RADWASTE ECONOMIC ANALYSES

BY MICROCOMPUTER

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ABSTRACT

Economic analyses of technologies for the volume reduction of low level radwaste have been demonstrated on a desktop microcomputer using the popular business package LOTUS 1-2-3 and the code VOLREDUCER. The hardware and software requirements, code structure, and features are described, including assumptions used in the model. Three waste processing technologies were examined with reference to BWR and PWR data taken from previous EPRI work. Results and sensitivity studies are presented for capital costs, discount rate, liquid waste volume, VR factor and distance from the disposal site. Results are comparable to those obtained from previous (mainframe computer) work.

INTRODUCTION

Both the domestic and international arenas continue to demonstrate their need for the evaluation of low-level radwaste management techniques and technologies. Utility managers and economists, power plant staff and engineering professionals all find it necessary to consider and evaluate the economic effects of new volume reduction products and processes, revisions to transportation and burial site charge schedules, and emerging operating experience. Previously published work [1-3] has cited the necessity for computer modeling in order to handle the large number of variable cost factors that enter into these complex studies. The ability to perform the comprehensive analyses required is now extended to readily available microcomputer hardware and software by the VOLREDUCER code described herein. Fast, consistant application of a comprehensive model to a specific case study can now be done on the desktop, together with rapid completion of sensitivity studies and graphical presentations.

CODE STRUCTURE

An overall view of VOLREDUCER's structure will facilitate understanding of its easy application. The code is intended for visual, interactive use rather than batch or card operation. It consists of a number of templates, or partially completed worksheets, stored on floppy disks. Each template describes a particular volume reduction technology and each template takes the form of a spreadsheet, generated by the ubiquitous software package from Lotus Development Corporation, "1-2-3". The shuffling of floppy disks to assure selection of the proper template is directed by on-screen prompts generated by an automatic executing batch file on the 1-2-3 system disk. Each template also incorporates an automated "prompting sequence" that directs the user to complete a finished worksheet. The storage of finished worksheets on floppy disk is accomplished by yet another automated command sequence associated with the template. Finally, each disk also stores the code library of binder, container and burial site rate data.

Hardware

Unlike the previous computer models, the VOLREDUCER code structure exists in a hardware and software environment that is becoming so common that it is nearly a standard. The microcomputer used is the IBM PC/XT/AT (or 100% compatible), with the operating system DOS 2.10 (or later). Random Access Memory (RAM) requirements are not unusual (384K or greater), and the memory expansion card must include a simulated disk drive, such as the AST package. A color monitor (or graphics card for a monochrome monitor) is extremely helpful, but not required. Two peripheral disk drives are required, both of which may be floppy drives. A desktop printer such as the EPSON FX-80 is sufficient for all hard copy output, although the code can utilize a wide carriage printer (such as the OKIDATA 93) and a plotter (such as the Hewlett Packard 7475A) to increase output quality.

Software

As mentioned, the integrated business software package 1-2-3 from Lotus is the key software external to the VOLREDUCER Code. Version 1A or later is required. This combination of software and hardware required exists in <u>many</u> forms, and it is extremely likely that the code can be used on any particular computer system that runs Lotus 1-2-3.

Very little programming expertise is required of the VOLREDUCER user. Some knowledge of 1-2-3 is required (in particular how to call for the command menus and how to enter numbers), but no knowledge of or experience with DOS, BASIC or FORTRAN is necessary.

SOFTWARE ASPECTS

The 1-2-3 integrated business software package has been discovered by many engineers to be well suited to a wide variety of technical applications [4,5,6]. The VOLREDUCER code utilizes a number of 1-2-3 features to enhance its applicability and to accommodate new users.

1) The spreadsheet format itself is an advantage in this application over conventional computer printout, as a large number of contributing calculations can easily display their results in columns labeled for quick identification and comparison with operating data or other performance milestones. Figure 1 illustrates the matrix nature of the VOLREDUCER output, each element corresponding to a distinct waste type.

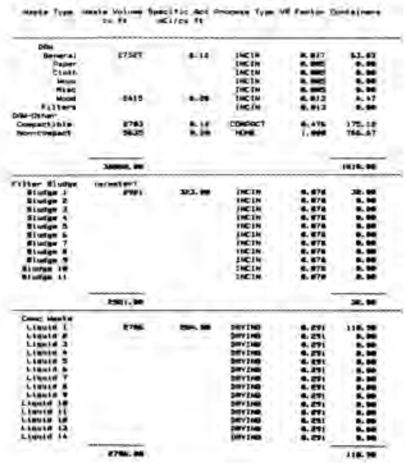

Fig. 1. Extract from VOLREDUCER Output.

2) 1-2-3 is noted for its advanced use of keyboard macros (7), and VOLREDUCER employs macros to make data entry and output faster and easier. Plain-English prompting appears on the monitor as soon as the system is started ("booted-up"). These prompts are generated by an automatic execution macro (\0) which directs the entry of waste characteristics and economic data with the /XN and /XL commands. Additional macros, manually initiated, prompt the user to enter data perturbations for sensitivity analyses, and create titles, axes and legends for specialized graphs.

3) Visual selection of options, by moving the display cursor across a 1-2-3 "menu" (the /XM commands), is used to select waste container types (6 options offered for each of five waste types), waste binders (7 options offered for each of five waste types), plant type (3 options) resin dewatering (3 options) and burial site (6 options).

