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CHEMICAL TECHNOLOGY DIVISION

NUCLEAR WASTE PROGRAMS

(Activity No. AR051005K; FTP/A No. ONL-WN07)

ANAEROBIC DIGESTION OF LOW-LEVEL RADIOACTIVE CELLULOSIC AND ANIMAL WASTES

T. L. Donaldson
G. W. Strandberg
B. D. Patton
F. E. Harrington

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
Operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

CONTENTS

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ABSTRACT

A preliminary process design and a cost estimate have been made for a volume reduction plant for low-level, solid radioactive wastes generated at ORNL. The process is based on extensions of existing anaerobic digestion technology and on laboratory studies indicating the feasibility of this technology for digestion of the organic portion of low-level, solid radioactive wastes. A gaseous effluent (CO_2 and CH_4) is vented in the process, and a liquid effluent containing undigested solids is filtered to remove solids, which are buried. The liquid is discharged to the low-level liquid waste system at ORNL. Overall volume reduction of solid waste by this process is estimated to be approximately 20:1. Costs appear to be comparable to costs for compaction. The process design is conservative, and several potential improvements which could increase efficiency are discussed in this report.

1. INTRODUCTION

Disposal of solid low-level radioactive waste (LLW) is an increasing problem for the nuclear industry. Shallow land burial, which has been used for many years as the major method for LLW disposal, has several disadvantages. The possibility of leaching of these radioactive materials by contact with ground water, the commitment of large land areas for burial grounds, and the long-term maintenance of the burial grounds make it necessary to find other solutions to the problem. A previous study (including cost estimates) at Oak Ridge National Laboratory (ORNL)[1] considered a variety of technologies for reducing the waste volume and, thus, the land required for shallow land burial. The purpose of the study was to identify a more economical option for future use at ORNL.

Recently an anaerobic digestion process has been proposed for volume reduction of organic LLW.[2] This process converts most of the organic solids (primarily cellulosic materials and animal tissue) to a liquid stream and gases (CO_2 and CH_4) that can be vented. Since the radioactive liquid waste systems at ORNL have surplus capacity, the conversion to a liquid waste form is an attractive alternative. At this time, laboratory experiments are being conducted to determine the rate and extent of solids degradation. A 70-L digester will be used to demonstrate the proposed process and to define operating parameters.

Five alternate processing paths for disposal of solid LLW at ORNL are illustrated in Fig. 1. Path 1 is a direct burial of the solid waste, as collected, with no volume reduction. This method requires large areas of land for burial. In Path 2, the solid waste is compacted to reduce the volume before shallow land burial. Incineration of the waste in Path 3 reduces the volume of waste to be buried, but requires very expensive and complex incineration equipment to control emissions. Paths 4 and 5 both utilize the proposed anaerobic digestion process for volume reduction. In Path 4, the products from the digester are separated into a solid stream and a liquid stream. The undigested solids are routed to shallow land burial, while the liquid component is processed in the existing ORNL low-level liquid waste system or in the intermediate-level liquid radioactive waste (ILW) system. No separation of liquid and solids is required in Path 5; the slurry product from the digester is routed

