LOW-LEVEL RADIOACTIVE WASTE GENERATION RATES AT DOMESTIC NUCLEAR POWER PLANTS — 1982 THROUGH 1985 UPDATE[a]

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ABSTRACT

A survey of low-level radioactive waste (LLRW) generation rates at domestic nuclear power plants was conducted from May, 1985 through September, 1985. Data were collected from twenty-two BWR sites (representing thirty-one units) and thirty PWR sites (representing forty-eight units). Actual annual volumes of both solidified or dewatered (WET) wastes and dry active wastes (DAW) were obtained for 1982 through 1984. The corresponding projected values for 1985 were also obtained.

Comparisons between the collected data and earlier data reported in EPRI NP-3370 for calendar years 1978 through 1981 were performed and analyzed for correlations, differences, and trends. For purposes of comparing with previously reported EPRI results, both BWR and PWR plants were separated into various groupings.

Trends in total LLRW shipped volumes, WET waste shipped volumes, and DAW shipped volumes were developed and compared to the earlier work for both BWR and PWR plants. For each type (BWR or PWR) and subtype various ratios were developed and compared with the corresponding values reported in EPRI NP-3370. The manner in which data treatment methods influence "typical" values is discussed for both the earlier EPRI work and the current work. An alternative method is proposed for the analysis of such data and trends.

INTRODUCTION AND BACKGROUND

As part of an extensive marketing study, one of our clients had an interest in quantifying the volumes of various types of low-level radioactive wastes (LLRW) which are generated at nuclear power plants. In the belief that the values previously reported by EPRI for calendar years 1978 through 1981 (1) might not be representative of actual values for 1982 through 1985 (and beyond), our client decided to conduct an independent survey of LLRW generation rates at domestic nuclear power plants.

Our firm was contracted to conduct the survey, analyze data, and report on the results. To meet the desired time schedule, Analytical Resources, Inc. was subcontracted to provide assistance with the data collection.

Data gathering commenced in May, 1985 and was completed in September, 1985. Data were collected from twenty-two BWR sites (representing thirty-one units) and thirty PWR sites (representing forty-eight units). Collected data included actual values for 1982 through 1984 and projected values for 1985.

The resultant data base is extensive, consisting of over one hundred pages of data tables, and is much too detailed to cover in this article. Rather, the intention of this article is twofold: first, to summarize some of the more general conclusions; second, to suggest changes in the methods of analyzing such data in the future.

METHODOLOGY

The work being described here was not intended to be as extensive as the three-volume EPRI report (1). All data for the present work were collected by telephone. Without the benefit of actual review of plant records, it was expected that the present study would be subject to less precision than the earlier work of EPRI.

An extensive data base was prepared. The data base contains all available data from 1977 through 1984. Projected values for 1985 were also included. The values for 1977 through 1981 were taken directly from Volume 3, the data base volume, of the earlier EPRI work.

The data base of this study included information related to the following: volumes, containers, packaging efficiencies, volume reduction achieved, equipment used, and services employed. Data related to activity, radionuclide composition of wastes, dose rates of waste packages, and personnel exposure were not included.

The original approach for comparison with the earlier EPRI work was to conduct the analysis of more recent data in a method which simulated the EPRI analysis. Unfortunately, we were not able to reproduce the EPRI summary tables from the EPRI data base. This led to a more detailed scrutinization of the EPRI summary tables and ultimate development of an alternative method for analysis of such data.

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[a] Data gathering was performed under contract to General Electric Company. The data are used with their permission. The conclusions and opinions contained in this paper are those of the author and not of the General Electric Company.

RESULTS AND DISCUSSION

We have utilized a categorization of LLRW which can be applied in parallel form for both boiling-water reactor (BWR) wastes and pressurized- water reactor (PWR) wastes, as follows:

- Low-level Radioactive Wastes (LLRW)
  - Dry Active Wastes (DAW)
    - Compacted (CO)
    - Non-compacted (NC)
    - Contaminated Components (CC)
  - Wet Active Wastes (WET)
    - Spent Resins (SR)
    - Concentrated Wastes (CW)
    - Filter & Demineralizer Sludges (FS)--BWR
    - Filter Cartridges (FC)--PWR

Our reasoning for proposing that such a categorization be utilized in future works is explained in the following paragraphs.

