COMPUTER ECONOMIC MODELING OF VOLUME REDUCTION SYSTEMS

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ABSTRACT

An interactive computer program for the economic analysis of volume reduction and solidification systems is discussed. The interactive nature of the program allows parameters to be varied with an immediate feedback of the results. The rapid turnaround time of the program allows many processing and financial options to be examined in a short period of time. The program output includes the number of burial containers, the first year disposal costs, the total levelized system cost, and the equivalent capital investment of the system.

INTRODUCTION

Over the past several years, the availability of low-level radioactive waste disposal sites in the United States has been greatly reduced. This is the result of both site closures and imposed volume limitations at the remaining operating sites. Additionally, disposal site charges have increased at an average rate of over 30% per year since 1975. These factors have created a great deal of interest in reducing the volume of low-level radioactive waste generated at nuclear power plants. The volume reduction of waste will not only conserve diminishing burial space, but will also reduce the size of on-site storage structures which may be required in lieu of waste shipment to disposal sites.

An extensive array of equipment is currently being marketed to perform volume reduction (VR) functions. There are no less than 16 suppliers of VR systems for liquid and wet wastes, and 16 suppliers of incinerators. There are also several vendors offering compactors and shredders for processing dry active waste (DAW) and evaporator/crystallizers for concentrating liquid waste. Deciding which process to use and which vendor to choose has become quite difficult. Not only do the waste quantities and other parameters vary from station to station, but the majority of these systems have little, if any, operational data to support manufacturers' stated VR factors.

An economic comparison of volume reduction and solidification (VRS) systems can aid in determining which system is optimal for a particular station. The economic comparison of current station processing techniques with the various VR systems under consideration entails a calculation with numerous options and many permutations. Due to the number of parameters involved and the redundant nature of the calculations, the economic comparison of such systems readily lends itself to computer modeling. The major benefit of a computer model is the speed at which results can be obtained. Calculations that would take several days by hand can be performed in minutes.

This is not to say that an engineering decision should be based solely on an economic comparison. However, many options can be examined quickly, allowing time-consuming, detailed engineering comparisons to be made on only the most appropriate systems for the station.

This paper will discuss in detail the Volume Reduction and Solidification Program (VRASP) which was written for making the necessary economic comparisons.

VRASP was developed at the University of Arizona as part of the author's Master's degree project, and has been upgraded at Sargent & Lundy.

Input Parameters

VRASP is an interactive program which allows either generic or site specific waste generation data to be used. The current generic waste generation data in the program is the "Typical Plant Untreated Waste Volumes and Activities" as presented in the ONWI-20, NUS-3314 Report (see Table I). If generic data is selected, the program will ask for the number of units, size of units, type of units (BWR or PWR) and the type of condensate water cleanup system in use at the station (see Fig. 1).

```
@XQT C.VRASP
 DO YOU HAVE WASTE VOLUME AND ACTIVITY DATA-YES NO?
>NO
  NUMBER OF UNITS
    N=
>1
  SIZE OF UNIT(S) IN MW
    S=
>860
  TYPE OF UNIT T= (1-BWR, 2-PWR)
    T=
>1
  PLANT CLEANUP TYPE
  I= 1-BWR DEEP BED  3-BWR FILTER/DEMIN
  I= 5-PWR CPS       7-PWR NO CPS
    I=
>1
  VOLUME REDUCTION SCENARIO
    VR OF CONCENTRATES =
>1
    VR OF RESIN =
>1
    VR OF FILTER SLUDGE =
>1
    VR OF DAW =
>4
```

Fig. 1 Interactive Generic Waste Volume and VR Factor Inputs

TABLE I

WASTE GENERATION FACTORS

BWR

	Deep Bed		Filter/Demin	
	(ft^3/MWe-Yr)	(Ci/MWe-Yr)	(ft^3/MWe-Yr)	(Ci/MWe-Yr)
Concentrates	8.1	0.4500	0.60	0.0160
Resin	4.6	1.9000	0.23	0.0014
Sludge	5.4	2.0000	7.70	0.5000
Cartridges	0.0	0.0000	0.00	0.0000
Compactable DAW	7.2	0.0052	7.20	0.0052
Noncompactable DAW	3.4	0.3970	3.40	0.3970
Average DAW	10.6	0.4000	10.60	0.4000

