ga-67	121.693 (3,289)	0.25%
I-125	52.725 (1,425)	0.11%
I-123	48.359 (1,307)	0.10%
In-111	32.375 (875)	0.07%
Subtotal	47,584.294 (1,286,062)	99.05%
All others	457.357 (12,361)	0.95%
TOTAL	**48,041.651 (1,298,423)**	**100**%

9 Radioactive White I, Yellow II, or Yellow III labels are specified in U.S. Department of Transportation regulations 49 CFR 172.403 and 172.436-440

10 LSQ refers to LSA quantities (Low Specific Activity - Limited Quantity Shipments).

4.3.1 Research Radionuclide Shipments

CORAR provided the Volpe Center with estimates for research-related radionuclide shipments for 1999. These shipments were provided as estimates (ranges from low to high values) (see Table 13). Table 14 summarizes the activity ranges for radionuclides shipped for research reported by CORAR. Estimates provided by CORAR are that 98 percent of these shipments are made by air, the balance by ground transportation.

Table 13 Summary of Reported CORAR Research Radionuclide Shipments (1999)

Number of Packages (2)	Low	High
Limited Quantity	100,000	300,000
White I	30,000	100,000
Yellow II	30,000	100,000
Totals	**160,000**	**500,000**

Table 14 Summary of Reported Research-Related Radionuclide Shipments

	Range in TBq (Ci) Activity	
Radionuclides	**Low**	**High**
H-3	9.99 (270)	30 (811)
C-14	0.99 (27)	2.99 (81)
P-32	2.99 (81)	9.99 (270)
P-33	0.296 (8)	0.99 (27)
S-35	0.99 (27)	2.99 (81)
I-125	0.296 (8)	0.99 (27)
All Others (3)	0.296 (8)	0.99 (27)
Total	**15.91 (430)**	**48.99 (1,324)**

5 DEPARTMENT OF ENERGY ENTERPRISE TRANSPORTATION ANALYSIS SYSTEM (ETAS)

Some data on United States Department of Energy shipments were readily available through published government sources. The United States Department of Energy (DOE) Transportation Activities Summary Report for Fiscal Years is based on data submitted through the Shipment Mobility Accountability Collection (SMAC) system. SMAC is an unclassified, computer-based historical transportation information system funded by DOE Office of Environmental Management, Office of Transportation, Emergency Management, and Analytical Services. These data are collected annually on DOE shipments and provide a general basis for estimating the types and expected volumes of shipments for non-governmental shippers as well as those under the DOE. DOE data attached to this report is from the Enterprise Transportation Analysis System (ETAS), which is a DOE-wide shipment summary by origin, destination and commodity for shipments containing radioactive material for the period August 1, 1998 through July 31, 1999.

A summary of the total number of shipments, packages, activity and transport index (TI)[11] for ETAS shipments appears in Table 15, DOE Shipments by Mode (1999). The most frequent mode of shipment is highway, which is also the mode by which the highest number of packages per shipment were made.

Using a United Nations Identification number (UNID, an international identifier used for materials classification) to categorize shipment data, allows both for a better understanding of the particular shipments made by DOE during the year for which data are provided as well as a more general understanding of the distribution of shipments by curie level and transport index. The distribution of shipments by UNID is shown in Figure 6. For the presentation of these data the following UNID numbers are used: UN2910 - Radioactive material - excepted package - limited quantity of material; instruments or articles; articles manufactured from natural or depleted uranium, or natural thorium; and Empty packaging; UN2912 - Low Specific Activity (LSA) material; UN2918 - Radioactive material, fissile, n.o.s.; UN2974 - Radioactive material, special form, n.o.s.; UN2982 - Radioactive material, n.o.s.

[11] Transportation index (TI) is defined in U.S. Department of Transportation regulation 49 CFR 173.403.

Table 15 DOE Shipments by Mode (1999)				
	Total # of Packages	Total # of Shipments	Total Activity TBq (Ci)	Total TI
Air	3,311	2,777	9,287 (251,000)	821
Highway	36,510	4,876	21,090 (570,000)	3,060
Rail	404	102	2.1571 E-4 (0.00583)	not available
Total	40,225	7,755	30,377 (821,000)	3,881