4) VOLREDUCER utilizes macro subroutines (via the /XC command) for retrieval of data files from the disk drive simulated in RAM. This greatly speeds execution. Subroutines also are used for display cursor positioning, preparation of data tables, and for retrieval of small templates from the simulated disk drive for the entry of unique or unusual data. These small templates are options selected from menus and are overlaid onto the overall worksheet template. They are accompanied by command line prompts for their completion. Such templates are used for the "Other" binder options, the "Other" container options, and "Other" burial rate schedules.

5) VOLREDUCER also utilizes the facile 1-2-3 lookup table structure (the @VLOOKUP function) to determine the cost of waste transportation, as shown in Table I. This table serves multiple duty, as it yields the number of disposal trips made as well as both the cask and truck rental charges.

TABLE I
Transportation Cost Assumptions

RADIATION	TRUCK CAPACITY LIMITS			CHARGES	
SDR MR/HR	WEIGHT LBS/TRIP	VOLUME DRUMS/TRIP	LINERS CU. FT./TRIP	CASK $/DAY	TRUCK $/DAY
0 TO 200	43000	150	1000	0	$250
200 TO 1,000	26000	75	1000	0	$250
1,000 TO 20,000	17700	14	200	$250	$350
20,000 TO 100,000	7000	7	85	$250	$350
100,000 TO 500,000	7500	7	85	$550	$350

- BASIC MILEAGE CHARGE - $1.60/MILE
- MILEAGE PER DAY BASIS - 400

*REF. 8,9

6) As previously noted, a macro routine in VOLREDUCER prompts entry of perturbed input values for sensitivity analyses. These values are used to create a data table (the /DT1 command) of annual cash flows for each perturbed entry, thus tabulating the sensitivity of the "bottom line" to that input.

7) The named graph feature of 1-2-3 has been employed to create a library of standard graph axes, titles and legends associated with each template. Graphs of net (cummulative) present value dollars versus time are stored for perturbed input values of discount rate, escalation rate, capital cost, waste volume and others. When a named graph is selected (the /GNU command) the data from a sensitivity analysis is displayed graphically. It is only left to the user to select the named graph, if any, corresponding to his particular sensitivity analysis.

8) Numerous error trapping routines have been installed in VOLREDUCER using the @ERR and @ISERR functions in 1-2-3. The appearance of error messages due to attempted division by zero is suppressed whenever a conditional branching statement can be used to insert a correct known value (the @IF function).

9) Conditional branching on arithmetic conditions is common in electronic spreadsheets, but conditional branching on text is not [10]. By an unusual application of the @DCOUNT function in 1-2-3, VOLREDUCER branches upon character string recognition to differentiate between the transportation limits on various types of waste containers.

10) Storage and retrieval of limited portions of a VOLREDUCER spreadsheet (the /FXVN and /FCCN commands) allow transfer of data between baseline templates and test case templates for consistant comparisons.

11) Accelerated program execution is obtained by using a manual recalculation mode available in 1-2-3. Instead of recomputing the entire worksheet with each datum entry, a single computation is made at the end of all entries. This is actually analogous to compiling and then executing a high level language program rather than interpreting it.

12) The repeated re-evaluation of iterative indices is accomplished by conversion of formulae to their current value (with the combined 1-2-3 commands [Edit] and [Calc.]).

SYSTEM MODELING ASPECTS

The results of processing low level radwaste, by particular volume reduction systems are considered by VOLREDUCER as applying to 5 types of waste - Spent Resins, Dry Active Waste (DAW), Filter Sludge, Liquid Concentrates and Filter Cartridges. Within each type of waste, as many as 12 classes may be broken out by activity, isotope or other factor, thus enabling the code to handle up to 60 different wastes. For each kind of waste generator (BWR, PWR or other) and each waste type, the volume and mass reduction factors and the waste incorporation ratios appropriate to each specific system are applied, along with a binder type, a container type and a drum filling level (percentage). The Spent Resin and Filter Sludge types may be optionally processed or de-watered; then for each class of waste, transportation, burial and material costs are tracked separately.

The results of processing are of course contained in the volume and mass reduction factors and the incorporation ratios. Actual operating data, or data from NRC topical reports, are used to the maximum extent possible to model each specific system. In general this produces a more conservative result than vendor promotional literature. The burial costs for the illustrations in this paper are computed using the latest Barnwell burial site rate schedule (changes are made to a library data file and not to the templates, thus simplifying the "update" procedure) and the other assumptions listed in Table II, although VOLREDUCER can access Beatty, Hanford and some overseas burial cost schedules as well.

TABLE II
Burial Cost Assumptions

- BARNWELL RATE SCHEDULE 4/15/85*
  - WEIGHT SURCHARGE <u>PER CONTAINER</u>
  - CURIE SURCHARGE <u>PER SHIPMENT</u>
  - <u>NO</u> RADIATION SURCHARGE
- NO ADDITIONAL CHARGES FOR HANDLING OR DECONTAMINATION
- ALL CONTAINERS OVER 1000 LBS. ASSUMED TO REQUIRE CRANE
- PLANT DISTANCE TO BURIAL SITE - 1000 MILES

*REF. 11

Transportation costs are taken from the lookup table and other data shown previously in Table I; waste is assumed to be shipped by unshielded van or shielded van for the two lowest SDR groups respectively. Finally, the material costs of processing each class of waste are accounted for according to the assumptions in Table III.