ORNL DWG 82-20642

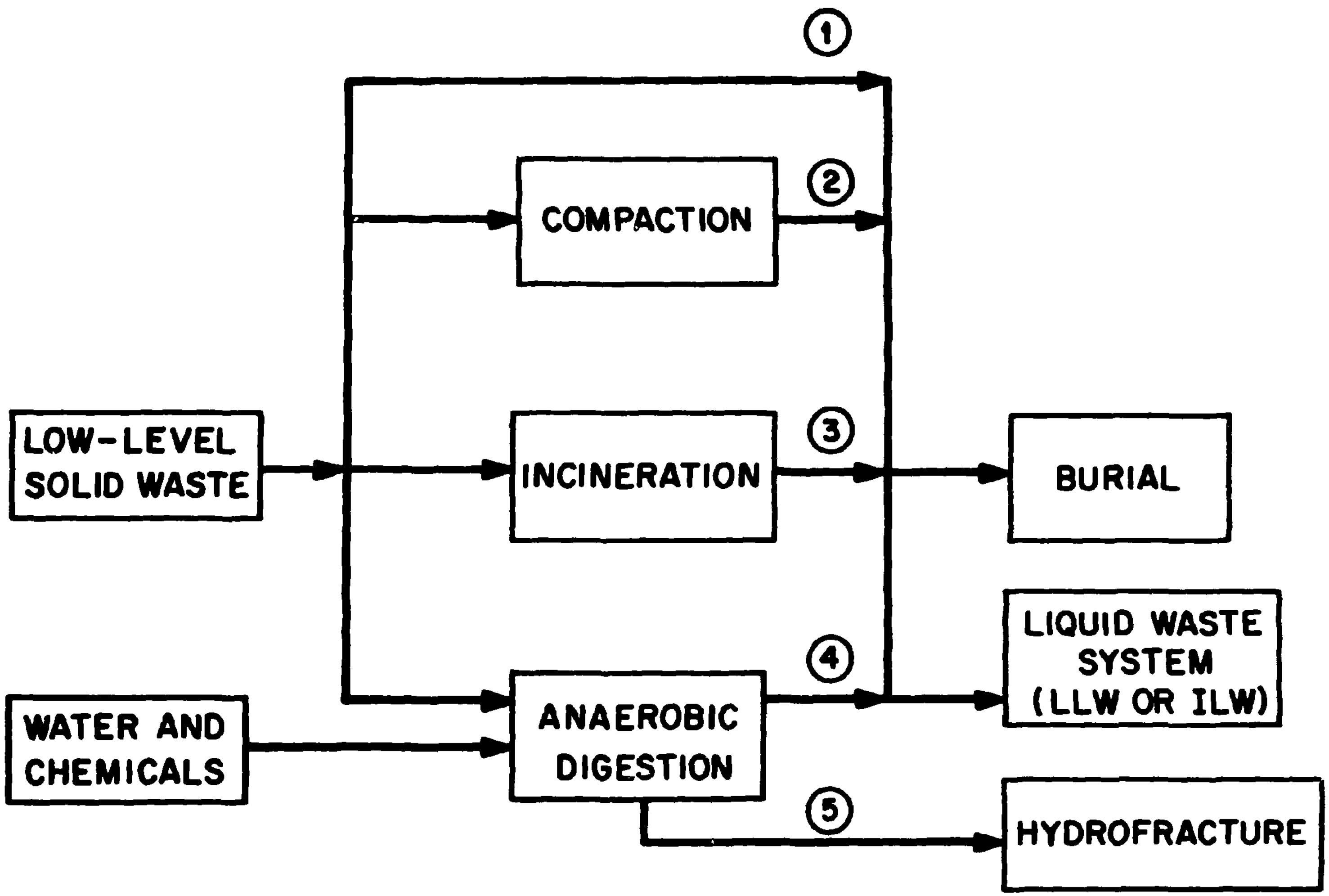


Fig. 1. Alternate processing paths for low-level solid wastes.

directly to the hydrofracture facility. If development work proves the slurry can be hydrofractured, the costs for Path 5 may be lower than tnose for Path 4.

This report addresses the costs associated with the anaerobic digestion process in sufficient detail to allow comparison with compaction (the most attractive alternative for the type of LLW involved) and incineration studied earlier. The approach has been to establish the process for Path 4, using very conservative assumptions, and to estimate the capital and operating costs using the same factors (contingencies, engineering, operational support) as the earlier study. The use of these very conservative process parameters yields a comparison of the worst case foreseen for anaerobic digestion versus the normal cases for compaction and incineration.

2. ANAEROBIC DIGESTION

Anaerobic digestion is the controlled utilization of a naturally occurring process in which organic materials are degraded by the actions of microorganisms in the absence of oxygen. This natural, spontaneous process is typified by the decay of organic matter over periods ranging from days to years. The most common directed utilization of this process is stabilization of sewage sludge from aerobic wastewater treatment processes.

The physical and biological chemistry of anaerobic digestion involves several steps in series. The organic matter must be solubilized (if not already soluble) through destruction and hydrolysis of the complex chemical structures. This step is followed by acidogenesis and then methanogenesis. Methane and carbon dioxide are evolved at this point, which is usually the desired end point. However, a residue of unconverted acids and refractory compounds will generally be found in the reaction mixture.

