IMPACT OF SOURCE TERM UNCERTAINTIES
ON DISPOSAL COSTS OF PWR RADWASTE

J. C. McCague
Bechtel National, Inc.
Fifty Beale Street
San Francisco, California 94105

ABSTRACT

Radwaste activities for spent resins, evaporator concentrates, and spent filter cartridges were extracted from the literature for a number of operating PWR's. Specific activities were sorted by magnitude, plotted on a bar graph, and compared to a Gaussian distribution for each waste type. Estimated radwaste disposal costs were determined over the range of reported activities. The effects of source term uncertainties on radwaste disposal costs and volume reduction viability were examined.

BACKGROUND

Examination of radwaste radiological data for a number of operating Pressurized Water Reactors reveals a concise list of isotopes which are present in a given radwaste type. The origin of these isotopes is well established. Transport mechanisms, which remove the isotopes from the primary system and carry them to a radwaste stream, have been rigorously pursued. By regulation, radioactivity measurements must provide reasonably accurate data for use in quantifying disposal site nuclide concentrations and inventories. Nevertheless, the reported activity of a given radwaste type shipped from the operating PWR's indicates a disparity in the data which spans as much as six orders of magnitude[1].

Estimated activities generally fall within a fairly narrow range due to the use of common assumptions in estimation techniques. Actual reported activities, however, are not limited to this range and may vary from the estimate to such an extent that preliminary radwaste disposal cost estimates are no longer valid. Why does this disparity in reported radwaste activities prevail and what are the effects on disposal costs? First let's examine the origin of the disparity.

DISPARITY IN SOURCE TERM DATA

Several factors affect the magnitude of radioactivity within radwaste. Most prominent are the failed fuel percentage and isotope specific escape rate coefficients. Studies [1,2] have shown that radwaste activity is directly related to the rate at which activity is released from the reactor core to the primary coolant. While escape coefficients vary little from plant to plant, designers are unable to accurately predict the amount of failed fuel which will occur in the years following system startup due to unforeseen operational events. Due to these uncertainties, the failed fuel percentage for PWR's is often conservatively estimated to be a maximum of 0.1 at the radwaste system design stage.

Apart from the failed fuel percentage, radiological data is most often reported in such a way that a meaningful comparison between radwaste activities from two or more PWR's is not possible. For example, spent resin activity reports often do not differentiate between primary and secondary cleanup systems, do not specify on-line time between changeouts or a spent/unspent resin ratio, do not report resin volumes, and do not specify the physical state of the sample, e.g., weight percent solids. None of the reports to date has provided sufficient detail to determine where the variations occurred. Until detailed reports are made available, we are left with a smattering of data that does not lend itself to simple analysis. However, despite the variations in data and the lack of detailed evaluations, some useful conclusions can be drawn. The technique employed and the results follow.

RADIOLOGICAL DATA ANALYSIS

Radwaste activity data for PWR's were extracted from several reports [3,4,5]. The accumulated data was sorted by magnitude, producing a Gaussian-like distribution. The results were plotted on a bar graph and overlayed with a true Gaussian distribution based on the total number of plant reports. This normalized distribution illustrated the randomness of the reported activities and lended itself to a mathematical treatment of occurrence probabilities.

This technique was employed for spent filter cartridges and iterated for evaporator concentrates and spent resins in Figs. 1, 2, and 3, respectively. Note that the spent resin activities were represented well by two Gaussian curves. One possibility for this occurrence was that both primary and secondary spent resin activities were reported under the single heading of spent resins. The low range of specific activities for this case are indicative of secondary spent resins while the high range reflects activity levels expected of primary spent resins.