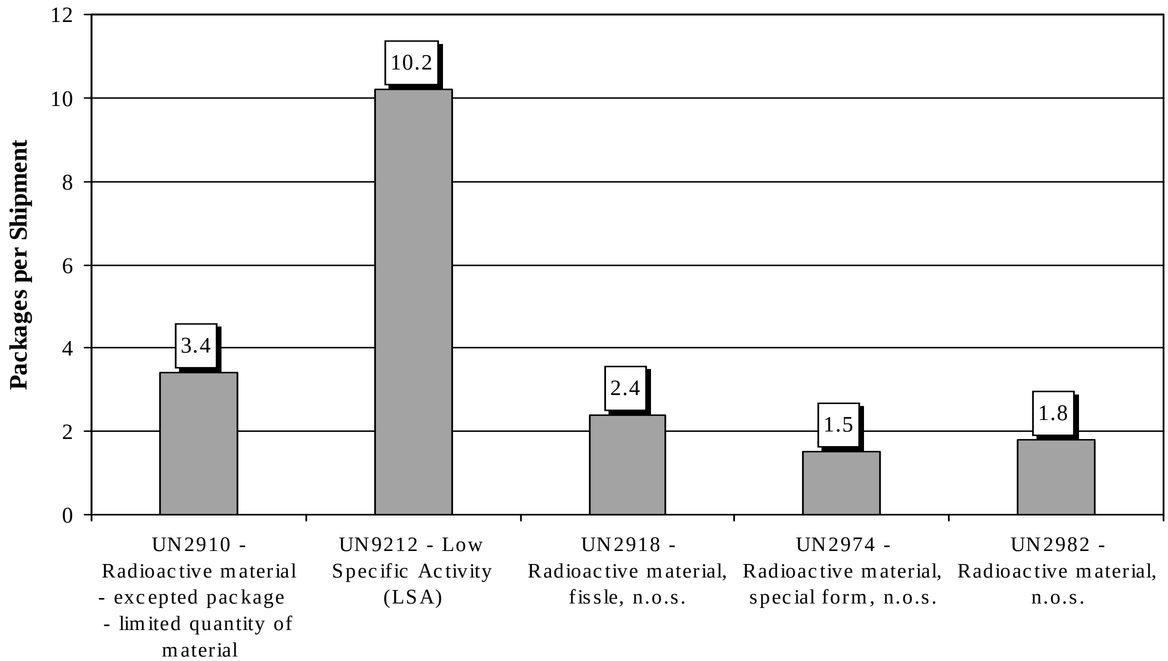

Figure 6 DOE ETAS Data: Total Shipments by UNID

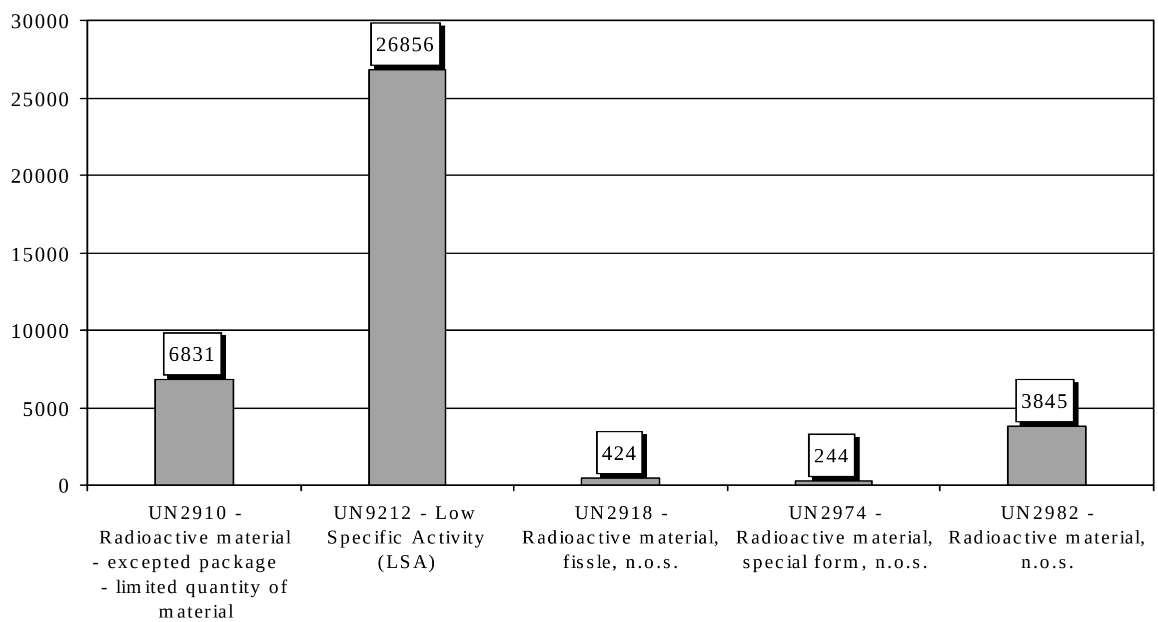

Figure 7 DOE ETAS Data: Total Packages by UNID

The distribution of the number of packages shipped by UNID is illustrated in Figure 8 and the number of packages per shipment in Figure 8. The most frequently shipped type of package is the LSA UNID 2912. The ETAS data report approximately 27,000 packages shipped during the study period. These packages were shipped at the highest rate per shipment (see Figure 8).

5.1 Distribution of Package TI

Package TI aggregates were calculated for the same set of packages by UNID number described in Figures 6, 7, and 8. The aggregate for all packages shipped as reported in the ETAS data appear in Figure 9.

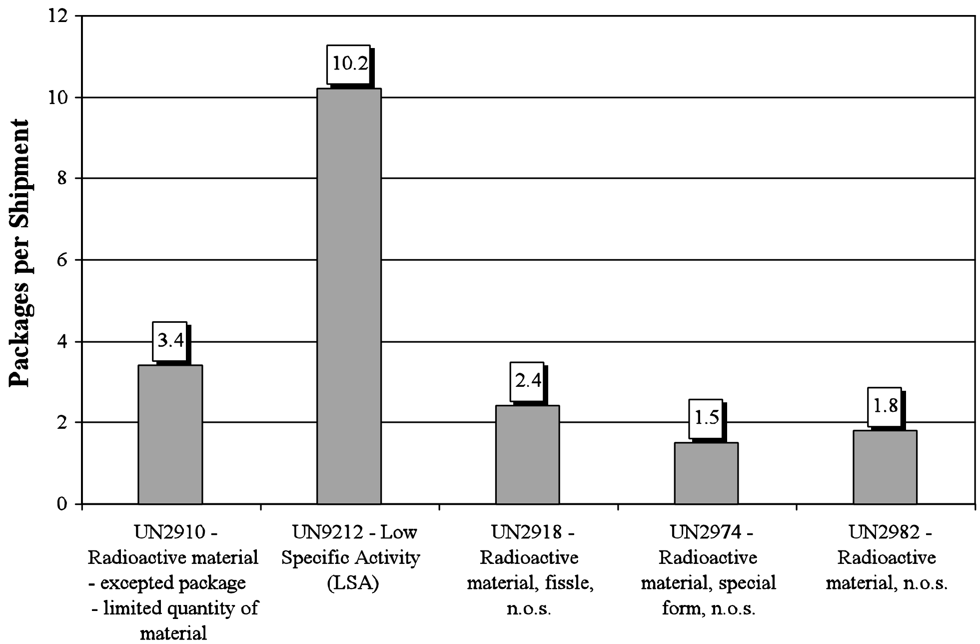

Figure 8. DOE ETAS Data: Packages per Shipment by UNID

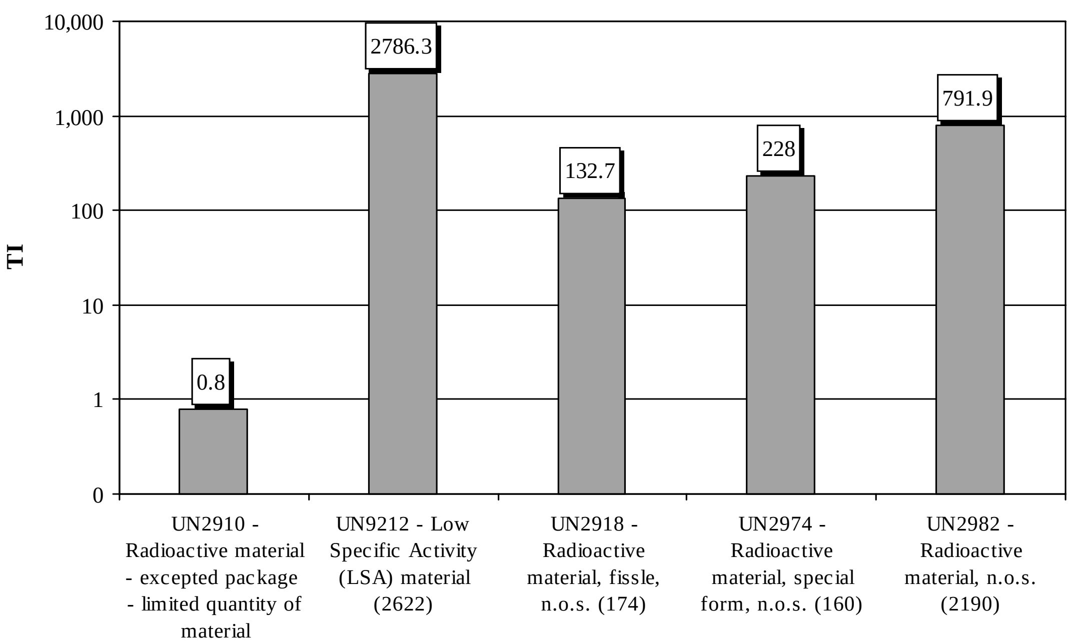

Figure 9. DOE ETAS Data: Aggregate Total TI by UNID

The distribution of TI by package and shipment is described in Figures 10 and 11. The shipments are grouped by the reported TI level (0 to over 18.2) in terms of the frequency of the number of shipments (Figure 10) and packages (Figure 11), respectively. The majority of shipments reported by DOE have a TI ranging from 0 to 0.5 (75%), TIs ranging from 0.5 to 2.1 represent the 15 percent between 75th and 90th percentiles and the remaining 10 percent of shipments have TIs between 2.1 and 18.2. (See Figure 10).