The biochemical reactions are carried out by a variety of microganisms found naturally in soil and sewage sludge. These organisms can be cultivated in submerged culture and in films attached to solid surfaces. Only a very small proportion of the organic substrate (~1%) is converted to cell mass in these systems.

Advanced anaerobic digestion systems are being developed for production of methane and for wastewater treatment. Large-scale demonstration systems are operating at several cattle yards and large dairy farms to produce methane via anaerobic digestion of the manure. An advanced, packed-bed bioreactor called ANFLOW has been developed at ORNL for treatment of municipal wastewaters.[3] Anaerobic digestion is also being developed to produce methane from municipal solid waste.[4]

A potentially attractive extension of this technology is volume reduction of LLW. The low-level, compactible, combustible wastes generated at ORNL are estimated to be about 75% cellulosics (such as clothing, wipes, and blotter paper) plus animal carcasses.[5] Laboratory work at ORNL[2] and at other laboratories has indicated that about 80% of this organic matter can be solubilized for conversion to methane and carbon dioxide or disposal in a liquid waste form. Hence there is the potential for as much as a 20:1 volume reduction for this organic waste (based on 4:1 compaction and 5:1 reduction in mass). Laboratory studies at ORNL during this past year have indicated that low levels of radiation

(300 μCi/L each of ^{60}Co and ^{3}H) have no measurable effect on the rate of digestion nor the ultimate extent of digestion.

3. BASIS FOR COST ESTIMATE

In order to develop capital and operating cost estimates for an anaerobic digestion process for volume reduction of cellulosic wastes, it is necessary to specify a plant capacity and process equipment. This has been done on a very conservative basis. The basic process is described in Sect. 3.1, and several potential process improvements are described in Sect. 3.2.

3.1 Process Description

A flowsheet for the proposed process is shown in Fig. 2 and a material balance is given in Table 1. The waste volume to be treated is assumed to be 425 m^3/year (15,000 ft^3/year) of uncompacted waste — 283 m^3/year from ORNL and 142 m^3/year from the Biology Division at the Y-12 site.[5,6] This waste is assumed to be 70% cellulosics and other organics and 30% inerts such as plastics and rubber. The average density of this waste is 102 kg/m^3 (6.35 lb/ft^3).[5] Total radioactivity in the waste appears to be ~10–200 Ci/year.

For design purposes, it is assumed that the waste will be further segregated by the generators to exclude nondegradable materials. Thus the waste feed to the process is taken to be 70% of the current generation rate, or 300 m^3/year total.

Waste is delivered to the plant site in dumpsters, where it is manually unloaded and fed to a wet shredder-pulper. Some sorting may be done at this point, if needed. Pulped waste is slurried in a mixing tank