PWR

	No CPS		CPS	
	(ft^3/MWe-Yr)	(Ci/MWe-Yr)	(ft^3/MWe-Yr)	(Ci/MWe-Yr)
Concentrates	2.60	0.21000	4.80	0.02400
Resin	0.94	0.61000	0.32	0.20000
Sludge	0.00	0.00000	0.15	0.01200
Cartridges	0.39	0.12000	0.39	0.12000
Compactable DAW	3.70	0.00064	3.70	0.00064
Noncompactable DAW	2.80	0.02840	2.80	0.02840
Average DAW	6.50	0.02900	6.50	0.02900

Adapted from ONWI-20. NUS-3314

If site specific waste generation data is available, it may be inserted into the program. The program prompts the user to insert both volume and curie quantities generated per year for concentrates, resins, sludges, cartridge filters, and DAW (see Fig. 2).

The program analysis is volumetric in nature and requires VR factors for each waste type treated by the proposed system. Thus, the computer prompts the user for VR factors for concentrates, resins, sludges, and DAW (see Fig. 1). If a certain waste type is not to be processed by the system being considered, a VR factor of one may be inserted. It should be noted that the VR factors required for this program are not overall VR factors (that is, the input waste volume divided by the solidified product volume). The VR factors used are intermediate or presolidified factors; that is, the input waste volume divided by the presolidified product volume. This approach has been used to allow different solidification agents to be combined with different VR processes. Care must be taken in the determination of the volume of dehydrated resin, powder and salt products. In the presolidified state, these products contain a considerable amount of void space which will be filled with a binder upon solidification. To properly calculate the volume of solidified material produced, the true density of the VR product must be used to determine the intermediate VR factor. Alternatively, if the overall VR factor and the waste to binder ratio (the volume of waste to the volume of binder in the solid product) is known, the intermediate VR factor is easily derived.

The next series of inputs define the processing techniques which are being considered and which are associated with the previouslyed inserted VR factors. Waste processing options include evaporation, crystallization, drying, incineration, compaction, and dewatering (see Fig. 3).

Liquid waste may be evaporated (or crystallized), producing a liquid product; or dried, producing a dry powder product.

DAW can be compacted or incinerated. In the case of compaction, only compactible waste is reduced in volume. For incineration, the majority of the waste is volume reduced at the specified VR factor. The noncombustible waste is either compacted or packaged, depending on its identity.

Resin can be treated by any of four choices. Resin can be (1) immobilized, (2) dewatered, (3) dried, or (4) incinerated. If incineration is chosen, only low activity resin will be processed; the high activity resin can either be dewatered or immobilized.

Cartridge filters can be immobilized or incinerated. Although most cartridge filters in use are not combustible, it is recognized that a few are. This option was also included as a particular process may predicate the type of filter to be used. If incineration is chosen, high activity filters are to be immobilized.

A choice of five solidification agents is available for slurries, resins, filters, salts, and ash (see Fig. 4).

Economic parameter inputs include the escalation rates of labor, materials, transportation rates, and burial rates. Utility specific economic parameters including the discount rate (rate of return) and the fixed charge rate are user inputs (see Fig. 5).

The transportation distance to a burial site is user supplied. The user is prompted to respond if the shipments will be east or west of the Mississippi River. Burial charges for Richland, Barnell and Beatty are available for the user's selection (see Fig. 5).

```
@XQT C.VRASP
 DO YOU HAVE WASTE VOLUME AND ACTIVITY DATA-YES NO?
>YES
  ENTER WASTE VOLUMES IN TERMS
  OF FT3/YR AND ACTIVITIES IN CI/YR
  VOLUME OF CONCENTRATES
    VOL=
>10000
  ACTIVITY OF CONCENTRATES
    ACT=
>2000
  VOLUME OF RESIN
    VOL=
>600
  ACTIVITY OF RESIN
    ACT=
>300
  VOLUME OF SLUDGE
    VOL=
>1000
  ACTIVITY OF SLUDGE
    ACT=
>200
  VOLUME OF CARTRIDGE FILTERS
    VOL=
>0
  ACTIVITY OF CARTRIDGE FILTERS
    ACT=
>0
  VOLUME OF COMPACTIBLE DAW
    VOL=
>13000
  ACTIVITY OF COMPACTIBLE DAW
    ACT=
>130
  VOLUME OF NONCOMPACTIBLE DAW
    VOL=
>2000
  ACTIVITY OF NONCOMPACTIBLE DAW
    ACT=
>130
  TOTAL DAW VOLUME
    VOL=
>15000
  TOTAL DAW ACTIVITY
    ACT=
>260
```