We recommend changing from "compactible" and "non-compactible" to "compacted" and "non-compacted" as more descriptive terms. The subdivision does not represent a difference in the compactibility of the waste itself. Rather, it represents the packaged condition of the waste. This is especially true when one considers the higher compression forces available with modern compaction equipment.

Contaminated components is a suitable generic term for various activated hardware and miscellaneous components. This subdivision could be used for the volumes of "atypical" wastes. Inclusion of such a subdivision allows for maintaining the integrity of a data base without automatically including "atypical" wastes in one of the other subdivisions.

(Of the various other recommendations for such a subdivision, we object to use of the term "irradiated hardware". This term is technically incorrect for the obvious reason that irradiated materials do not necessarily become radioactive.)

The authors of the comprehensive EPRI report included filter cartridges with dry wastes, perhaps because of past waste packaging practices. More recently, our experience indicates that filter cartridges are more likely processed as a wet waste. That is, filter cartridges almost always require stabilization, as defined in 10 CFR Part 61 (2), prior to disposal. We suggest that filter cartridges be included with wet wastes in future works.

Recognizing that BWR plants are generally equipped with precoat filtration equipment while PWR plants are generally equipped with cartridge filtration equipment, we have recommended separate subdivisions under WET. The categorization scheme eliminates the inclusion of filter & demineralizer sludges for PWR plants--a subdivision which provided no data for the EPRI report.

Since implementation of 10 CFR Part 61, utilities have been required to maintain more detailed records describing waste types. One result is that more plants are reporting "miscellaneous" wet waste volume data. If this trend continues to a point of providing meaningful data, the above scheme could easily be modified to add a fourth category under WET. We have called this "other" and have used the acronym OT.

Accuracy of Data

Although our developed data base includes estimates of generated waste volumes as well as shipped waste volumes, we will address only shipped volumes in this article.

The single most accurate number available from any plant is the total volume of LLWR shipped. Accuracy decreases monotonically with increasing level of subdivision of the total volume of LLRW shipped.

Generally, the subdivision of LLRW into DAW and WET portions is reasonably well documented and available. Even this major subdivision is, however, subject to inaccuracies. In some cases the major subdivision maintained at a plant is that of shielded and unshielded shipments. This subdivision of shielded and unshielded shipments is sometimes used to approximate the subdivision into DAW and WET shipped volumes. This is an example of telephone survey inaccuracy which could be removed by actual review of plant shipping records.

Information concerning the subdivision of DAW into compacted (CO) and non-compacted (NC) fractions was sometimes not available over the phone. We did not obtain sufficient data to corroborate or refute the fractions summarized in EPRI NP-3370. In many cases we had to rely upon the proportions of CO and NC DAW listed in the EPRI report. We, as others, are looking forward to the publication of the updated EPRI study later this year (3).

Similarly, the subdivision of WET into spent resins (SR), concentrated wastes (CW), and either filter & demineralizer sludges (FS) or filter cartridges (FC) was sometimes not available to our telephone surveyor. When specific information was obtained, the data indicated significant changes for the period from 1982 through 1984 when compared to the generalizations in EPRI NP-3370 for 1978 through 1981.

Analysis of Volume Data

For purposes of this article the focus will be on two questions. First, is the volume of LLRW generated at nuclear power plants changing with time? That is, is there a trend in the volume of LLRW shipped for disposal? Second, is the composition of LLRW shipped for disposal changing? That is, are the portions of DAW and WET (as well as subdivisions of those portions) changing with time? Implicit in such questions is the desire for a model which could provide a reasonable predictive capability.