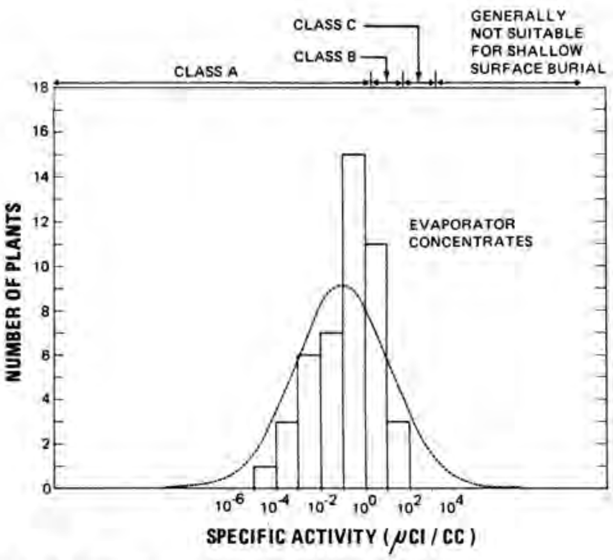

Fig. 2. Reported evaporator concentrate activities.

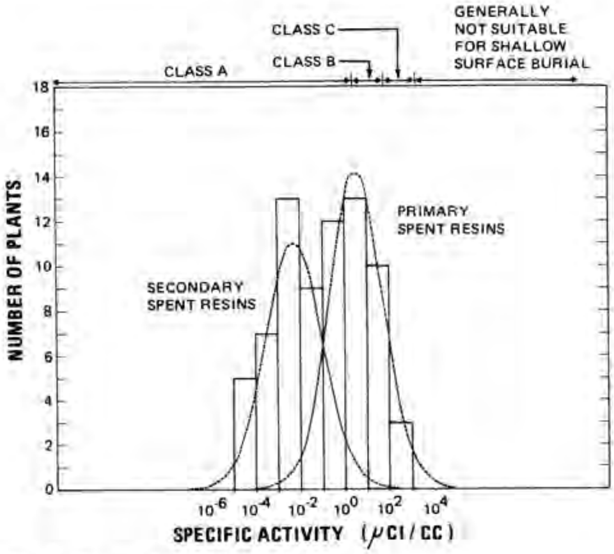

Fig. 3. Reported spent resin activities.

Also provided on the figures are the estimated activity ranges for waste Classes A, B, and C as defined by the NRC's regulations for disposal of LLW (10CFR61). The range limits indicate where additional waste disposal costs may arise due to requirements to segregate the wastes in each class. The waste class activity limits were based on:

1. Isotope activity limits set forth in 10CFR61,
2. A one-to-one ratio for Co-60 and Cs-137 activity levels,
3. Scaling factors[3] keyed to Co-60 and Cs-137 activities for determining other isotopic activities in PWR process wastes,
4. Sum of the fractions rule for mixtures of radionuclides.

These assumptions resulted in specific activity limits of about 2 µCi/cc for Class A waste (limiting isotope Cs-137), 60 µCi/cc for Class B waste (limiting isotope Cs-137), and 1200 µCi/cc for Class C waste (limiting isotope I-129).

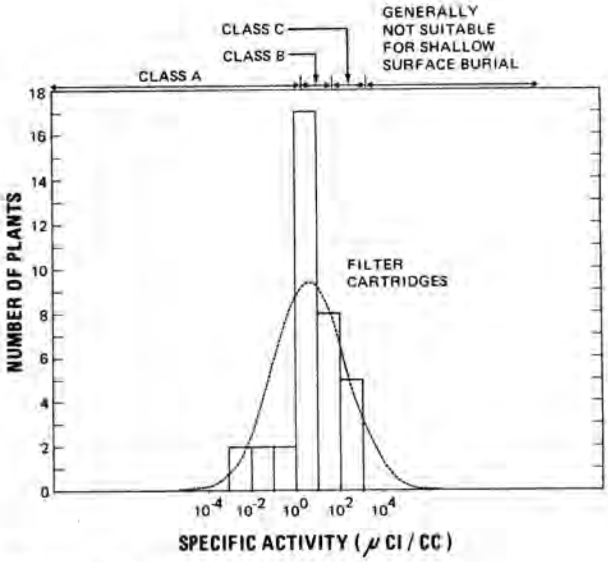

Fig. 1. Reported filter cartridge activities.