Figure 11 illustrates the distribution of TI by package, using the same percentile distributions as the shipment data. The majority of packages shipped (approximately 38,000) have TIs between 0 and 0.5.

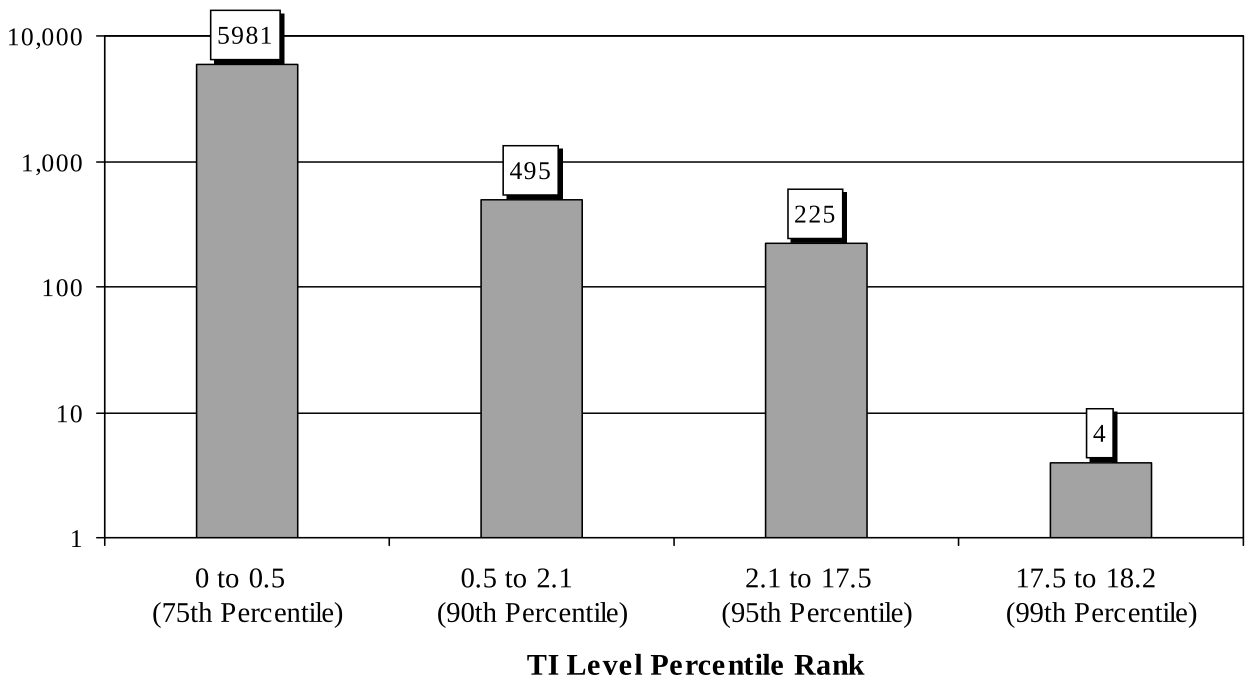

Figure 10. DOE ETAS Data: Total Shipments by TI Level Range

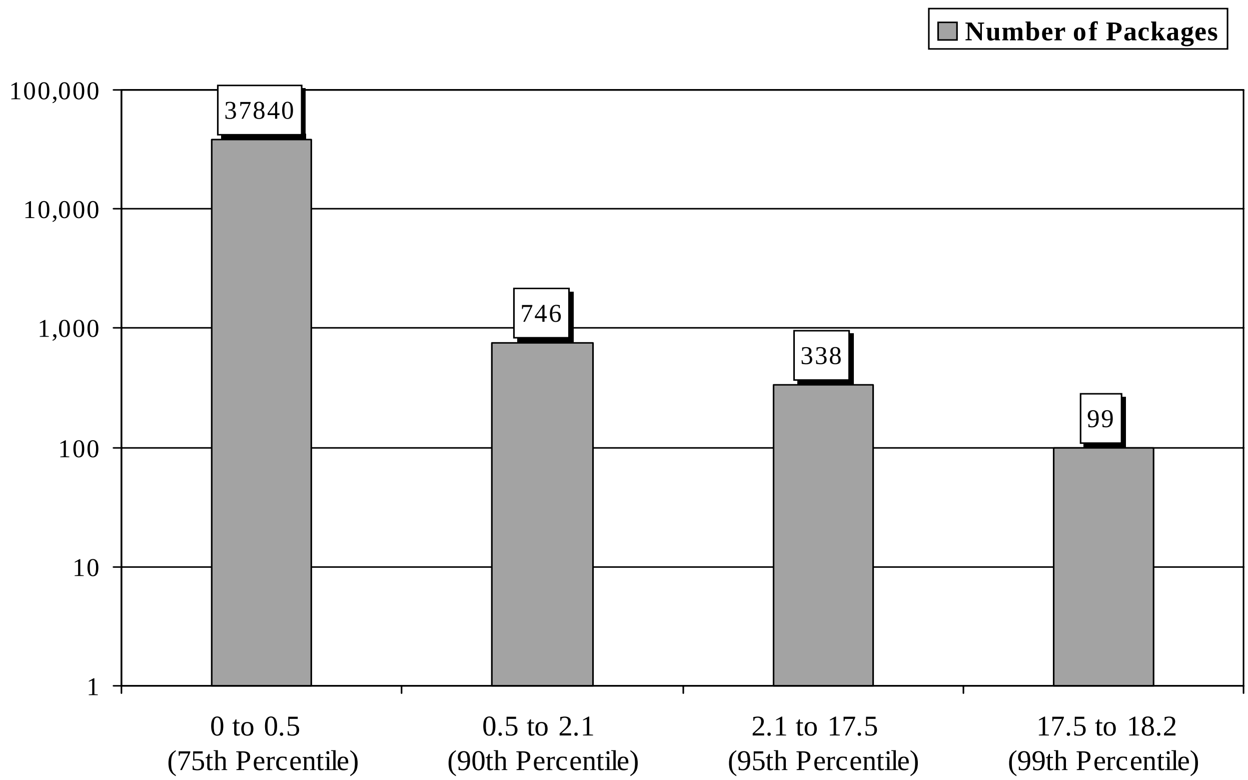

Figure 11. DOE ETAS Data: Total Packages by TI Level Range

6 WASTES

Types of radioactive wastes frequently shipped in the United States are Low-Level Radioactive Waste (LLRW or LLW) and "Naturally Occurring or Accelerator Produced Radioactive Materials" (NARM). A significant portion of NARM is "Naturally Occurring Radioactive Materials" (NORM).

LLW is radioactive waste conforming to the definition of Low-Level Radioactive Waste specified in the Low-Level Radioactive Waste Policy Amendments Act of 1985. LLW is covered by the Atomic Energy Act and is regulated by the NRC. NARM, on the other hand, is radioactive material that is not covered by the Atomic Energy Act and not regulated by the NRC. It may be naturally occurring or produced by an accelerator. NARM wastes are frequently regulated by the states. NORM, naturally occurring radioactive materials with enhanced radioactivity, is a subset of NARM.