Such questions are of interest to various segments of the industry. Utility personnel continue in the pursuit of LLRW minimization. In order to evaluate progress, they need to know the past and present situations. Service vendors are interested in such questions as part of their market potential analyses. Low-level radioactive waste compact commissions are interested as part of planning for future LLRW disposal facility capacity.

In EPRI NP-3370 an attempt was made to answer such questions by calculating values for the "average" BWR and the "average" PWR for both single-year and multiple-year intervals. Two problems result from the methods employed in that work. The first involves a conflict of terms; the second involves the use of an undefined mathematical quantity. One consequence is a mismatch between the summary tables and the data base values in NP-3370. In the following paragraphs these concerns are addressed and alternatives are proposed.

The data from BWR units for 1981 have been chosen as an example to help clarify the concerns. Data from 1981 represent the most complete and most current data contained within the data base of Volume 3 of NP-3370. This is also the only year for which both single-year summary tables and complete data base information are presented in the EPRI report.

In Table I and Table II, the EPRI data base values for BWR plants and calendar year 1981 are listed. The only difference in format is that volumes from multiple-unit plants have been partitioned into the individual units according to the partitioning factors listed in the data base. The values for the BWR units have been arranged in decreasing order of total LLRW shipped volume. The corresponding "average" values, calculated using the EPRI method, have been included in Table I an Table II. The following discussion will refer to these tables.

TABLE I

LLRW Shipped Volumes (cubic feet) from BWR Units for 1981 from EPRI NP-3370

Unit	SR	CW	FS	OT	WET
01	12435	5152	6688	0	24275
02	12435	5152	6688	0	24275
03	1600	9400	9000	0	20000
04	4500	0	3500	0	8000
05	5036	2497	2590	300	10123
06	2448	0	9209	0	11657
07	2448	0	9209	0	11657
08	600	0	8952	0	9552
09	600	0	8952	0	9552
10	600	0	8952	0	9552
11	390	12555	585	0	13530
12	280	0	6218	0	6498
13	1318	0	5027	0	6345
14	1318	0	5027	0	6345
15	1599	6088	685	0	8372
16	1342	5219	895	0	7455
17	1342	5219	895	0	7455
18	140	0	5945	150	6085
"Average"	2802	2849	5501	25	11151

TABLE II

LLRW Shipped Volumes (cubic feet) from BWR Units for 1981 from EPRI NP-3370

Unit	CO	NC	CC	DAW	LLRW
01	31613	8873	0	40485	64760
02	31613	8873	0	40485	64760
03	34400	8600	0	43000	63000
04	32000	11200	0	43200	51200
05	8359	31872	90	40321	50444
06	14068	15466	0	29534	41190
07	14068	15466	0	29534	41190
08	18103	3400	364	21867	31419
09	18103	3400	364	21867	31419
10	18103	3400	364	21867	31419
11	14250	0	0	14250	27780
12	8598	8609	0	17207	23705
13	11332	3455	0	14786	21131
14	11332	3455	0	14786	21131
15	10382	0	0	10382	18754
16	5840	3264	94	9198	16653
17	5840	3264	94	9198	16653
18	8694	705	0	9399	15484
"Average"	16483	7406	76	23965	35116

Both problems mentioned earlier result from a common basis--the use of an average (arithmetic mean) value for defining the "average" BWR and the "average" PWR. It is commonly accepted that BWR units ship more LLRW than do PWR units. The differences are so apparent that any attempt to calculate an average LLRW shipped volume for the "average" nuclear power reactor unit would be met with much skepticism. In technical terms, it's obvious that BWR and PWR units are not members of a single population of nuclear power reactor units with respect to the volume of LLRW shipped for disposal. One could perform elaborate mathematical tests to verify that obvious fact. Common sense observation makes such testing unnecessary.