Fig. 2 Interactive Site Specific Waste Data Inputs

Capital investments, which may include a VRS facility cost or VRS equipment and installation costs, may be inserted. If the base case for the comparison is being evaluated (the current processing technique), zero may be inserted for the initial equipment cost. The lifetime of the proposed system or the desired evaluation period in years is also a user-supplied input parameter.

Burial Container Calculation

The calculation method is specific to the processing method and the waste type being investigated. The basic factors involved are: (1) the VR factor of a process for a waste type, (2) the waste to binder ratio, and (3) the surface dose rate factor. VR factors have been discussed above. The waste to binder ratio is the volume of waste divided by the volume of binder in a solidified product. These factors are included within the program and are specified by the input parameters when a binder selection is made for a certain waste type. The surface dose rate factors ($Ci/ft^3/R/hr$) were obtained from the NUREG/CR-2206 Report and are based upon the dominate gamma emitting isotopes for the various waste types (see Table II).

Given a volume of waste, the appropriate VR factor is applied resulting in a reduced waste volume. For compacted DAW, this volume divided by the burial container size determines the number of containers.

For the solidification of slurries in cement, the waste to binder ratio is applied to the reduced waste volume to obtain the required binder volume. Since the slurry water reacts with cement, the solid product volume is approximately equal to one-half of the binder volume plus the reduced waste volume. If a significant deviation from this rule is expected for a proposed system, the waste to binder ratios may be modified for the affected waste types. The product volume divided by the burial container volume determines the number of containers.