6.1 Waste Disposal Facilities

In the United States, LLW, NARM, and NORM, with certain exceptions, are currently shipped to the following commercial low-level radioactive waste disposal facilities:

- Chem-Nuclear Systems, Inc., Barnwell, South Carolina
- Envirocare of Utah, Clive, Utah
- United States Ecology, Richland, Washington

Formerly, wastes were also sent to a commercial facility at Beatty, Nevada; however, this facility stopped receiving wastes in the early 1990s.

6.2 Waste Data Source

Information about the wastes received at the three currently active low-level waste repositories is available from the United States Department of Energy's (United States DOE's) Manifest Waste Management System (MIMS). MIMS can be accessed online at *http://mims.mactec.com/*. The information that can be accessed using MIMS on-line includes volume, activity, isotopes, generators, and waste categories. Information can be broken out in a variety of ways, including by state, year, and waste facility. Detailed information can be obtained on individual generators, isotopes, and manifests.

The MIMS database includes only LLW and NARM disposed of at commercial facilities. It does not include any wastes disposed of at federal government facilities. Additionally, MIMS only reports on wastes being disposed of at the commercial facilities by commercial or non-defense government sources. It does not include wastes being disposed of at the Waste Isolation Pilot Plant (WIPP) or at Envirocare in Utah by the U. S. DOE.

6.3 Waste Shipments in 1999

For this report, the focus is on the disposal of LLW, since only LLW is covered by the AEA and regulated by the NRC. Table 16 presents the total LLW waste shipments for all states in 1999 by waste disposal facility. MIMS does not identify the number of shipments made. Instead, shipment information is broken out by manifest and by container. In deriving the package numbers in Table 16, the number of packages arriving at Envirocare were assumed equal to the number of manifests. Additionally, the shipment column in Table 16 was derived by assuming that each manifest represents one shipment. These assumptions, however, were not verified.

6.4 Selected Sources

The following sources were consulted in the preparation of this section:

Mixed Waste Glossary, EPA, Radiation Protection Program, Mixed Waste Team, *http://www.epa.gov/radiation/mixed-waste/mw_pg5.htm*.

Manifest Information Management System (MIMS) website, *http://mims.mactec.com/*.

Communication from Ronald L. Fuchs, Idaho National Engineering and Environmental Laboratory (INEEL), July 27, 2000. (MIMS was formerly maintained for the United States DOE by INEEL.)

Table 16 Total Waste Shipments – All States (1999)

	Volume m^3 ($feet^3$)	Activity TBq (Ci)	Packages	Shipments
Barnwell	4,730.70 (167,063.13)	12,100.04 (327,028)	3,270	814
Richland	3,759.56 (132,767.52)	57,338.46 (1,549,688)	1,244	190
Envirocare	880,24946.06 (961.69)	8.89 (240.2547)	1,657	1,657
TOTAL	33,436.32 (1,180,792.34)	69,447.38 (1,876,956.25)	6,171	2,661

Source: MIMS

7 EXEMPT QUANTITY SHIPMENTS - CONSUMER PRODUCTS

The possession, use, and transfer of certain products or materials containing radioactive source and byproduct material are exempted from the requirements for domestic licensing under Title 10 of the *Code of Federal Regulations*. Many of the exemptions are for various consumer products. Some of the exemptions, it might be noted, are for products and materials that have never been manufactured, transported, or distributed (in commercial quantities). Others are for items that were formerly manufactured, transported, or distributed in the United States, but that activity has now ceased.

A wide variety of products and materials currently in use are exempted from the requirements for domestic licensing. These include many familiar types of products. Timepieces and clocks with dials and hands containing minute quantities of radioactive material that cause them to glow in the dark are exempted. Incandescent gas mantles containing thorium, which are sometimes used in the portable lanterns familiar to campers, also are exempted. This section provides information on products and materials for which an exemption exists that are currently manufactured. It does not address the transport and distribution of items that are no longer manufactured. Thus, it does not address the transport and distribution of, for example, Fiesta Ware, which had a slightly radioactive glaze, even though it is a collectible and there is undoubtedly some transport and distribution of it at present.

The chapter also does not address the transport and distribution of products and materials considered for exemption by the NRC, but which had not received an exemption as of 1999. This includes static eliminators, which the NRC's "Systematic Radiological Assessment of Exemptions for Source and Byproduct Materials," NUREG-1717, "Systematic Radiological Assessment of Exemptions for Source and Byproduct Materials" (see Section 7.3 for complete citation) indicates are mainly covered by a general license rather than by an exemption.

7.1 Data Source

Current information on the quantities of most exempt products and materials being manufactured, transported, or distributed is very difficult to obtain. For that reason, this chapter relies exclusively on estimates developed for NRC's NUREG-1717. That report estimated the quantities of a number of products exempted and materials being manufactured. It also identified those exempt products and materials that are no longer manufactured. NUREG-1717 is, as stated in its abstract,

> …an assessment of potential radiation doses associated with the current exemptions from licensing for the majority of Part 30 byproduct and Parts 40 and 70 source material in Title 10 of the *Code of Federal Regulations* (CFR)….In addition, assessments of potential doses due to accidents and misuse were estimated.

The basic purpose of NUREG-1717, thus, is not the estimation of the quantity of products and materials with exemptions that are currently manufactured, transported, and distributed in the United States Rather, those estimates, when available, are an input used to calculate dose levels. When unavailable, the report uses values based on staff judgment.

This section uses those numbers derived for NUREG-1717 for which there is a basis. The arbitrary values used in NUREG-1717 are not used in the estimates presented in this chapter. Also, at least once, NUREG-1717 derived multiple estimates and then proceeded to use the one with the greatest value. In this situation, this chapter uses the most reasonable estimate, and not necessarily the greatest one.

7.2 Exempt Products and Materials Shipments in 1999

Table 17, Summary of Exempt Products and Materials, presents estimates of the total quantities and the numbers of shipments for all states by exempt product or material. The table lists all exemptions, plus the main products and materials in each category. Some of the exemptions have never been used (i.e., products or materials covered by the exemption have never been manufactured, transported, or distributed in commercial quantities). When this is known to be the case, a zero value has been entered in the table. Also, some exemptions cover materials and products that are no longer manufactured, transported, or distributed in the United States. When this is known to be the case, a zero value has also been entered in the table.

Generally, usable shipment estimates were not available from NUREG-1717. Consequently, except in those few cases where usable shipment estimates were available, shipments were derived from quantities by assuming that (1) all shipments contain 1,000 items and (2) no item is shipped more than once. Because values are not available for all of the exempt products or materials listed in the table, the shipment total at the bottom of the table represents a lower bound on the number of shipments of exempt products and materials that were made.

As can be seen in Table 17, the largest category of exempt products appears to be electron tubes. An estimated 84.5 million tubes are manufactured and distributed per year. Electron tubes can contain minute quantities of 3-H, 60-Co, 63-Ni, 85-Kr, 137-Cs, or 147-Pm. The tubes can be found in a wide variety of products, including household appliances, electronic games, electronic instruments, communications equipment, voltage arrestors, and surge protectors. Incandescent gas mantles rank second in the table with 25 million produced per year. Smoke detectors and vacuum tubes in microwaves tie for third with 10 million of each produced per year.