Why then is it assumed that all BWR units belong to a single population and that all PWR units belong to a single population with respect to the volume of LLRW shipped for disposal? The data do not support such a conclusion. Any reasonable statistical test will verify the point. The inescapable conclusion is that the use of an average value for the volume of LLRW shipped for disposal from either BWR units or PWR units is mathematically invalid. The problem is compounded by attempts to calculate average values for subcategories of LLRW which are not reported by all units in the set being considered.

The "average" values in Table I and Table II were calculated by summing the values in each column and dividing each sum by 18--the total number of BWR units in the set. The "average" values of Table I match the EPRI "average" values of the BWR WASTE SUMMARY table in Volume 2 of NP-3370 (allowing for rounding to the nearest 50 cubic feet).

This provides an example of one concern--the reported "average" for concentrated wastes (CW) is listed in Volume 2 of NP-3370 as 2850 cubic feet. However, only eight of the BWR units reported concentrated wastes as being shipped for disposal. For these eight BWR units, the "average" value for CW is 6400 cubic feet. It is difficult to understand the meaning of the calculated "average" CW value for all 18 BWR units when only eight of those units reported shipping concentrated wastes.

Apparently the method applied was influenced by a desire to assure that the "average" for the subcategories would equal the total for a category. In this case, WET=SR+CW+FS. Yet, such is only true for eight of the 18 BWR units. For the other ten BWR units, WET=SR+FS. That is, the 18 BWR units are not members of a single population with respect to WET shipped for disposal.

It is suggested that such obvious subsets be retained as distinct in future works. Meaningful information can be obtained while retaining the distinctions. This will be addressed in more detail later in this article.

In the case of DAW data listed in Table II, it was not possible to reproduce the "average" values reported in Volume 2 of NP-3370. This might be a result of the exclusion of "atypical" DAW. If so, such detail is not provided to the reader of the EPRI report. It is suggested that such information be specifically included in future works so that the reader can reproduce summary values independently.

Table II also contains an example of a reported "average" for 18 BWR units when only a subset reported shipping a subcategory of DAW--in this case non-compacted (NC) DAW. The "average" NC for the 16 BWR units which reported shipping NC DAW is 8300 cubic feet. Furthermore, the two BWR units which reported shipping all of their DAW in compacted (CO) form also reported total DAW values which differ considerably from the "average" total DAW from the other 16 BWR units. Once again, the situation is that the 18 BWR units are not a single population with respect to DAW shipped for disposal.

Another concern related to the use of "average" values deals with the computation of multiple-year averages. One of two general situations must exist--the volume of LLRW shipped is either remaining constant or it is not remaining constant. If the shipped volume is not remaining constant over a multiple-year interval, then no "average" exists for that interval. This is a straightforward consequence of the mathematical fact that the average (arithmetic mean) is identical to the least-squares value for a single value--that is, a straight horizontal line exists.

Sufficient data exist to indicate that the shipped volumes of LLRW from both BWR units and PWR units have decreased over the past several years (even though the statistics might be poorly defined). Acceptance of such a trend precludes a contradictory computation of a multiple-year average.

The prior discussion indicates some of the deficiencies of calculating "average" values for all BWR units in the set. As an alternative, it is suggested that median values be calculated. The median value is mathematically defined for any set of numbers arranged in sequential order. The median values for all categories of LLRW from the example set have been calculated and are presented in Table III together with the low and high extremes.

The interpretation of the median value is simply that half of the BWR units in the set reported values higher than the median values and the other half of the BWR units in the set reported values lower than the median value. Thus, the use of the median value provides for a meaningful interpretation. As indicated in Table III, the interpretation of data might be enhanced by including the reporting of the low value and the high value together with the median value. For example, the 18 BWR units for 1981 reported shipping LLRW volumes which ranged from 15500 cubic feet to 64800 cubic feet with a median value of 31400 cubic feet (rounded to the nearest 100 cubic feet). Of this group, 8 BWR units reported shipping CW volumes which ranged from 2500 cubic feet to 12600 cubic feet with a median value of 5200 cubic feet.