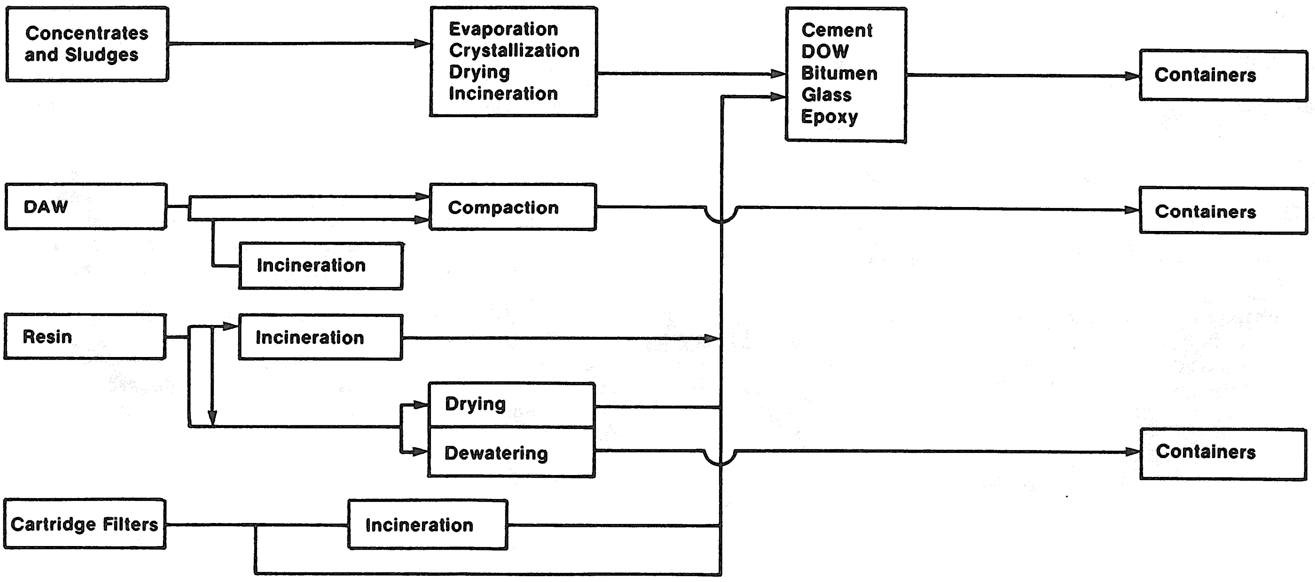

Fig. 3 Logic Flow Chart of VR Options

```
  IMMOBILIZE RESINS A=1
  DEWATER RESINS  A=2
  INCINERATE LOW ACTIVITY RESINS, DEWATER REST  A=3
  INCINERATE LOW ACTIVITY RESINS, IMMOBILIZE REST  A=4
    A=
>1
  COMPACT DAW   B=1
  INCINERATE DAW B=2
    B=
>1
  EVAPORATION OR CRYSTALIZATION  C=1
  INTENSIVE DRYING OR OTHER    C=2
    C=
>1
  BNDER TYPES 1-CEMENT    2-DOW
   3-ASPHALT  4-GLASS  5-EPOXY
  BINDER TYPE FOR CONCENTRATED SOLUTIONS AND SLUDGES D
    D=
>1
  BINDER TYPE FOR SALT OR ASH E
    E=
>1
  BINDER TYPE FOR RESIN AND CATRIDGE FILTERS F
    F=
>1
  NO CARTRIDGE FILTERS G=0
  CARTRIDGE FILTERS IMMOBILIZED G=1
  CARTRIDGE FILTERS INCINERATED G=2
    G=
>0
```

Fig. 4 Interactive Process Path Inputs

For other solidified waste, the product volume is equal to the binder volume plus the reduced waste volume which is based on the material's true density. The determination of the number of burial containers is performed as above. The number of burial containers required for dewatered resin and immobilized cartridge filters is based on factors derived from operational experience which are included in the program library. In this manner, the number of burial containers per year is calculated for each waste type per the process path selected.

The cost of burial containers is calculated along with the binder, and operational and maintenance costs. Specific binder costs are included in the program and are identified upon user selection of a binder. The operational and maintenance costs are assessed on a per drum rate. These costs are included in the program library.

Transportation and Burial Cost Calculation

The activity content of the burial containers is determined by dividing the initial waste curie content by the number of burial containers. The activity content determines which type of transportation vehicle the waste can be shipped in (see Fig. 6). The options include unshielded vans, shielded vans, 14-drum casks, and 7-drum casks (see Table II). For each waste type, the program calculates the number of shipments required per year. The transportation cost associated with a shipment of waste in a certain vehicle over the required distance is calculated and the annual cost for each waste type is determined. The annual costs of all the waste types may be summed to obtain a first year transportation cost.

```
  INITIAL EQUIPMENT COST OR CAPITAL INVESTMENT ($)
    P=
>1000000
  RATE OF RETURN (%)
    R=
>12
  LEVELIZED FIXED CHARGE RATE (%)
    FCR=
>20
  SYSTEM LIFE (YEARS)
    YEARS=
>30
  ESCALATION OF LABOR FOR O & M (%)
    ESOM=
>6
  ESCALATION OF CONTAINERS AND BINDER (%)
    ESCAB=
>8
  ESCALATION OF TRANSPORTATION RATES (%)
    ETR=
>10
  ESCALATION OF BURIAL RATES (%)
    EB=
>30
  BURIAL SITE
  RICHLAND H=1
  BARNWELL H=2
  BEATTY H=3
    H=
>1
  SHIPMENT IS EAST OF MISS. O=1
  SHIPMENT IS WEST OF MISS. O=2
    O=
>2
  DISTANCE TO BURIAL SITE IS LISTED AS L (MILES)
    L=
>1000
```

Fig. 5 Interactive Economic and Burial Site Inputs

The surface dose rate of the burial container can be determined by applying the surface dose factors to the specific activity of the burial container. The dose rate, curie content and type of transportation shipment are all required to determine the burial cost for the containers.

For each waste type, the dose rate, as calculated above, will identify the proper radiation surcharge for the container (see Fig. 6). The curie content of the containers and the type of transport vehicle will determine the number of curies contained in each shipment. The number of curies per shipment will identify the curie surcharge rate for each shipment. Weight surcharges are determined by the type of shipment as are cask handling fees. All of these charges may be summed for each waste type to determine the first year burial cost.