TABLE III
Material Cost Assumptions

• 55 GALLON DRUM	$26
• HIGH INTEGRITY CONTAINER	$300
• CEMENT	$0.04/LB.
• DOW 101 BINDER W/PROMOTER, CATALYST	$1.64/LB.
• ASPHALT	$0.12/LB.
• DISPOSABLE MIXER/CAP	$80

Other operating costs (for services, labor and maintenance) for processing each type of waste are accounted for under the assumptions in Table IV. Since labor is usually performed on a shift basis, the cost of each operating shift is apportioned to each type of waste in proportion to the number of containers produced for that type.

TABLE IV
Operating Cost Assumptions

• ELECTRICITY	- $0.09/KW-HR*
• COOLING WATER	- $0.001/GAL.
• DEMINERALIZED WATER	- $0.01/GAL.
• CAUSTIC NaOH	- $0.14/LB.
• LABOR (ENGINEER)	- $4000/MONTH*
• LABOR (TECHNICAN)	- $2880/MONTH*
• LABOR (OPERATOR)	- $2640/MONTH*
• MAINTENANCE	- 50% OF LABOR

*REF. 8

Capital costs include hardware, installation, and construction. Finally, the economic assumptions used to complete the analyses are indicated in Table V. The present value of revenue requirements methodology has been used[12] but the individually escalated yearly operating costs are used rather than a factor for the present value of an escalating series. The annual present values for a processing system are compared to baseline present values to show cash flow, as well as ultimate savings.

TABLE V
Economic Assumptions

- DISCOUNT RATE - 10%
- ESCALATION RATE - 7%
- LIFETIME - 30 YEARS
- OFFSET BEFORE STARTUP
  - FLUID BED VR - 5 YEARS
  - EXTRUDER/EVAPORATOR VR - 4 YEARS
- METHODOLOGY
  - PRESENT VALUE OF REVENUE REQUIREMENTS

APPLICABILITY

The ability of this microcomputer code to produce useful results is illustrated by the following case studies. Data regarding waste generated at boiling waste reactors and pressurized water reactors[11,12] was extracted to yield the as-produced averages shown in Tables VI and VII.

TABLE VI
As-Produced Average (1978-1981) Volume of Low-Level Radwaste One Unit BWR

WASTE TYPE	VOLUME		ACTIVITY		DENSITY	
	cu m	(cu. ft.)	μci/cc	(mci/cu. ft.)	g/cc	(lbs./cu. ft.)
SPENT RESIN	31.3	(1105)	25.5	(722)	1.03	(64.5)
COMPACTIBLE DAW						
COMBUSTIBLE	774	(27327)	0.004	(0.12)	0.13	(8)
NON-COMBUSTIBLE	76.6	(2703)	0.004	(0.12)	0.13	(8)
NON-COMPACTIBLE DAW						
COMBUSTIBLE	68.4	(2415)	0.007	(0.20)	0.35	(22)
NON-COMBUSTIBLE	160	(5635)	0.007	(0.20)	0.35	(22)
FILTER SLUDGE	82.7	(2921)	11.4	(323)	1.03	(64.5)
LIQUID CONCENTRATES	76.6	(2706)	7.2	(204)	1.25	(78)
FILTER CARTRIDGES		—		—		—

*REF. 13,14

TABLE VII
As-Produced Average (1978-1981) Volume of Low-Level Radwaste One Unit PWR

WASTE TYPE	VOLUME cu m	(cu. ft.)	ACTIVITY µci/cc	(mci/cu. ft.)	DENSITY g/cc	(lbs./cu. ft.)
SPENT RESIN	16.5	(583)	54	(1530)	1.03	(64.5)
COMPACTIBLE DAW						
COMBUSTIBLE	396	(13972)	0.008	(0.22)	0.13	(8)
NON-COMBUSTIBLE	29.8	(1052)	0.008	(0.22)	0.13	(8)
NON-COMPACTIBLE DAW						
COMBUSTIBLE	51.4	(1815)	0.01	(0.40)	0.35	(22)
NON-COMBUSTIBLE	104	(3685)	0.01	(0.40)	0.36	(22)
FILTER SLUDGE		–		–		–
LIQUID CONCENTRATES	74.8	(2640)	0.38	(10.9)	1.03	(64.2)
FILTER CARTRIDGES	7.1	(250)	7.1	(200)	0.50	(31)

*REF. 9,10

Each of these data sets was then analyzed with VOLREDUCER for three operating cases:

1) conventional operation with compaction of DAW and cement solidification of waste, for a baseline.

2) volume reduction with fluid bed drying, incineration and polymer solidification of the resultant dry product.

3) volume reduction with extruder/evaporative processing and asphalt solidification of all waste except DAW.

The important assumptions made for each of these cases are shown in Table VIII.

TABLE VIII
Baseline Case Assumptions

- CEMENT SOLIDIFICATION OF LIQUID WASTE
- CONVENTIONAL COMPACTION OF DAW
- DEWATER PWR RESINS, SOLIDIFY BWR RESINS

FLUIDIZED BED VR CASE ASSUMPTIONS

- INCINERATION OF COMBUSTIBLE DAW
- DEWATER PWR RESINS; INCINERATE BWR RESINS
- CAPITAL COST $14.5 M

EXTRUDER/EVAPORATOR VR CASE ASSUMPTIONS

- CONVENTIONAL COMPACTION OF DAW
- SOLIDIFY BOTH BWR AND PWR RESINS
- CAPITAL COST $4.5 M

The results of the analysis is in each case a completed worksheet including, for each type of waste,

1) the number of waste containers
2) their surface dose rate
3) the annual cost for transportation, burial, containers, binder, labor, maintenance and services
4) the annualized capital costs and (escalated) operating costs
5) the net cumulative present value dollars as a function of time for the plant lifetime.