Some analysts see as a disadvantage of the median-value method the fact that the sum of median values for subcategories does not necessarily equal the median value of the total for the category. This in itself is a direct consequence of the fact that a single population is not under consideration. If large disagreements appear, the analyst is forewarned not to draw conclusions. (The "average" method obscures this meaningful indicator. If the 18 BWR units were a statistically representative sample of a single population, then the mean value and the median value would coincide.)

Two strong advantages exist for use of the median-value method. First, the mathematical definition is sound. Second, the method forces the analyst to consider appropriate subsets independently. For example, the median value for CW is defined only for the eight BWR units which reported having shipped CW.

TABLE III

LLRW Median Shipped Volumes (cubic feet) from Various Subsets of BWR Units during 1981

Category	Low	Median	High
All 18 BWR Units for which LLRW=DAW+WET:			
LLRW	15500	31400	64800
DAW	9200	21900	43200
WET	6100	9600	24300
The 16 BWR units for which DAW=CO+NC:			
LLRW	15500	31400	64800
DAW	9200	21900	43200
CO	5800	14100	34400
NC	700	6000	31900
WET	6100	9600	24300
The 02 BWR Units for which DAW=CO:			
LLRW	18800	23300	27800
DAW	10400	12300	14300
WET	8400	11000	13500
The 08 BWR Units for which WET=SR+CW+FS:			
LLRW	16700	39100	64800
DAW	9200	27300	43000
WET	7500	11800	24300
SR	400	1600	12400
CW	2500	5200	12600
FS	600	1700	9000
The 10 BWR Units for which WET=SR+FS:			
LLRW	15500	31400	51200
DAW	9400	21900	43200
CO	8600	14100	32000
NC	700	3500	15500
WET	6100	8800	11700
SR	100	1000	4500
FS	3500	7600	9200

Application of Method

Any item of interest previously approached using the "average" method can be addressed using a combination of actual reported volumes and the median-value method for analysis. In this section selected examples of updated information are presented using the median-value method for analysis.

As previously stated, it is believed that the single most accurate number available at a nuclear power plant is the total volume of LLRW shipped for disposal. The most accurate subdivision is separation into WET and DAW portions. In Fig. 1, Fig. 2, and Fig. 3 the median shipped volume from subsets of nuclear power plants are plotted for total LLRW, DAW, and WET, respectively. From these figures it can be seen that the small group of salt-water-cooled (SALT) BWR units are no longer isolable as the highest producers of LLRW volumes. (This appears to be the result of deliberate and successful LLRW minimization efforts at those sites.)

Two cautions are noted for viewing Fig. 1, Fig. 2, and Fig. 3: First, 1985 data are projected data developed during the third quarter of 1985. As such, the 1985 data are not comparable to the actual data for the other years. Second, the number of BWR units and PWR units reporting volumes varies from year to year. Thus, the significance of single-year values varies. To properly analyze the data, a least-squares fitting method must be invoked. In performing the least squares analysis, the single-year values must be

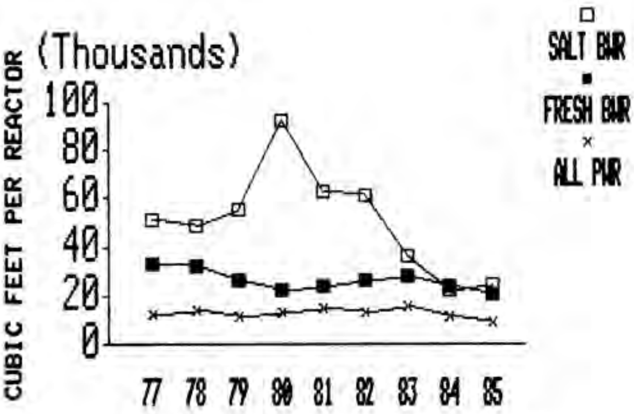

Fig. 1. LLRW Median Shipped Volumes.