TABLE II

DETERMINATION OF TRANSPORTATION GROUP

Waste Type	Average Mev Gamma	Maximum Curies/ft³: Unshielded(2)	Maximum Curies/ft³: Shielded Van(1)	Maximum Curies/ft³: Type 'A'	Maximum Curies/ft³: Type 'B'	Surface Dose Factor $(Ci/ft^3)\div(R/hr)$
BWR						
Spent Resins	0.92	0.0227	0.1140	0.450	200	0.1140
Concentrated Liquid	1.16	0.0220	0.1100	0.140	37	0.1100
Filter Sludge	1.69	0.0042	0.0210	0.043	5	0.0210
DAW	1.59	0.0086	0.0430	0.060	7	0.0430
PWR						
Spent Resins	1.01	0.0202	0.1010	0.270	90	0.1010
Concentrated Liquid	0.70	0.0426	0.2130	2.700	5,000	0.2130
Filter Sludge	1.69	0.0042	0.0210	0.043	5	0.0210
Filter Cartridge	1.69	0.0042	0.0210	0.043	5	0.0210
DAW	1.26	0.0100	0.0499	0.100	22	0.0499

(1) Maximum contact dose of containers 1R/hr.
(2) Maximum contact dose of container 200 mR/hr.

Adapted from NUREG/CR-2206

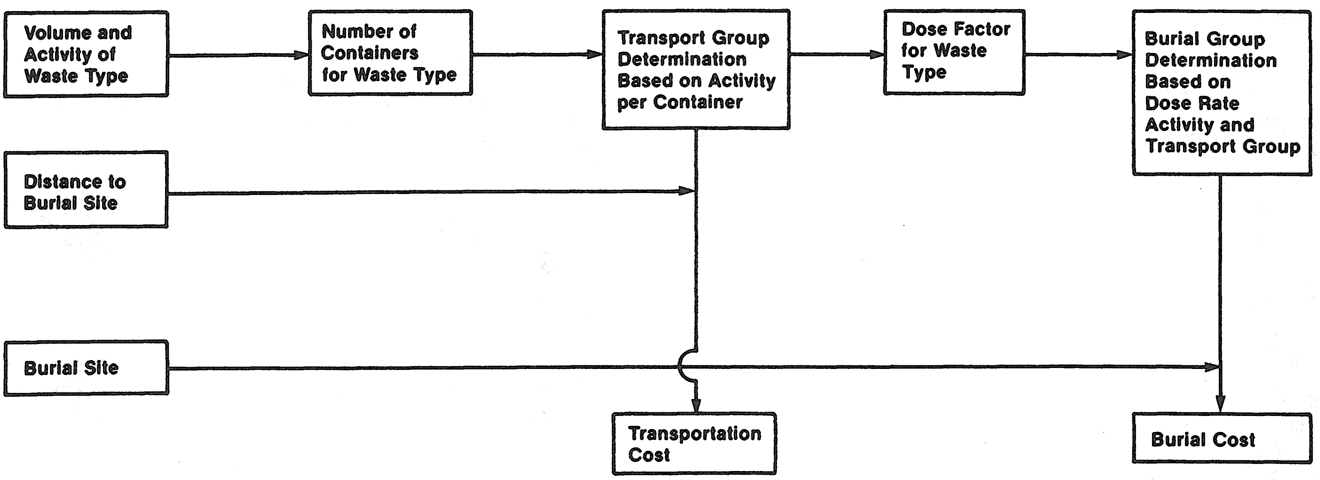

Fig. 6 Logic Flow Chart of Transport and Burial Cost Calculation

Economic Calculations

The economic comparison of VRS systems involves a comparison of the initial and annual cost items for different systems. The initial costs involve the capital investment items such as engineering, equipment, installation and, if required, a building to house the equipment. The annual costs include container cost, binder cost, operating and maintenance costs, transport cost, and burial cost. The initial and annual cost items must be evaluated on a common basis so that the various systems can be compared. By comparing the life cycle cost of such systems, a proper comparison can be made.

To properly account for the time value of money, both levelized and equivalent capital investment methodologies are incorporated in the program. The levelized methodology will be considered first.