Table 17 Summary of Exempt Products and Materials			
Exemption*	Product/Material*	Estimated Annual Quantity**	Estimated Annual Shipments** (Thousands)
A. Byproduct Material Exemptions			
1. Concentrations of Byproduct Material	Irradiated Topaz Gemstones	2.25 million	2.3***
	Other	unk	unk
2. Timepieces, Hands, and Dials	Timepieces containing 3-H	1.6 million	1.6***
	Timepieces containing 147-Pm	0.2 million	0.2***
3. Electron Tubes	Electron Tubes	84.5 million	84.5
4. Ionizing Radiation Measurement Instruments Containing, for Purposes of Internal Calibration or Standardization, One or More Sources of Byproduct Material	241-Am Sources for Instruments	unk	unk
	133-Ba Sources for Instruments	12	unk
	36-Cl Sources for Instruments	72	unk
	60-Co Sources for Instruments	2	unk
	137-Cs Sources for Instruments	631	unk
	55-Fe Sources for Instruments	19	unk
	90-Sr Sources for Instruments	29	unk
	99-Tc Sources for Instruments	5	unk
5. Quantities of Byproduct Material	Various Radionuclides	unk	unk
6. Self-Luminous Products	Electronic Watches	unk	unk
	Gun Sights	unk	unk
7. Gas and Aerosol Detectors	Smoke Detectors	10 million	10***
	Chemical Detectors	unk	unk
B. Source Material Exemptions			
1. Chemical Mixture, Compound, Solution, Alloy Containing <0.05 Percent by Weight of Source Material	Various	unk	unk
2. Incandescent Gas Mantles	Gas Mantles	25 million	25***
3. Thorium in Vacuum Tubes	Vacuum Tubes	0.1 million	0.1***
	Tubes in Microwaves	10 million	10***
4. Welding Rods Containing Thorium	Welding Rods	5 million	5***
5. Thorium in Electric Lamps for Illuminating Purposes	Electric Lamps	unk	unk
6. Thorium in Germicidal Lamps, Sunlamps, and Lamps for Outdoor or Industrial Lighting	Lamps	unk	unk

Table 17 Summary of Exempt Products and Materials (continued)			
Exemption*	Product/Material*	Estimated Annual Quantity**	Estimated Annual Shipments** (Thousands)
7. Rare Earth Products Containing Less Than 0.25% by Weight of Source Material	Many Products	unk	unk
8. Thorium in Personnel Neutron Dosimeters	Dosimeters	0.08 million	0.375
9. Piezoelectric Ceramic Containing Not More Than 2 Percent by Weight of Source Materials	Ceramic	0.2 million	2***
10. Glassware	Glassware	unk	unk
11. Finished Tungsten- or Magnesium-Thorium Alloy Products or Parts	Magnesium-Thorium Items	100 kg	unk
	Tungsten-Thorium Items	Counted Elsewhere	---
12. Uranium in Counterweights	Counterweight for planes, etc.	600	unk
13. Uranium Shielding in Shipping Containers	New, Unused Containers	120	0.12
	Containers in Use	2 thousand	2
14. Thorium in Finished Optical Lenses	TV Camera Lenses	unk	unk
	Photographic Camera Lenses	unk	unk
	TOTAL	>138.9 million	>143.95

Notes:
*Exemptions and products/materials with 0 quantity and 0 shipments have not been included in this table.
**Estimates presented in this table may differ from those used in NUREG-1717.
***Estimated assuming (1) 1000 items per shipment and (2) all items are shipped only once.
> = Greater than
unk = Unknown
Source: Based on estimates developed for NUREG-1717.

7.3 Selected Sources

The following sources were consulted in the preparation of this section.

"Environmental Assessment of Consumer Products Containing Radioactive Material," NUREG/CR-1775, Prepared for the NRC by Science Applications, Inc., October 1980.

Systematic Radiological Assessment of Exemptions for Source and Byproduct Materials," NUREG-1717, Prepared for the NRC by Oak Ridge National Laboratory and J. Stewart Bland Associates, Inc., June 2001.

8 OTHER DATA

8.1 Radiography and Well-logging

Radiography is a process that employs radioactive material to measure, gauge, or trace the flow of materials in inaccessible locations or sealed containers. Radiography is also frequently employed in remote locations where traditional X-ray imaging technology is too cumbersome. Gamma radiography is similar to X-rays in that gamma rays pass through objects and are used to produce an image of the object on film. Unlike traditional X-ray imaging technology which require large bulky equipment for production, and must be used where electricity is available, gamma-based radiographic devices employ small pellets of radioactive material in a sealed container (usually titanium). Due to the fact that these small sources can be easily transported and employed in almost any environment, field use of radiographic equipment is frequent. Applications such as weld inspections are often performed using this type of equipment. Due to its wide application, transportation of the radioactive sources and the devices in which they are used is frequent throughout the world.

Gamma applications in gauging range from estimates of the thickness of film, to pavement, to the height of coal in a rail hopper. The basic principle is that the intensity of radiation from a radioisotope is known, and materials between it and a detector absorb a certain amount of this radiation. The process can be used to measure thickness, as well as coatings on surfaces (such as road surfaces). Therefore, a large number of individual shipments of gauges containing radioactive material are made annually.[12]

The primary use of nuclear well-logging is in the search for petroleum. For all practical purposes, all petroleum exploration today makes use of nuclear well-logging. According to the U.S. Geological Survey (USGS), 0.111 to 0.185 TBq (3 to 5 Ci) sources are the standard for this type of well-logging. It is also reported that neutron generators are becoming the source of choice for petroleum well-logging.

The use of nuclear well-logging in exploration water is limited, because most states forbid the use of radioactive sources in the search for potable water. While nuclear well-logging can be used for a number of different minerals other than petroleum, it appears that it is only rarely used in the exploration for any non-petroleum minerals other than coal.

An estimate for the total number of shipments for radiography and well-logging activities was provided by industry representatives.[13]

"For radiography shipments there are approximately 1,500-2,000 shipments on a daily basis. These are primarily Type B quantities of Ir-192 and Co-60. Almost 100 percent of these would be transported as Yellow II. There are another estimated 40-50 on a daily basis from the manufacturers

[12] NRC estimates that typical sources may be up to 0.074 TBq (2 Ci) Cs-137 and up to 0.74 TBq (20 Ci) AmBe-241.
[13] Kathleen Roughan, Fred Paillet, AEA Technologies.

and these go 95 percent by air. This would be half Yellow II and half Yellow III shipments. Type B and Ir-192 and Co-60.

For other types of transport(i.e., gauging applications) we estimate 200 Type A shipments a week, but this doesn't consider road gauges. Primary isotopes … Cs-137 [3.7 E-3 TBq (100 mCi)] and AmBe [0.185 - 0.37 TBq (5-10 Ci)]. These would also primarily go as Yellow II."

Using the data provided by this industry representative, an estimate for well-logging, radiography, and other measuring device shipments was developed. The summary appears in Table 18 Radiography, Well-Logging, and Gauge Packages.

8.2 Neutron Sources

Neutron sources are metal capsules generally containing one of several radioactive materials. The most commonly used material in neutron sources is Californium-252. Americium-beryllium neutron sources are another fairly common type of source. As their name suggests, the purpose of a neutron source is to be a source of neutrons. They are used in a variety of equipment employed frequently, although by no means exclusively, for measurement purposes by a multiplicity of industries, both in the United States and elsewhere.