Each worksheet requires about 200K of peripheral storage and can be printed in 15 wide carriage pages. The worksheet, however, is simply the basis for the must useful and interesting feature of the code-fast and easy sensitivity analysis.

Perturbations of worksheet data which affect only the volume reduction cases (such as capital cost or volume reduction factor) are termed simplex perturbations; those affecting both the baseline case and the volume reduction cases (such as discount rate or distance from the burial site) are termed duplex perturbations. Sensitivity analyses for each type of perturbation are generated by separate macro routines, with automatic storage and retrieval of perturbed results and on-screen prompting for perturbed data entry and disk shuffling. The results of these sensitivity analyses are contained in new, smaller worksheets tabulating the perturbed inputs and resulting outputs, as shown in Fig. 2. The meaning of the analyses, however, is made most clear in graphical form. Figures 3-19, generated directly by the PrintGraph portion of Lotus 1-2-3, show the sensitivity of the cumulative net present value to distance from the burial site, discount rate, volume of liquid concentrates, capital cost and volume reduction factors.

These figures have been scaled to allow easy comparison of sensitivity among perturbations of the same plant/processing combination, without sacrificing resolution. (This requires that the Automatic Scaling feature of Lotus 1-2-3 be over-ridden).

BWRFB/R1-CAPCOST2 CAPITAL COST SENSITIVITY 14-Jan-86

Table Range Entry Parameter	Year Number 0	Year Number 2	Year Number 4	Year Number 6	Year Number 8	Year Number 10
		$4,911,533	$9,850,946	$14,766,038	$19,616,217	$24,370,348
$8,000,000	$0	$5,597,060	$11,050,897	$16,341,810	$21,455,915	$26,384,008
$10,000,000	$0	$5,267,406	$10,448,801	$15,514,556	$20,442,580	$25,216,886
$12,000,000	$0	$4,937,752	$9,846,705	$14,687,301	$19,429,244	$24,049,765
$14,000,000	$0	$4,608,098	$9,244,609	$13,860,047	$18,415,909	$22,882,643
$16,000,000	$0	$4,278,443	$8,642,514	$13,032,793	$17,402,574	$21,715,522

BWRFB/R1-CAPCOST2 CAPITAL COST SENSITIVITY 14-Jan-86

Table Range Entry Parameter	Year Number 12	Year Number 14	Year Number 16	Year Number 18	Year Number 20
	$29,004,979	$33,502,887	$37,851,881	$42,043,818	$46,073,798
$8,000,000	$31,120,626	$35,663,286	$40,011,858	$44,168,051	$48,134,999
$10,000,000	$29,826,409	$34,264,031	$38,525,794	$42,610,245	$46,517,902
$12,000,000	$28,532,191	$32,864,775	$37,039,730	$41,052,439	$44,900,805
$14,000,000	$27,237,973	$31,465,520	$35,553,666	$39,494,632	$43,283,707
$16,000,000	$25,943,756	$30,066,264	$34,067,603	$37,936,826	$41,666,610