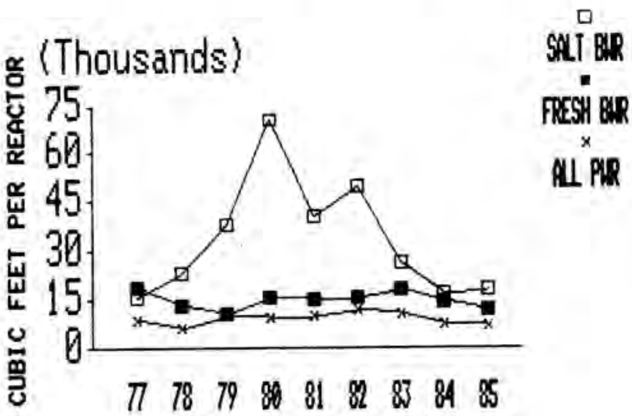

Fig. 2. DAW Median Shipped Volumes.

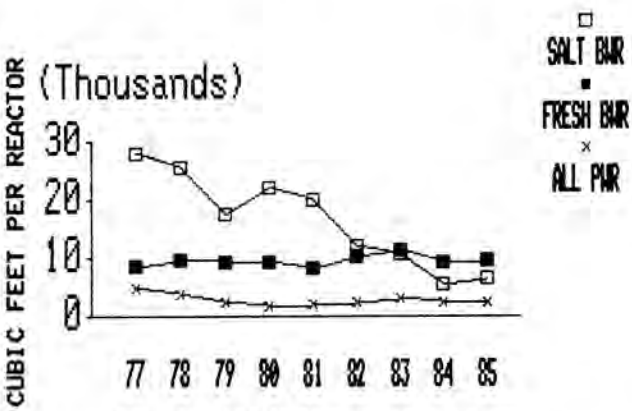

Fig. 3. WET Median Shipped Volumes.

properly weighted according to the defined methods for weighted-least-squares analysis.

Other ratios of interest can be similarly determined directly from the data. For example, the subdivision of WET into SR, CW, and FS can be determined directly from the volume data without any manipulation. The only restriction is that such proportioning is valid for only those units which report values for all of the portions. A separate proportioning must be determined for those units which, for example, report only SR and FS shipped WET volumes.

In Fig. 4 and Fig. 5 the trend in WET median shipped volumes from subsets of both BWR and PWR units are presented. These figures indicate clear past distinctions between the subsets within the larger sets (either BWR or PWR). The merging of the BWR subsets in later years is interesting to note and arouses curiosity.

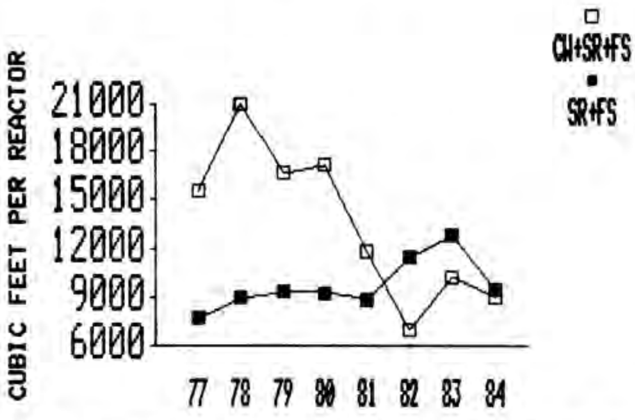

Fig. 4. WET Median Shipped Volumes from BWR Units.

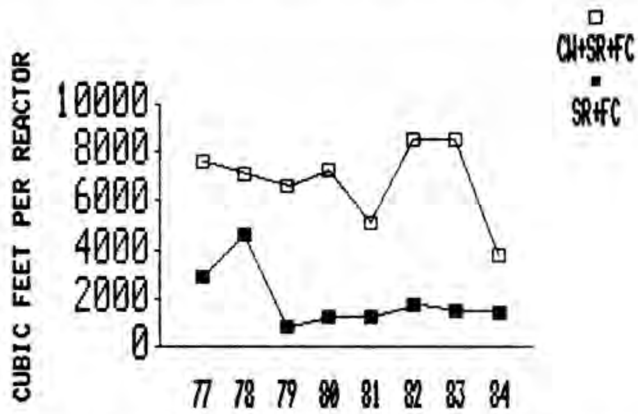

Fig. 5. WET Median Shipped Volumes from PWR Units.