This category includes only the transport of neutron sources themselves. The transport of the raw radioactive material for the neutron sources and the transport of equipment containing neutron sources are both included in other categories.

Only a few firms currently are in the business of manufacturing neutron sources. These include (in alphabetical order) Frontier Technology, GE-Westinghouse, Hitachi, Mitsubishi, and Toshiba.

Table 18 Radiography and Gauge Packages

<table>
<tr><th></th><th>Packages</th><th>Shipment Frequency</th><th>Package Type</th><th>Total Packages</th><th>Isotopes</th></tr>
<tr><td>Radiography</td><td>1,500</td><td>260</td><td>Yellow II</td><td>390,000</td><td>Ir-192 and Co-60</td></tr>
<tr><td>Radiography (air)</td><td>20</td><td>260</td><td>Yellow II</td><td rowspan="2">5,200</td><td rowspan="2">Ir-192 and Co-60</td></tr>
<tr><td>Radiography (air)</td><td>20</td><td>260</td><td>Yellow III</td></tr>
<tr><td>Total Radiography</td><td></td><td></td><td></td><td>395,200</td><td></td></tr>
<tr><td colspan="6">Gauges / Measuring Devices</td></tr>
<tr><td>Gauges / measuring devices (not road)</td><td>200</td><td>52</td><td>Type A</td><td>10,400</td><td>Cs-137 3.7 E-3 TBq (100 mCi) and AmBe 0.185 - 0.37 TBq (5 - 10 Ci)</td></tr>
</table>

Information on the total transport of neutron sources in the United States is not available, and as a consequence, must be estimated. By assuming that the five firms listed above all share equally in the United States market for neutron sources, an upper bound on the total number of shipments can be estimated using proprietary shipment information provided by one of the manufacturers of neutron sources in the United States (the estimates represent an upper bound because they are based on shipment information from one of the largest manufacturers, and other manufacturers, while assumed equal to the larger manufacturer for estimation purposes, are likely to actually be smaller in reality). Table 19 presents this upper bound estimate of the total number of shipments of neutron sources in the United States in 1999.

The outgoing columns in the table represent an upper bound on shipments in the United States in 1999 of new neutron sources. The incoming columns give some idea of the upper bound for shipments of radioactive materials used in the production of neutron sources in the United States. For purposes of estimating the activity of these shipments, all neutron sources are assumed to use Californium 252.

The following should be noted with respect to Table 19. First, some of the outgoing shipments represent sales of materials to other source producers, rather than sales of neutron sources. Unfortunately, it is not possible to separate shipments of source materials to other producers from shipments of sources to industrial manufacturers. Second, the table includes only shipments of industrial neutron sources, and does not include shipments of any of the larger, "military" neutron sources, which are reportedly manufactured at Oak Ridge, Tennessee. Third, all neutron sources do not use Californium 252.

Table 19 Estimated 1999 Shipments of Neutron Sources and Related Materials

μg	Incoming (to US facilities)			Outgoing (from US facilities)		
	US	Foreign	Total	US	Foreign	Total
<1	5	-	5	15	5	20
1<10	40	10	50	55	15	70
10<50	20	10	30	65	65	130
50<100	-	-	-	20	100	120
100<500	10	-	10	20	5	35
500<1000	5	-	5	5	-	5
1000<2540	-	-	-	5	5	10
2540<3750	5	-	5	-	-	-
3750<5000	5	-	5	-	-	-
Total	**90**	**20**	**110**	**185**	**205**	**390**

Note: Activity of shipments can be estimated by assuming that (a) all shipments are of sources using Californium 252 (Cf-252) and (b) 1μg of Cf-252 = 1.98 E-5 TBq (0.53619 millicurie).

8.3 Selected Sources

The following selected sources were consulted in the preparation of this section.

Communications with management at a manufacturer/distributor of industrial neutron sources during 2001.

Comments on the draft report by NEI, November 26, 2001.

8.4 Local Government

Local government, as used here, is any governmental organization or agency in the United States other than those of the federal government. It includes all agencies of city, county, and state government.

Local governments use radioactive materials for a variety of purposes. Schools operated by local governments use radionuclides for teaching, training, and research. Medical facilities and institutions operated by local governments use radioactive materials for testing and treatment. Local street and highway departments use radioactive materials for making measurements, that is, portable density gauges. Local agencies use radioactive materials for civil defense purposes. Uses by educational institutions and medical facilities of local governments are included within educational and medical licensee categories, and are not considered further here. The focus of this category is on the use of materials by street and highway departments, and the use of materials for civil defense. It should be noted that some minor uses of radioactive materials are ignored. As a consequence, the estimates presented may underestimate actual number of packages shipped.

An attempt was made to collect data by local governments through the Operations Survey conducted by the National Association of Counties (NACO). At the request of the United States Department of Transportation's Volpe Center, NACO incorporated three questions about the use of radioactive materials into its 2000 Operations Survey. The survey was sent to approximately 500 counties throughout the United States, and approximately 60 percent of those counties responded to the survey questions. Unfortunately, response rates on these questions were too low to be included in this report. The total number of packages estimated for this category were extrapolated upon the value reported in the 1985 study.

9 SUMMARY AGGREGATE ESTIMATE

The total number of packages and shipments estimated to be made for one year (1999) has been constructed by attempting to provide an updated estimate for each of the strata identified in the 1985 SRI survey. This assumes that the 1985 categories are inclusive of the variety of shippers who are currently operating in the United States, and that any aggregation among the separate categories that are made in this study does not over or under-represent the actual number of shipments. In the previous sections the types of shippers that fall into each of these categories, the business or government enterprises that they represent, and the estimated number of packages and shipments made by that sector were discussed. When combined with DOE shipments, this generally represents most of the radioactive material shipments in the United States.

In Section 3, a comparison of the distribution of licensee categories within the United States based upon the 1985 survey, and three Agreement State distributions was made. With some exceptions, most states had licensees that (a) were identified as belonging to one of the categories, thereby validating that the category was still applicable, and (b) had a representation somewhat like the overall United States value in 1985. It was concluded therefore, that using the distribution of licensee categories developed in 1985 as a guide for data collection in the current survey was a valid approach.

Some sectors changed dramatically from their 1985 levels. The most notable is the radiopharmaceutical industry. Trends in the industry, changes in the method of creating doses (from hospital-based pharmacies in 1985 to central distribution from the manufacturers in 1999), and an increase in demand for therapeutic uses, resulted in an estimate of the volume of shipments in this category that is 14 times the 1985 estimate (1.26 million in 1985 versus 17.298 million in 1999).[14]

Another notable increase occurs in the 1985 and 1999 estimates for radiography. The 1985 estimate (54,000 packages annually) is significantly lower than the estimated 395,200 packages derived from contacts with the radiography industry.

Overall, Table 3, Summary of Estimated Packages by Strata, provides an estimate of about 17,991,267 million packages shipped in 1999 or more than 6 times the 2,817,738 estimated to have been shipped in the 1985 study.

[14]Note: Radiopharmacies did not report research and treatment-related shipments separately in 1985. Total radiopharmaceutical shipments include 17,138,756 treatment-related shipments and 160,000 research-related shipments.