Fig. 2. Worksheet Table of Perturbation Results

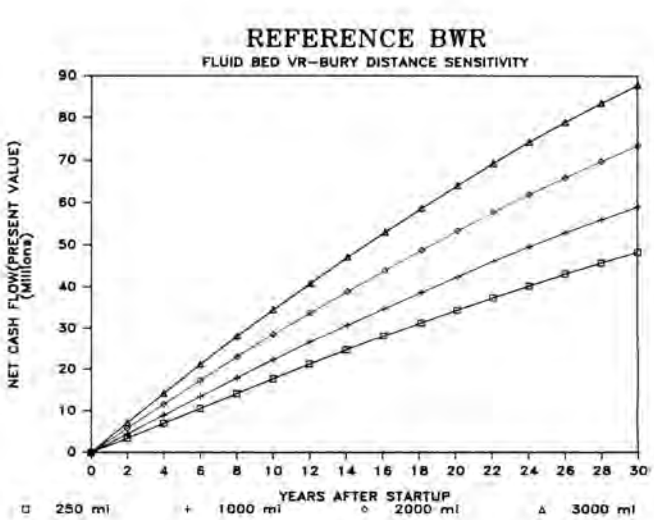

Fig. 3. BWR Case 2 – Sensitivity to Distance from Burial Site

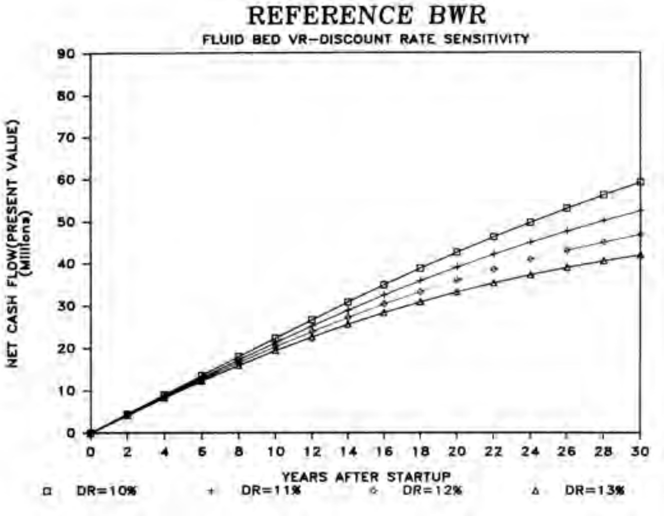

Fig. 4. BWR Case 2 - Sensitivity to Discount Rate

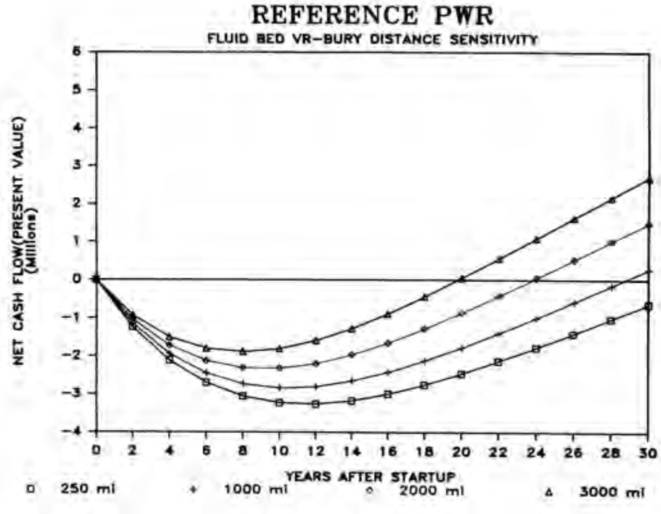

Fig. 7. PWR Case 2 - Sensitivity to Distance to Burial Site

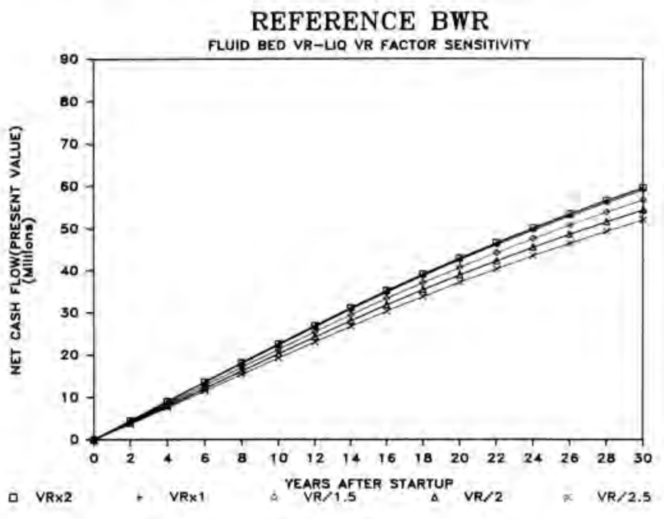

Fig. 5. BWR Case 2 - Sensitivity to VR for Liquid Concentrates

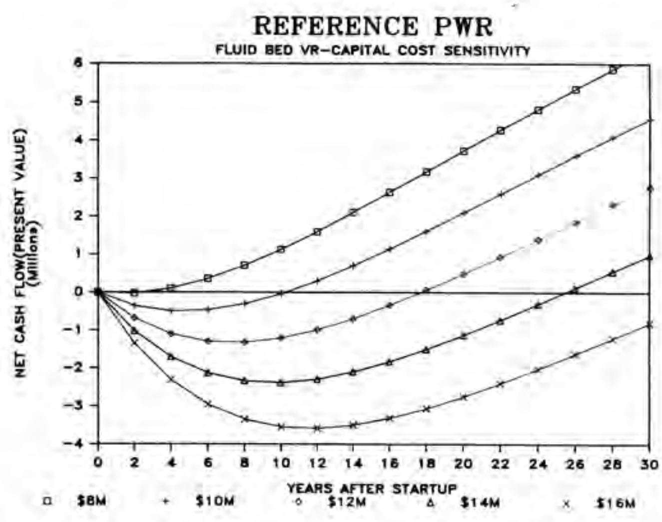

Fig. 8. PWR Case 2 - Sensitivity to Capital Costs

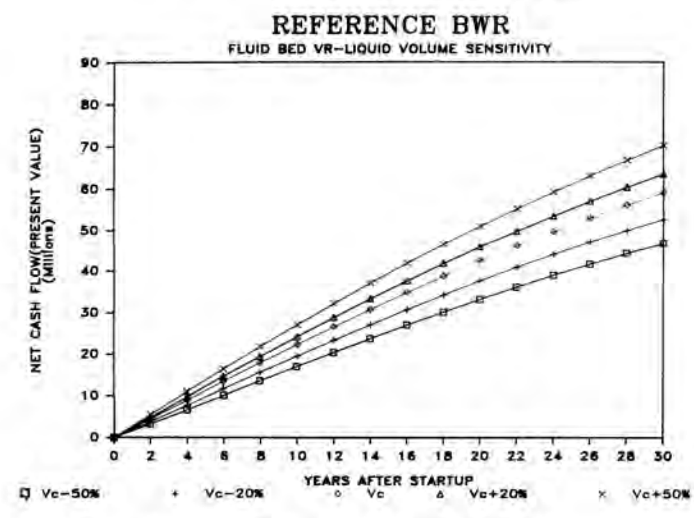

Fig. 6. BWR Case 2 - Sensitivity to Volume of Liquid Concentrates

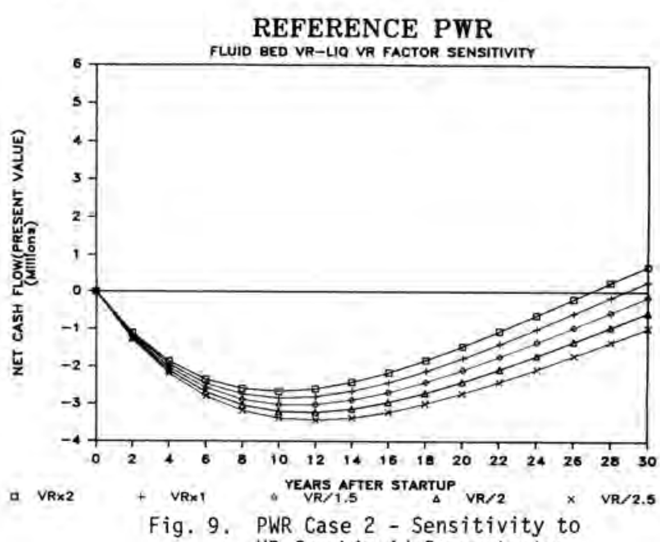

Fig. 9. PWR Case 2 - Sensitivity to VR for Liquid Concentrates

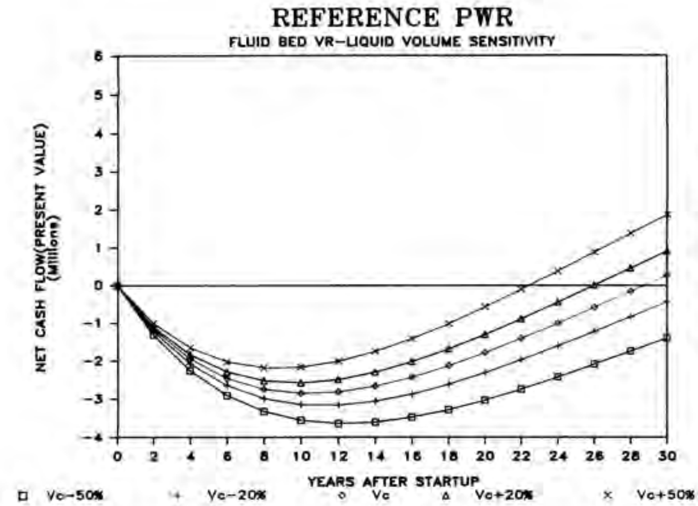

Fig. 10. PWR Case 2 - Sensitivity to Volume of Liquid Concentrates

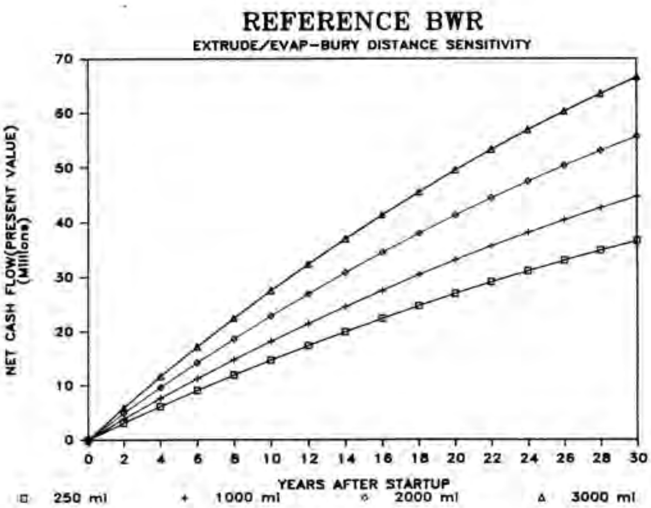

Fig. 11. BWR Case 3 - Sensitivity to Distance from Burial Site

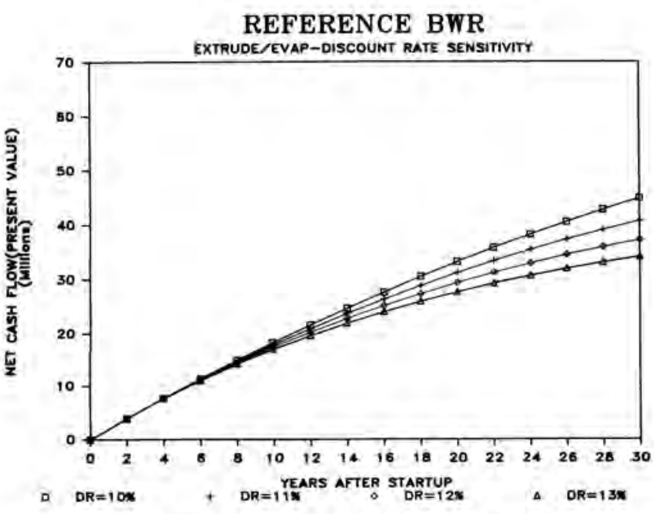

Fig. 12. BWR Case 3 - Sensitivity to Discount Rate

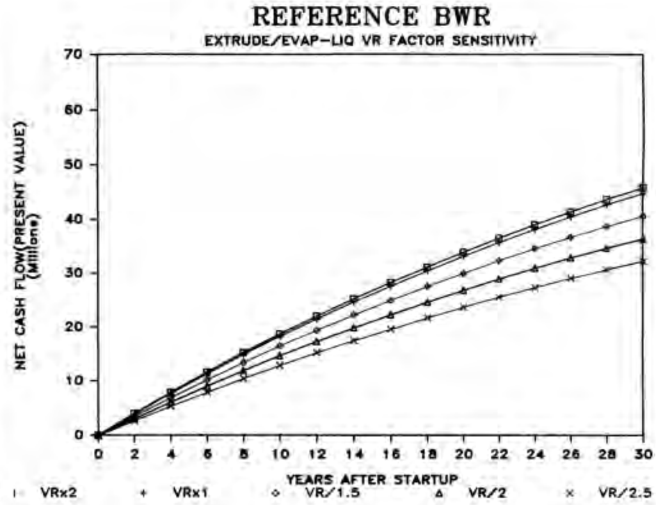

Fig. 13. BWR Case 3 - Sensitivity to VR for Liquid Concentrates