To determine the total levelized cost of a proposed system, the initial cost must be annualized and the annual costs must be levelized.

The initial capital costs are multiplied by the levelized fixed charge rate which results in an annualized initial cost at the selected rate of return and system life. The various calculated annual costs are derived in terms of present worth dollars. These values must be escalated and levelized to account for the time value of money. The present worth of an escalating series can be determined by applying the present worth of an escalation series factor to the first year cost. The factor is:

$$PWECS = \frac{\left(\frac{1+e}{1+i}\right)^N - 1}{e-i}$$

Where e is the escalation rate of the item (%)/yr),

i is the discount rate (%/yr), and

N is the number of years.

This formula is based on the assumptions that both the first year cost and the subsequent payments are end of the year values.

The present worth of these escalated annual costs can be levelized by applying the capital recovery factor over the system life and desired rate of return. The capital recovery factor is:

$$CRF = \frac{i\ (1+i)^N}{(1+i)^N - 1}$$

Where i and N are as stated above.

The annualized initial costs and the levelized annual cost may now be summed to obtain a total levelized VRS cost.

The determination of the levelized cost for each option allows for a life cycle comparison taking in-plant, transportation and burial costs into account.

Levelized costs of VRS systems in an economic comparison will enable one to rank the proposed systems; however, this method does not demonstrate which systems are affordable. That is, levelized costs do not clearly identify the capital investment required. For this reason, the Equivalent Capital Investment (ECI) is also calculated.

The ECI is the sum of the initial capital investment and an equivalent capital investment requirement for the annual costs. The levelized annual costs can be capitalized to an equivalent capital investment by dividing the levelized annual costs by the levelized fixed charge rate.

With the use of these two methodologies, the economic ramifications of a proposed VRS system are more clearly identified. Not only can a proposed system be ranked in accordance to other systems but some assessment of the venture capital required to obtain and operate the system is also presented.

Outputs

Outputs from the program include the number of burial containers per year. The first year cost of containers, binder, operation and maintenance, transportation, and burial are presented. The total annualized cost of the processing option chosen is presented as well as the equivalent capital investment (see Fig. 7).

```
BURIAL SITE DISTANCE = 1000
NUMBER OF DRUMS/YR = 2088
FIRST YEAR COST OF DRUMS ($/YR) =     62640.00
NUMBER OF HIC/YR =    0
FIRST YEAR COST OF HIC ($/YR) =           .00
FIRST YEAR COST OF BINDER ($/YR) =                  51396.92236
FIRST YEAR OPERATIONAL & MAINT COST ($/YR) =    292320.00
FIRST YEAR TRANSPORT COST ($/YR) =  1378086.20
FIRST YEAR BURIAL COST ($/YR) =   248979.10
TOTAL LEVELIZED VR COST ($/YR) =             19340873.75000
ECI OF ANNUAL COSTS($)=                      95704370.00000
 TOTAL ECI ($)=                    96704370.00000
DO YOU WANT TO MAKE CHANGES - YES OR NO?
```

Fig. 7 Program Output

Conclusion

As previously mentioned, the benefit of a computer model is the speed at which calculation can be performed. Although the exact value of many of the parameters may not be defined, the computer serves as a useful tool for performing a sensitivity analysis of the parameters for any specific station. The effect of different VR factors for specific wastes can be examined as well as the effect different economic scenarios have on the evaluation of a system. Minimum performance criteria can be identified for a specific station based upon a break-even or acceptable cost for a VRS system. In this way, the computer model can help to bound the uncertainties involving both equipment performance and economic trends.

Updating calculations due to changes in service charges or processing assumption can be made quickly in the computer program, saving a considerable amount of time while preserving the significance of historical evaluations.

With the vast number of parameters involved in an economic comparison and the state of flux in the industry, computer modeling can save time and money in the evaluation of VRS systems.

References

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2. G. Trigilio, "Volume Reduction Techniques in Low Level Radioactive Waste Management," NUREG/CR-2206, Teknekron Inc., September 1981.

3. C. C. Miller, "A Comparison of Volume Reduction and Solidification Systems for Low Level Radioactive Wastes from Nuclear Power Plants," Masters Project, Department of Nuclear and Energy Engineering, University of Arizona, April 1982.