ORNL DWG 82-20641

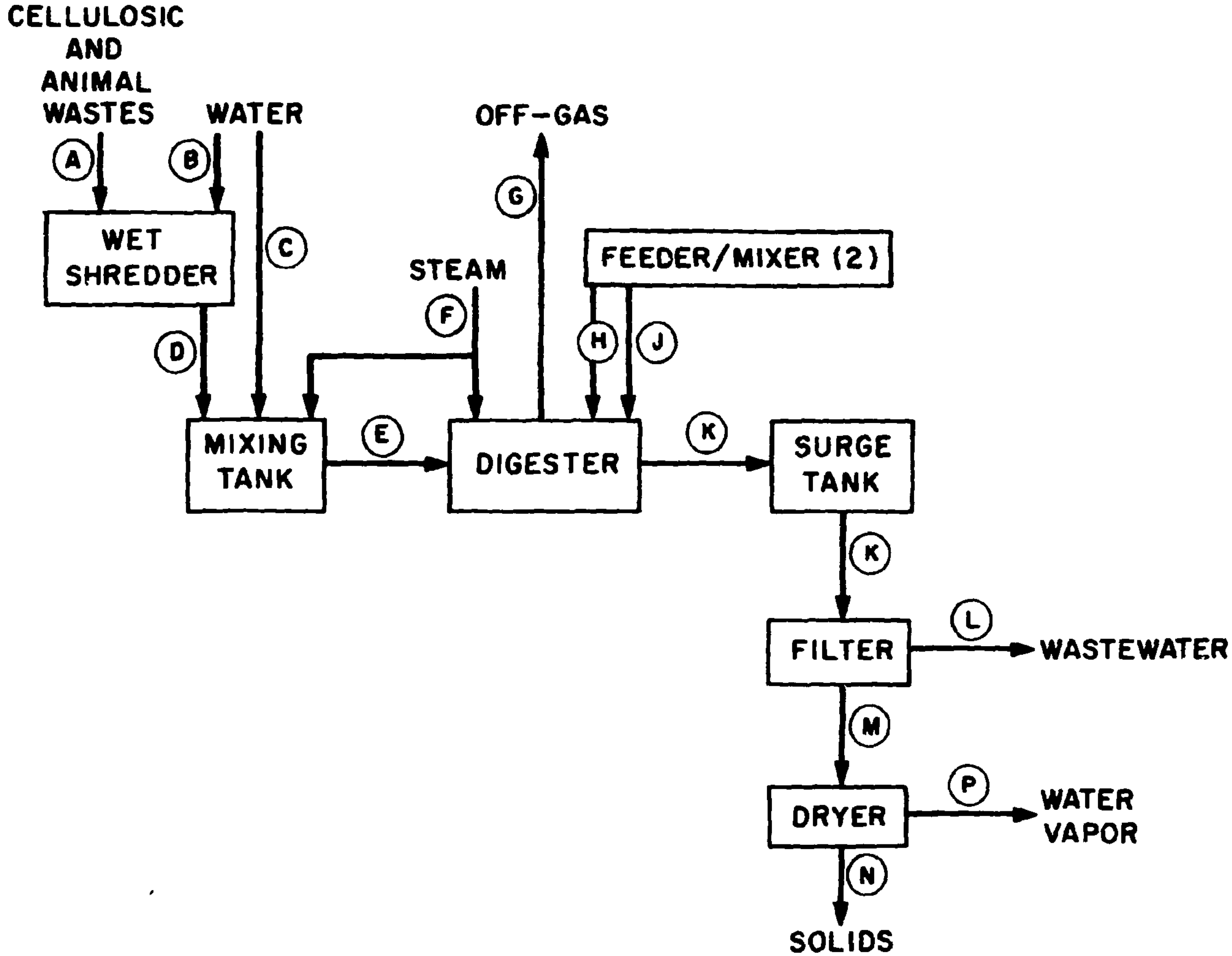


Fig. 2. Process flowsheet for anaerobic digestion of low-level radioactive solid waste. Circled letters labelling the process streams correspond to the material balance in Table 1.

Table 1. Material balance for anaerobic digestion process
Basis: 260 days of operation per year

Component \ Stream	A	B	C	D	E	F	G	H	J	K	L	M	N	P
Digestible Solids, kg/d	117			117	117					23		23	23	
Water, L/d		3600	8000	3600	11,600			90	90	12,300	12,200	90		
Nitrogen, kg/d								9		9	9			
Phosphorus, kg/d								2		2	2			
NaOH, kg/d									10	10	10			
Steam, kg/d						550								
Gas (CO_2,CH_4), m^3/d							37							
Gas (H_2O), m^3/d														105
Solids, %	100			3.1	1.0					0.19		20	100	

to the proper solids concentration for feeding to the digester (~1%). The 150-m^3 (40,000-gal) digester is batch-fed daily with 11,600 L water and 117 kg waste. At the same time, an equal amount of liquid digest is removed to a surge tank. Hydraulic residence time in the digester is approximately two weeks, which is expected to produce 80% degradation of solids to soluble organics plus gas. The gas will be vented (and flared, if necessary) after it passes through a demister. The digester is maintained at 35–40°C with live steam and is mildly agitated. Caustic is added automatically to maintain the pH at 7, and small amounts of nutrients are added to maintain the microorganism population. Effluent from the digester is filtered to remove the suspended solids, and the supernatant is discharged to the ORNL low-level liquid waste system or the ILW system (11,600 L/d). The solids are dried and packaged for burial (23 kg/d).

The digester tank and associated equipment are housed in a prefabricated steel building. More details on the process equipment and facilities are given in the Appendix to this report.