The next step was to determine the relationship of activity to the disposal cost for PWR radwaste. Once this relationship was established, the effects of source term uncertainty on PWR operating costs, as well as on cost projections for meaningful trade-off studies, could be ascertained.

UNIT RADWASTE DISPOSAL COSTS

Isotopic distribution and activity level have a direct impact on the transportation and burial costs for radwaste. Larger source strengths result in higher waste container dose rates. This, in turn, results in higher shielding and handling requirements, surcharges for high curie content, and a potentially increased number of waste shipments. Each of these can have a dramatic effect on total disposal costs. To investigate this relationship, the computer program RWCOST[7] was utilized. Disposal costs were estimated over the entire range of reported activities for the three waste types. Major assumptions employed in the cost impact analysis were:

1. 55-gal shipping containers,
2. Cement solidification agent, binder-to-waste ratio of 1:1,
3. 90% packing efficiency,
4. Transportation distance of 750 miles by Tri-State Motor Transit Co.,
5. Burial at Barnwell,
6. Radwaste activity *composition:* 50% Co-60, 50% Cs-137,
7. Maximum allowable container surface dose rate of 100 R/hr. Waste volumes per container were adjusted, were necessary, to meet this criteria.

The cost analyses indicated that the major determinant in transportation and burial costs was the total activity content of the waste container. Fig. 4 illustrates the radwaste disposal cost per unit volume over a range of activity levels. The data was plotted on a log-log basis.

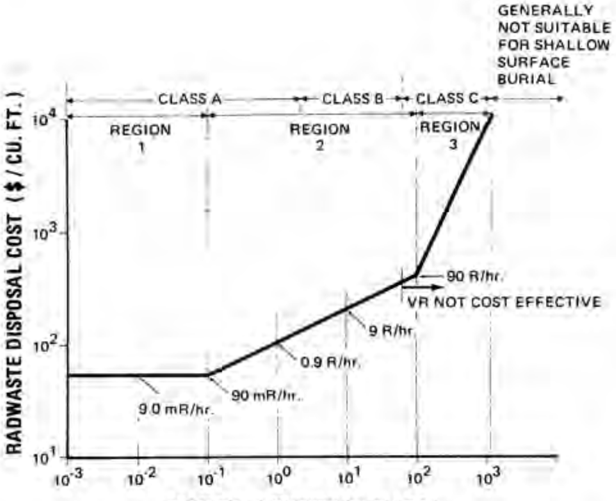

Fig. 4. Disposal cost as a function of activity.

CONCLUSIONS

The foremost application of the data is the enhancement of radwaste disposal cost analyses. By placing confidence factors on each of the parameters employed in establishing waste source terms, the radwaste system designer can determine the expected radwaste disposal cost, as well as upper and lower cost bounds. Some immediate conclusions can be drawn by examining Fig. 4 where three distinct regions of log-log linearity are apparent.

Region 1 shows that disposal costs are constant for specific activities below 0.1 μCi/cc. No shipping cask is required and as many as 75 drums at a time may be transported to the burial site in a shielded van. Activity levels below this level do not result in significant radiation or curie surcharges at the site. As a result, the costs result from material handling requirements rather than the radiation level.

Region 2 shows a moderate gradient in which disposal costs double for each ten-fold increase in specific activity between 0.1 and 100 μCi/cc. Various shipping casks are required within this activity range. The number of containers per shipment ranges from 21 at the low activity end to 5 at the high activity end. Surcharges for cask handling, drum surface dose rate, and curie content begin to figure prominently in the disposal costs.