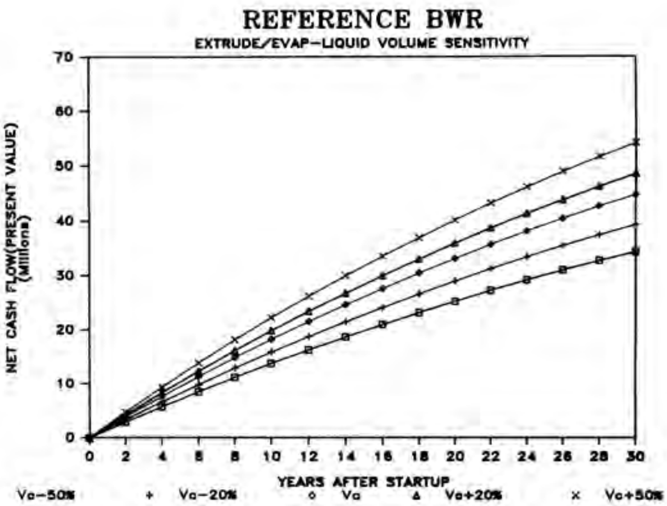

Fig. 14. BWR Case 3 - Sensitivity to Volume of Liquid Concentrates

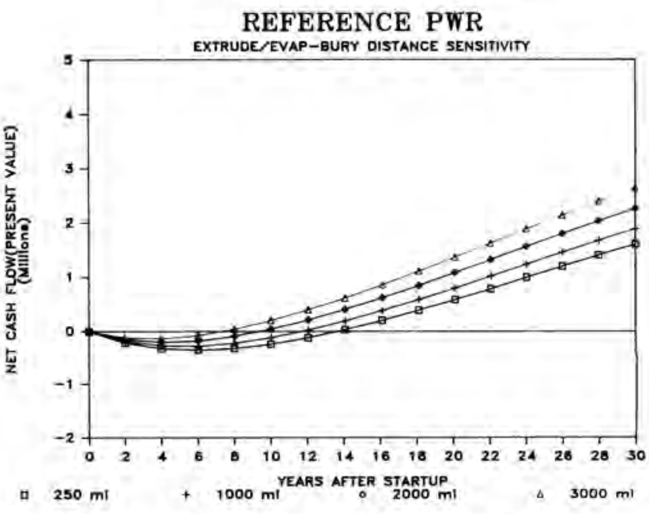

Fig. 15. PWR Case 3 - Sensitivity to Distance from Burial Site

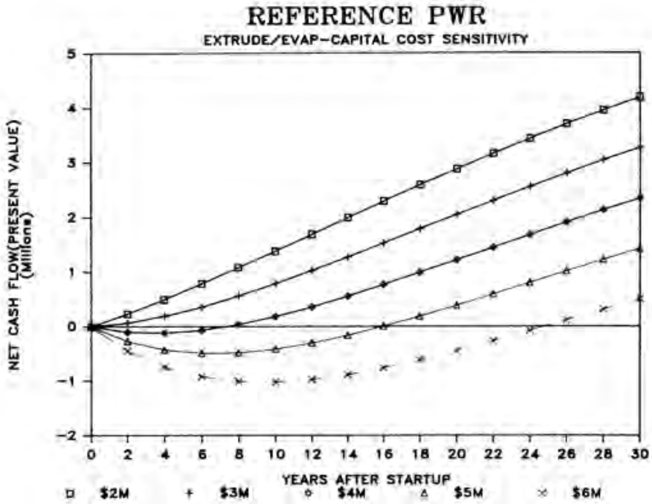

Fig. 16. PWR Case 3 - Sensitivity to Capital Cost

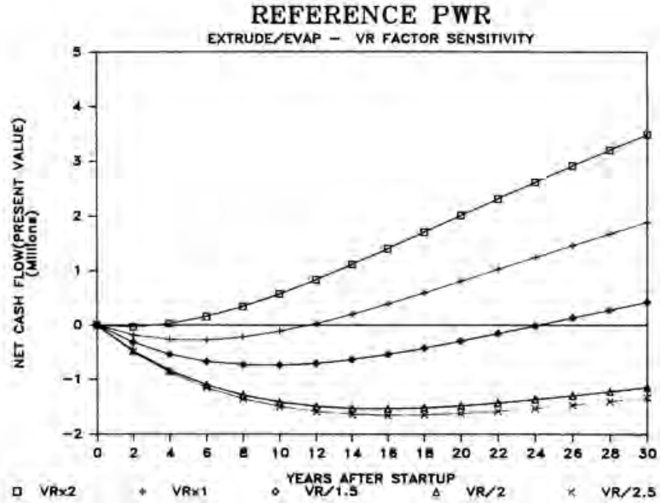

Fig. 19. PWR Case 3 - Sensitivity to Overall VR Efficiency

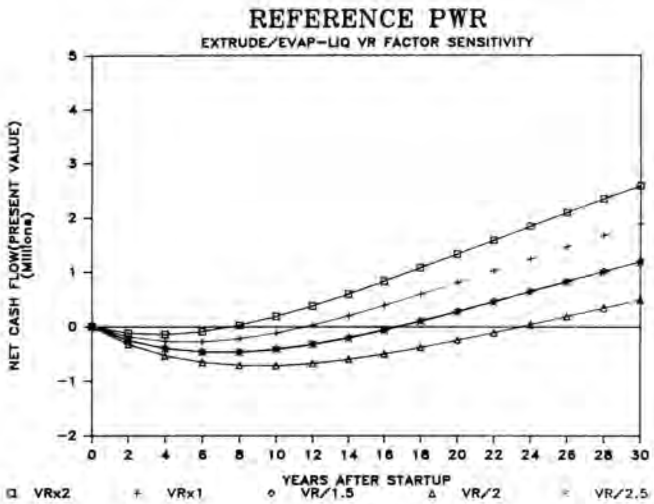

Fig. 17. PWR Case 3 - Sensitivity to VR for Liquid Concentrates

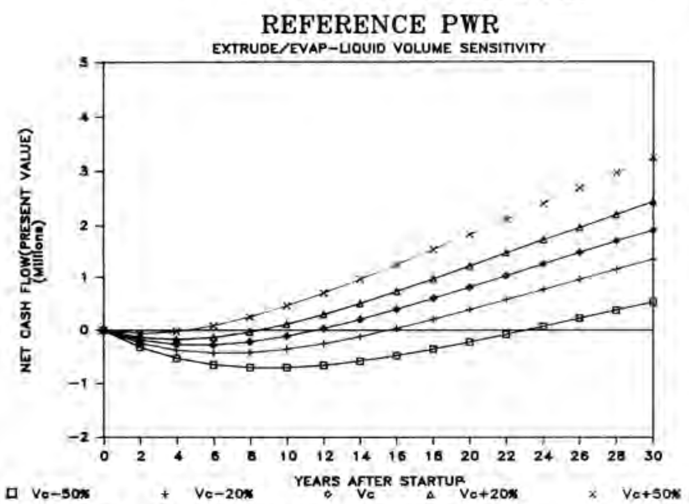

Fig. 18. PWR Case 3 - Sensitivity to Volume of Liquid Concentrates

DISCUSSION

As with all analyses of this type, conclusions regarding specific waste generators are best if drawn from their specific source and operating data. In general, however, the sensitivity studies show that for the reference cases described, some conclusions are relatively insensitive to perturbation:

1) Both VR systems studied are much less favorable economically at a 1 unit PWR than at a 1 unit BWR,

2) the fluid bed technology may offer a BWR a long term economic advantage over the extruder evaporator technology,