3.2 Process Improvements

The basic process specifications in Sect. 3.1 for making the cost estimate are quite conservative. It is likely that operation efficiency can be improved, which would allow some reductions in equipment size or an increase in capacity. However, these potential improvements will need to be studied experimentally before process parameters can be specified in detail. A FY 1983 experimental program with a 70-L digester is planned to investigate these opportunities for process improvement.

3.2.1 Higher solids loading

The basic design utilizes 1% solids feed. Published studies of the anaerobic digestion of cellulose by other investigators indicate that perhaps 3–4% solids can be fed to the digester.[7,8] When the solids level in the digester approaches 5%, the digestion process appears to be inhibited, for reasons that are unknown. The particular behavior of ORNL wastes must be determined experimentally.

Major advantages of a higher solids loading are (1) less water is required for "dilution" of the waste solids and hence a smaller digester is required, and (2) less liquid effluent is generated for eventual disposal.

3.2.2 Higher operating temperature

It may be possible to develop a population of microorganisms which will thrive at 55–60°C. There are published reports (e.g., ref. 7) of such populations for anaerobic digestion of cellulose. At this higher temperature, the degradation rate has been reported to be greater and the extent of degradation of somewhat refractory materials probably would be greater. These potential improvements need to be demonstrated experimentally. The major process advantage would be a reduction in equipment size (primarily the digester).

3.2.3 Effluent disposal via hydrofracture

Filtration of the digester effluent and drying of the solids for packaging and burial could be avoided entirely if the effluent were utilized directly in the existing hydrofracture facility. The attractiveness of this option depends greatly on the quantity of effluent and on what (if any) treatment is needed to prevent plugging of the hydrofracture well by suspended solids. These factors will be investigated in more detail during FY 1983.

4. COST ESTIMATING METHODOLOGY

The costs estimated in this study are the capital cost for the facility and the operating cost for the process. Both costs were estimated using the same methodology and personnel (when possible) as those used in the earlier study.[1] This approach makes the results as comparable as possible with the options for compacting and incinerating combustible waste.

The packaging and disposal (shallow land burial) costs are not estimated, although the volume of solid waste to be packaged and buried is estimated using the conservative process specifications outlined in Sect. 3.

The capital cost estimations are conceptual design levels, and the estimating sheets are presented in the Appendix. Cost components include:

1. Land improvements — site preparation such as grading, fencing, and access roads;
2. Building — a pre-engineered building containing a pit for process equipment and basic services;
3. Special facilities — the processing equipment required (instrumentation allowed at 15% of all equipment shown in Fig. 2); and
4. Outside utilities — installation of the required utilities to the new building.

The total cost includes an additional 30% of fixed-price prime contractor costs for engineering and an additional 40% of all costs (including engineering) for contingencies. The annualized capital recovery factor is calculated assuming a 10% interest rate and 20 years amortization.

Operating costs are estimated (as in ref.1) for the following components:

1. direct labor,
2. support labor and materials (maintenance),
3. materials and supplies (worked materials),
4. administrative and clerical, and
5. duration materials (indirect materials and services).

Experience at ORNL and Union Carbide Corporation, Nuclear Division (UCCND) was used in estimating these components. The direct labor and materials costs are estimated using the conservative flowsheet presented earlier. Maintenance is allowed as 2% per year of capital cost for the special facilities. The major cost component, man-hours for direct labor, is estimated conservatively high at 6 man-hours/d for the conservative flowsheet and all required operations.

5. RESULTS AND CONCLUSIONS

The capital and operating cost estimates for anaerobic digestion are summarized in Tables 2 and 3, respectively. Details may be found in the Appendix. Table 4 presents for comparison the cost estimates for compaction and incineration.[1]

The effectiveness of each process can be measured by the volume fraction of initial solid waste that remains to be packaged and buried after treatment. These volume fractions are shown in Table 5. The total cost per cubic meter of waste treated, when divided by (1 — volume fraction of initial waste remaining after treatment), yields the total cost per

Table 2. Capital cost estimates

Item	Estimated cost ($)
Land improvements	35,000
Building	71,700
Special facilities	320,000
Outside utilities	42,600
Total construction	469,300
Engineering	140,700
Contingency	244,000
Total	854,000

Table 3. Operating cost estimates

Item	Estimated cost		
	($/year)	($/m^3 waste)	($/ft^3 waste)
Direct labor	56,000	188	5.33
Support labor and materials	11,000	39	1.10
Worked materials	6,600	22	0.63
Administrative and clerical	5,600	19	0.53
Duration materials	1,400	5	0.13
Total	81,200	273	7.72