APPENDIX A 1992 CANADIAN SURVEY OF RADIOACTIVE MATERIALS TRANSPORT

In 1992, the Canadian Atomic Energy Control Board (AECB), Canada's equivalent of the United States Nuclear Regulatory Commission (NRC), undertook to perform a comprehensive survey of the transport of radioactive materials transport occurring in Canada during 1992. Previously, Canada had performed two comprehensive surveys: one in 1977 and the other in 1981. Prior to the 1977 survey, Canada had performed at least five ad hoc surveys of the shipments of specific types of radioactive materials, the first in 1948.

Canada, like the United States, licenses users of radioactive materials. The AECB has nearly 75 license categories, which include power reactors, industrial gauging, oil well logging, and a variety of medical uses. In 1992, Canada had about 2600 licensees who held over 3900 individual licenses.

The 1992 Canadian survey represented a departure from the stratified statistical sampling used by Canada to gather data in 1981 and perhaps earlier. Sampling was undertaken by license category, with the sampling rates varying from 1 to 100 percent, depending on the license category. Both telephone contacts and survey forms were used in the effort. Survey information was supplemented with data from other reliable sources whenever possible.

The information sought from those surveyed included the following: (1) material identity and activity, (2) package and shipment types and numbers, (3) the transport index, (4) mode of transport and distance, (5) origin of shipment, and (6) import/export data.

Over 350 licensees were surveyed in 1992. Less than five percent of those surveyed could not, would not, or did not cooperate.

The 1992 Canadian survey found that about 883,000 packages were transported in Canada in that year in nearly 740,000 shipments. These figures, it should be noted, exclude excepted quantity packages. Approximately 88 percent of the material moved by highway, 10 percent moved by air, 2 percent moved by water, and a minimal percent moved by rail. A summary of the results of the 1992 Canadian survey is presented in the following two tables (Tables A-1 and A-2).

Table A-1 1992 Radioactive Transport Overview for Canada

	Type A Packages	Type B Packages	Industrial Packages	Total
Packages	678,873	124,665	79,591	883,129
Shipments	614,869	118,502	4,223	737,594
Activity TBq (Ci)	4.95 E4 (1,338,147)	4.37 E6 (118,110,366)	3.93 E4 (1,062,234)	4.45 E6 (120,510,747)
Mass (kg)	1,932,664	561	36,131,995	38,065,220

Table A-2 1992 Radioactive Packages by Mode for Canada				
	Type A Packages	Type B Packages	Industrial Packages	Total
Road	585,183	124,157	66,568	775,908
Rail	753	0	1,628	2,381
Sea	3,307	347	11,344	14,998
Air	89,630	161	51	89,842
Total	678,873	124,655	79,591	883,129

Excepted quantity packages were estimated to total 4.5 million in Canada in 1992.

The AECB indicates that the accuracy of the estimates derived from the 1992 survey are plus or minus 25 percent. That is, the actual quantities being transported in Canada in 1992 are expected to have been no less than 75 percent of the estimated values and no greater than 125 percent of the estimated values. Because of the conservative way the estimates were derived, the AECB expects a priori that the estimates are likely to be low.

The level of cooperation from industry that was obtained by the survey team is little short of amazing. A 95 percent participation rate in a survey is phenomenal. The success of the survey would appear to be attributable to at least three factors. Part of the success of the survey is attributed by the AECB to the persistence of the survey team. While certainly very important to the success of the survey, at least two other factors undoubtedly also played a role. The first was the centralized nature of licensing in Canada. All licensing in the country is conducted directly by the AECB. A second factor undoubtedly contributing to the success of the survey was the active participation of AECB licensing officials familiar with the various license categories. Expert assistance in a survey such as this one can identify and help overcome hurdles. Expert assistance can also be helpful in identifying alternative and supplemental sources of data, and in properly and correctly interpreting the data that is obtained. Furthermore, a familiar name associated with the survey (a licensing official's) probably made some licensees more willing to cooperate.

The 1992 survey was conducted by license category. Essentially, what this means is that in 1992, 70-some odd related mini-surveys were conducted. While the surveys all used the same basic format, they were not inter-related or dependent on each other. This has the advantage of allowing updates to be undertaken on a piecemeal, as-needed basis, an advantage recognized by the AECB. This is a definite advantage over the more traditional stratified statistical sampling approach that Canada had used prior to 1992. Furthermore, as also recognized by the AECB, ad hoc surveying by license category can allow an improvement in the quality of the data obtained over time. Problems that may have impaired the quality of the survey in the past can be identified and work-arounds can be developed for them.

It is interesting to note that the Canadian license categories appear to be far more limited in number and scope than those found in the United States, even when the number of uses are considered (some Canadian license categories cover more than one related use—Radiography, for example, covers five uses). This may help explain in part the success of the 1992 Canadian survey. Most categories appear to represent only one or a few related industries. Some categories, in fact, appear to include only one organization or entity, and not an entire industry or set of related industries. Licensing officials responsible for the categories would have had an easier time keeping on top of their industries than comparable officials in the United States.

The 1992 Canadian survey used some additional information to supplement the formal survey. As mentioned before, the supplemental information appears to have consisted primarily of export permit data and reports from licensees. There were also telephone contacts with licensees, but most of those were presumably directed at filling in gaps in survey forms. The AECB reports that gathering the additional information helped enhance the confidence in the survey results, especially in those cases where corroborating overlapping or duplicate data was gathered. This approach, which relies not only on more formal survey results, but also on other reliable information, would seem to have considerable merit. Under this scheme, it is possible that updates to the survey could be performed in certain cases using supplemental information alone. For example, if supplemental data on industry growth gathered during the survey was corroborated by the survey results, then the view of the reliability and applicability of subsequent industry growth data would be enhanced, and that growth data might be used in conjunction with the survey results with confidence to develop new updated estimates.

Canada noted a problem that impacted their survey: the year chosen for analysis, 1992, turned out to be part of "a period of low or stagnant economic activity" for some radioactive industries. For some of those surveyed, transport of radioactive materials was off from previous years. As a consequence, Canada found that it was not possible in some cases to develop "a true representation" via sampling.

This type of problem can be expected to impact any industry "snapshot", but those looking at a single year are certainly the most vulnerable. Without additional background information and a careful evaluation of the "current" situation, it can be very easy to mistake a time of boom or bust for an industry as "normal." This can lead to mistaken conclusions when two different snapshots are compared. Normal variations in the business cycle of an industry can be mistaken for secular (long-term) changes in that industry. Furthermore, extrapolating from information provided by an industry snapshot can result in dubious estimates. Applying a totally reliable industry transport growth rate, for example, to the amount an industry transported in a specific year may not result in a particularly good estimate of what the situation will be like in the future or what it was like in the past.

Sources:

G.B. Johnson, J.J. McLellan, A. Nixon, "Transport Activity in Canada: 1992".

Advisory Committee on Nuclear Safety,

"Transport of Radioactive Material in Canada" (excluding spent nuclear fuel and low-level historical waste), September 1997, an advisory committee of the Atomic Energy Control Board, Ottawa, Canada.

Communication from John McLellan, AECB, to John Cook, NRC, March 16, 1998.

G.B. Johnson, "Radioactive Material Transport in Canada: The AECB Survey of 1992," *Bulletin of the Canadian Radiation Protection Association*, Vol. 17, No. 3, July 1996, pp. 22-24.