3) the extruder evaporator technology can offer a PWR a long term return to offset the period of negative cash flow, while the fluid bed technology may not.

In addition, we can draw some conclusions regarding the sensitivity of each reference plant to specific perturbations:

1) the BWR is most sensitive to its distance from the burial site, is insensitive to capital costs, and is more sensitive to liquid waste volume than to liquid VR factor. There is some sensitivity to the discount rate (Fig. 3-6, 11-14).

2) the PWR is most sensitive to capital cost (though at a <u>much</u> lower level of net return then for a BWR), <u>is</u> insensitive to discount rate, and is more sensitive to liquid waste volume than to liquid VR factor. There is some sensitivity to distance from the burial site. (Fig. 7-10, 15-18).

We can also observe some interesting features characterizing the sensitivity of each VR technology:

1) the extruder evaporator is sensitive to VR factor when the system is used to treat resins and sludges as well as liquid concentrates. As the VR factor gets lower (worse), the return to a PWR may actually <u>improve</u> as waste is shipped without requiring casks. (Fig. 17, 19),

2) neither technology realizes a significant improvement in cash flow with an increase (improvement) in the volume reduction of liquid concentrate. (Fig. 5, 9, 13, 17).

These conclusions are of course heavily dependant on the assumptions made and the VOLREDUCER model itself. Their qualitative agreement with previously published results [15,16] indicates the validity of the microcomputer approach.

CONCLUSIONS

VOLREDUCER demonstrates the ability of a desktop microcomputer to meet the needs of professional personnel requiring rapid analysis of new, changing or current radwaste volume reduction technologies. This code is open ended (any number of new technologies can be modeled without changes to basic code structure), flexible and user-friendly. It can provide the user with printed or graphical output, and is fully compatible with a variety of hardware/software combinations. Best of all, it frees the user from expensive mainframe computer models and their accompanying jargon. Economic analysis of radwaste volume reduction technologies is now a tool for engineering and management; no longer is it an end in itself.

REFERENCES

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