Table 4. Costs for volume reduction

Process	Estimated cost ($/m^3) Capital	Operating	Total cost
Anaerobic digestion	340	273	613
Compaction	1413	340	1753
Incineration	6039	621	6660

Table 5. Process effectiveness

Process	Volume fraction of solids remaining for burial	Total cost of volume reduction ($/m^3)
Anaerobic digestion	0.05	643
Compaction	0.11	1967
Incineration	0.02	6780

cubic meter of volume reduction. This cost, shown in Table 5, reflects both the cost of processing and the effectiveness of the processing method for reducing the volume of waste for burial. For these calculations, it is assumed that the anaerobic process solubilizes 80% of the solids and yields a dried cake of undigested material with a density about four times that of the as-received waste.

These cost and volume reduction estimates should be regarded as approximate. The compaction and incineration treatments assumed that the 425 m^3/year of combustible low-level waste now collected was processed in a multi-purpose modification or addition to an existing facility. The anaerobic digestion approach assumed 300 m^3/year of cellulosic and animal wastes in a new single-purpose facility. This operation would require modification of the existing collection system at the sites to collect nondigestibles (primarily plastics) separately. If this change were undertaken, a concerted effort would also be made to substitute cellulosic materials for plastics, which would increase the digestible waste volume. The volume to be packaged and buried after anaerobic digestion plus compaction of the segregated undigestibles would be less than after compaction alone. No costs are included for liquid waste disposal.

Anaerobic digestion offers an attractive approach for reducing the volume of solid low-level radwaste requiring packaging and burial, although the volume reduction is less than that achievable by much more expensive incineration. Development should continue to demonstrate the process in scalable equipment. Process parameters should be determined, and at least one campaign using optimal parameters should be run for a period >1 month. If the results from this experimental program are favorable, consideration should be given to the potential for hydrofracture of the residual undigested solids.

The major process assumptions made in this feasibility study should be investigated during further process development work. These parameters (and the assumed values) are:

1. solids loading in the digester (1%),
2. solubilization of solids (80%),
3. hydraulic residence time (14 d), and
4. volume reduction factor (20:1).

These conservative values are based on published studies of anaerobic digestion of cellulosic wastes[7,8] and on our own laboratory studies.[2] The attractiveness of the process would be further increased if process development work indicates that better performance can be expected.

These development data should be obtainable in 12 to 18 months. At that time, a decision should be made regarding further development work and/or a conceptual design leading to an operating plant.

6. ACKNOWLEDGMENT

The capital cost estimates were made by K. D. Cook and D. E. Brashears, UCCND Engineering.

7. REFERENCES

1. J. M. Chandler, et al., *A Comparison of Costs for Treatment and Storage or Disposal of Low-Level Solid Radioactive Wastes at ORNL*, ORNL/TM-8092 (May 1982).
2. G. W. Strandberg, *Volume Reduction of Solid Waste by Biological Conversion of Cellulosics*, ORNL/TM-7653 (June 1981).
3. R. K. Genung, C. W. Hancher, A. L. Rivera, and M. T. Harris, "Energy Conservation and Methane Production in Municipal Wastewater Treatment Using Fixed-Film, Anaerobic Bioreactors," *Proceedings of the Fourth*

Symposium on Biotechnology in Energy Production and Conservation, Gatlinburg, TN (May 1982).

4. J. T. Swartzbaugh, J. W. Miller, and C. C. Wiles, "Operating Experience with Large Scale Digestion of Urban Refuse with Sewage Sludge," *Clean Fuels from Biomass and Wastes*, Institute of Gas Technology, Chicago, IL (1977).

5. W. H. Bell and L. E. Borneman, *Low-Level Waste Pilot Facility Source Term Waste Characterization*, NUS 3678, NUS Corporation (November 1980).

6. Discussions with E. M. King, Operations Division, ORNL (1982).

7. J. T. Pfeffer, "Temperature Effects on Anaerobic Fermentation of Domestic Refuse," *Biotech. Bioeng*. 16, 771–787 (1974).