To further investigate the downward trend in BWR WET median shipped volumes noted in Fig. 4, the percentage composition of WET can be examined. In Fig. 6 and Fig. 7 the percentage composition of WET for each subset of BWR units is presented graphically. The proportions were calculated using

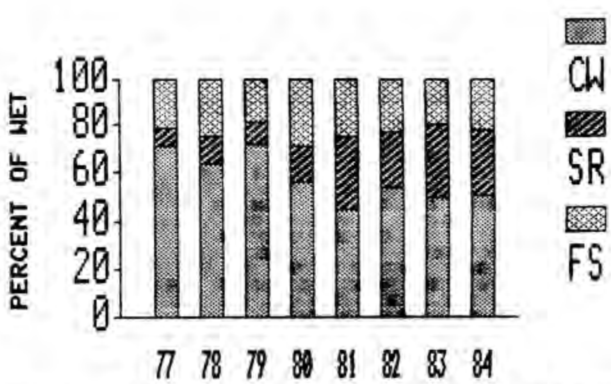

Fig. 6. Percentage Composition for WET Shipped from BWR Units where WET=CW+SR+FS.

the total reported volumes from all BWR units in the subset. That is, Fig. 6 is based on data from, and is only valid for, those BWR units where: WET=CW+SR+FS; and, Fig. 7 is based on data from, and is only valid for, those BWR units where WET=SR+FS.

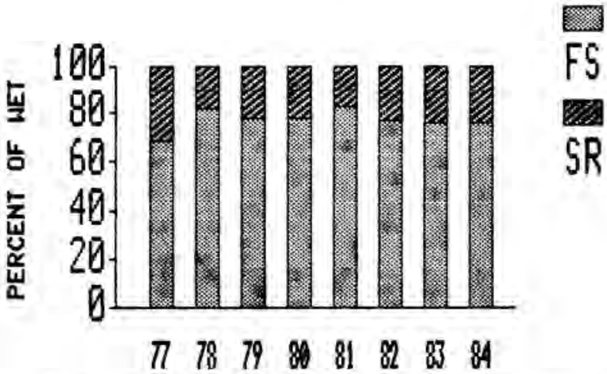

Fig. 7. Percentage Composition for WET Shipped from BWR Units where WET=SR+FS.

SUMMARY AND CONCLUSION

An extensive and detailed data base has been established which contains LLRW data for domestic nuclear power plants from 1977 through 1984. The data base will be expanded as new data become available.

Certain general conclusions drawn in earlier work based on data from 1978 through 1981 are no longer valid. Thus, the updating work being undertaken by EPRI should be of general interest and genuine value to the industry.

As updated reports are produced, it is suggested that the methods of data analysis be revised to more strictly adhere to mathematically consistent standards. It is specifically suggested that the concept of an "average" plant be abandoned in favor of a median-value method. Incorporation of this suggestion would assure retention of subset identities and help avoid the drawing of erroneous conclusions.

ACKNOWLEDGMENT

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REFERENCES

1. C. P. Deltete, G. S. Daloisio, and R. B. Wilson, "Identification of Radwaste Sources and Reduction Techniques," EPRI NP-3370, Volumes 1, 2, and 3, Electric Power Research Institute, Palo Alto, CA (January 1984).

2. "Licensing Requirements for Land Disposal of Radioactive Waste," Title 10, Code of Federal Regulations, Part 61 (effec. January 26, 1983).

3. C. P. Deltete and G. S. Daloisio, work in progress, EPRI RP 1557-26, Electric Power Research Institute, Palo Alto, CA (1987).