Region 3 shows a steep gradient in which disposal costs nearly triple for each two-fold increase in specific activity above 100 μCi/cc. The waste volume per container was adjusted to assure a container surface dose rate below 100 R/hr to avoid special handling charges. This minimized the overall waste disposal costs at the burial site but it also resulted in an increased number of waste shipments. Above 200 μCi/cc, only one drum could be transported to the burial site per shipment because of shield cask capacity restrictions. Volume adjustment, surcharges for cask handling, drum surface dose rate, and curie content all result in a dramatic increase in waste disposal costs within this region. We can conclude that source term uncertainties have a large impact on disposal costs for Class C waste, a moderate impact for Class B waste, and zero to moderate impact for Class A waste.

Another important application of the data for the radwaste system designer is the activity range over which volume reduction (VR) is cost effective. The upper limit of the activity range is the point at which the VR factor is equal to the disposal cost increase factor as shown in Equation 1.

$$\mathrm{VRF} = \frac{C(\mathrm{VRF} \times A)}{C(A)} = \mathrm{CIF} \tag{1}$$

VRF = volume reduction factor
C = disposal cost as a function of activity level, \$/cu. ft.
A = activity, μCi/cc
CIF = cost increase factor

The offset points are 60, 70, and 80 μCi/cc for VR factors of 4, 3, and 2, respectively. Since the maximum specific activity for Class B waste is approximately 60 μCi/cc, the conclusion is drawn that VR is generally a viable approach for reduction of waste disposal costs for both Class A and B wastes. Conversely, VR is not cost effective for any Class C wastes. Referring back to Fig.'s 1 through 3, the normalized distributions yield the percentage of PWR's which are expected to report activities below 60 μCi/cc for a given radwaste type and, therefore, can employ cost effective volume reduction techniques. These percentages are:

1) 72% for filter cartridges,
2) 77% for primary spent resins,
3) 90% for evaporator concentrates,
4) 99% for secondary spent resins.

Finally, the data yields the most probable range of specific activities for each radwaste type. These values are not based on the mean of all reported specific activities since high activity levels place an undue bias on the mean. Instead, the values listed below indicate the range under which the greatest number of reported data points fell. From Fig.'s 1 through 3, the most probable ranges of occurrence for PWR radwaste are:

1) 0.002 - 0.02 μCi/cc for secondary spent resins,
2) 0.05 - 0.5 μCi/cc for evaporator concentrates,
3) 1.0 - 10.0 μCi/cc for primary spent resins,
4) 2.0 - 20.0 μCi/cc for filter cartridges.

REFERENCES

1. V. F. BASTON, J. H. McFADDEN, and W. A. YUILL, "An Analytical Method for Calculating Steady State Fission Gas Release -- Fission Product Fuel Model (FPFM) Code," UC-80, Aerojet Nuclear Co., Idaho Falls, Idaho (1971).

2. W. D. FLETCHER and L. F. PICONE, "Fission Products from Fuel Defect Test at Saxton," WCAP -3269-63, Westinghouse Electric Corp., Pittsburgh, Pennsylvania (1966).

3. R. E. WILD, O. I. OZTUNALI, J. J. CLANCY, C. J. PITT, and E. D. PICAZO, "Data Base for Radioactive Waste Management," NUREG/CR-1759, Dames and Moore, Inc., White Plains, New York (1981).

4. H. R. HELMHOLZ, G. F. PALINO, P. S. WALL, and T. J. LIANG, "Solid Radwaste *Radionuclide* Measurements," EPRI NP-2734, NWT Corp., San Jose, California (1982).

5. J. PHILLIPS, F. FEIZOLLAHI, R. MARTINETI, W. BELL, and R. STOUKY, "A Waste Inventory Report for Reactor and Fuel Fabrication Facility Wastes," ONWI-20, UC-70, NUS Corp., Rockville, Maryland (1979).

6. NUCLEAR REGULATORY COMMISSION CODE OF FEDERAL REGULATIONS, Title 10, Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste" (1982).

7. C. F. GUENTHER and R. J. TOSETTI, "Radwaste Economics Using the RWCOST Program," ANS Transactions, Vol. 39, p. 168 (1981).