APPENDIX B SOURCE DATA TABLES

Table B-1 Waste Shipment Detail Waste Shipments

Year Received	State	Volume m^3 (ft^3)	Activity TBq (Ci)	Number of Shipments
1999	Alabama	105.68 (3,732.01)	8.51 E-2 (2.3)	83
1999	Arizona	1.79 (63.45)	5.18 E-3 (0.14)	14
1999	Arkansas	40.12 (1,416.84)	6.734 E-2 (1.82)	44
1999	California	731.64 (25,837.81)	3.3 E-1 (8.94)	158
1999	Colorado	12.9 (455.56)	<3.7 E-4 (<0.01)	16
1999	Connecticut	141.12 (4,983.49)	6.5 E-2 (1.77)	167
1999	D. of Columbia	0.51 (18)	<3.7 E-4 (<0.01)	1
1999	Florida	156.65 (5,532.05)	1 E-1 (2.72)	160
1999	Georgia	109.15 (3,854.48)	1.3 E-1 (3.52)	82
1999	Illinois	517.89 (18,289.07)	3 E-1(8.13)	276
1999	Indiana	0.34 (12.06)	<3.7 E-4 (<0.01)	1
1999	Iowa	4.53 E-3 (0.16)	<3.7 E-4 (<0.01)	1
1999	Kansas	62.33 (2,201.23)	2.88 E-2 (0.78)	31
1999	Kentucky	85.10 (3,004.87)	4.96 E-2 (1.34)	33
1999	Louisiana	202.69 (7,158.05)	1.4 E-1 (3.79)	109
1999	Maine	207.94 (7,343.44)	1.96 E-2 (0.53)	81
1999	Maryland	189.93 (6,707.49)	4.44 E-2 (1.2)	89
1999	Massachusetts	499.63 (17,644.2)	2.18 E-1 (5.91)	181
1999	Michigan	1442.83 (50,953.21)	1.37 E-1 (3.7)	245
1999	Minnesota	41.25 (1,456.76)	3.89 E-2 (1.05)	38
1999	Mississippi	54.10 (1,909.22)	5.37 E-2 (1.45)	46
1999	Missouri	191.34 (6,757.17)	1.81 E-1 (4.88)	41
1999	Nebraska	0.02 (0.55)	<3.7 E-4 (<0.01)	1
1999	New	0.46 (16.2)	<3.7 E-4 (<0.01)	1
1999	New Jersey	190.03 (6,711.08)	3.64 E-1 (9.83)	126
1999	New Mexico	63.21 (2,232.41)	2.96 E-3 (0.08)	16
1999	New York	415.81 (14,684.06)	1.69 E-1 (4.58)	342
1999	North Carolina	838.05 (29,595.48)	1.03 (27.79)	227
1999	North Dakota	0.40 (14.3)	1.85 E-3 (0.05)	2
1999	Ohio	2092.75 (73,904.81)	1.15 E-1 (3.1)	201
1999	Oklahoma	0.02 (0.66)	<3.7 E-4 (<0.01)	1
1999	Pennsylvania	3257.02 (124,555.4)	0.95 (25.62)	454
1999	Rhode Island	1.28 (45.2)	4.44 E-3 (0.12)	3

1999	South Carolina	237.15 (8,374.87)	3.15 E-1 (8.5)	182
1999	Tennessee	8170.02 (288,521.43)	3.47 (93.82)	1,026
1999	Texas	3707.46 (130,927.56)	1.74 E-1 (4.69)	338
1999	Vermont	38.01 (1,342.45)	4.4 E-2 (1.19)	46
1999	Virginia	828.01 (29,240.92)	2.28 E-1 (6.18)	206
1999	Washington	16.83 (594.2)	1.85 E-3 (0.05)	5
1999	Wisconsin	24.62 (869.49)	2.29 E-2 (0.62)	39
	Totals:	24946.06 (880,961.69)	8.89 (240.25)	5,113

Table B-2 Research Reactors

Facility	Reactor Type	Power (kW)
Nuclear Regulatory Commission Licensees		
Aerotest Operations	TRIGA Conversion	250
Armed Forces Radiobiological Research Institute	TRIGA Mark F	1000
Cornell University	TRIGA Mark II	500
Dow Chemical Company	TRIGA Mark I	300
General Electric Co.	Tank	100
Idaho State University	AGN-201	0.005
Kansas State University	TRIGA Mark II	250
Massachusetts Institute of Technology	Tank, LW Mod, HW Reflector	4900
McClellan Nuclear Radiation Center	TRIGA Mark II	2000
National Institute of Standards and Technology (NIST)	Heavy Water	20000
North Carolina State University	PULSTAR	1000
Ohio State University	Pool, LW Moderated	500
Oregon State University	TRIGA Mark II	1100
Pennsylvania State University	TRIGA Conversion Mark III	1000
Purdue University	Pool, LW Mod, Plate Fuel	1
Reed College	TRIGA Mark I	250
Rensselaer Polytechnic Institute	Critical Facility, LW Mod	Critical
Rhode Island Nuclear Science Center	Pool, LW Moderated	2000
Texas A&M University	TRIGA Conversion	1000
	AGN-201M	0.005
University of Arizona	TRIGA Mark I	100
University of California – Irvine	TRIGA Mark I	250
University of Florida	Argonaut	100
University of Maryland	TRIGA	250
University of Massachusetts – Lowell	Pool, LW Mod, Graphite Reflector	1000
University of Michigan	Pool, LW Moderated	2000
University of Missouri – Columbia	PWR, Open Pool, LW Mod and Cooled	10000
University of Missouri – Rolla	Pool, LW Moderated	200
University of New Mexico	AGN-201	0.005
University of Texas – Austin	TRIGA Mark II	1100
University of Utah	TRIGA Mark I	100
University of Wisconsin	TRIGA Conversion	1000
United States Geological Survey	TRIGA Mark I	1000
United States Veterans Administration	TRIGA Mark I	20
Washington State University	TRIGA Conversion	1000

Worcester Polytechnic Institute	Pool, LW Moderated	10

United States Dept. of Energy and United States Army Reactors

Aberdeen Proving Grounds	APRFR, Fast Burst	10
Argonne National Laboratory – West	NRAD, TRIGA Mark II	250
Babcock & Wilcox Hanford Co.	FFTF*	400000
Brookhaven National Lab	BMRR, Tank*	3000
Idaho National Environmental and Engineering Laboratory	Advanced Test Reactor	250000
	Advanced Test Reactor Critical Facility	5
Los Alamos National Lab	Comet	Critical Assemblies
	Flattop	
	Godiva, Fast Burst	
	Planet	
	SKUA, Fast Burst	
	SHEBA, Solution, High Energy Burst	5
Oak Ridge National Lab	HFIR, Tank	85000
Sandia National Laboratories	ACRR	4000
	SPR-II, Fast Burst	5
	SPR-III, Fast Burst	15
White Sands Missile Range	FBR, Fast Burst	10

*Currently shutdown.

It should be noted that no new research reactors are planned or under construction in the United States.

Sources:

International Atomic Energy Agency (IAEA), “Nuclear Research Reactors in the World,” reference data series #3, Sept. 2000.

Research Reactors: An Overview, by Colin West, *ANS Nuclear News*, Oct. 1997.

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