8. J. T. Pfeffer, "Engineering, Operation and Economics of Methane Gas Production," *Experientia* 38, 201–205 (1982).

APPENDIX: COST ESTIMATE SHEETS

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE 37830

LOCATION: ☐ K-25 ☒ X-10 ☐ Y-12 ☐

COST ESTIMATE SUMMARY SHEET

PROJECT TITLE AND BUILDING: Anaerobic Digestion of Cellulosic Wastes
ORNL

TYPE OF ESTIMATE	CONSTRUCTED BY	BASE COST DATE	ESTIMATE VALID UNTIL	ESO OR ORDER NO.
☐ C ☐ I ☐ II ☒ OTHER Preliminary	☐ UCND ☐ CPFF ☐ LSSC ☒ FPPC	FY-82, 2nd Qtr.		A-2584P-AA

ESTIMATE BASED ON: ☐ VERBAL INFORMATION ☐ SKETCHES ☐ MARKED PRINTS ☐ PRELIM. DESIGN ☐ FINAL DESIGN	REVISION	DATE	REVISED BY		DATE	
	1	8-20-82	DEB	ESTIMATED BY: KDC	6-10-82	P. ENGR.: Terry Donaldson
	REVISION	DATE	REVISED BY	CHECKED BY	DATE	F. ENGR.
FUND SOURCE: ☐ EXP ☐ EQPT ☐ GPP ☐	REVISION	DATE	REVISED BY	APPROVED BY	DATE	DISTRIBUTION:

	ITEM	SHEET NO.	MATERIAL	LABOR		TOTAL	
1	Acct. 2000 Land Improvements	3	25,500	9,500		35,000	
2	Acct. 3000 New Building	6	42,700	29,000		71,700	
3	Acct. 6000 Special Facilities	10	286,000	34,000		320,000	
4	Acct. 7000 Outside Utilities	12	32,200	10,400		42,600	
5						469,300	
6			~~Construction Total~~				
7			Engineering ~ 30%			140,700	
8							
9			Contingency ~ 40%			244,000	
10							
11			Job Total FY-'82, 3rd Qtrs. $			854,000	
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							

UCN-8125C (12 5-78)

ESTIMATE SHEET 1 OF 12

For Computer Estimates Only

CODE NO. 1 2000	JOB TITLE AND BUILDING 9 Anaerobic Digestion of Cellulosic Wastes	SUBTITLE 41 Land Improvements	
SUBPROJECT 1	WORK ORDER NO. 9	UNION CARBIDE CORPORATION NUCLEAR DIVISION OAK RIDGE, TENNESSEE 37830	BILL OF MATERIAL NO. 41
ACCOUNT NO. 1	CATEGORY ... AND IMP. BLDG. ADD. ETC. 9 Land Improvements		BILL OF MATERIAL SHEET 1 OF 2
PARTICIPANT 7 FPPC	CONSTRUCTION BY 9 FPPC		PROJECT ENGINEER 41
	LEVEL OF ESTIMATE 9 Preliminary	**COST ESTIMATE**	PRINCIPAL ENGINEER 41 Terry Donaldson

DRAWING OR OTHER SOURCE 1

TYPE	ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL UNIT COST	MATERIAL TOTAL	LABOR HOURS UNIT	LABOR HOURS TOTAL	LABOR RATE	CFT	LABOR TOTAL
		The site is assumed to be on the northeast side of the hydrofracture facility ~ 200 yds. from the ILW waste storage tanks.									
	1.	Clear & grub small trees to 6" Ø	1.2	acres	805 00	966			870 00		1044
	2.	Rough grade site avg. 2' cut 200 x 200 ft. - Bulldose to perimeter only ~ 1/2 loose shale	2960	cy	1 03	3049			34		1006
	3.	Perimeter fence - 7' high chain link - 9 ga. galv. wire - 2" line posts 10' oc - 3 strand barbed wire out riggers. inc. ground	800	LF	8 40	6720			3 73		2984
	4.	Gate 12' - (2-6') swinging 2" Ø frame 9 ga. wire 4" Ø posts	1	ea	408 00	408			51 00		51
		TOTAL				11,143					5085

UCN-6125S (1 10-77) | LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF

JOB TITLE AND BUILDING: Anaerobic Digestion of Cellulosic Wastes

COST ESTIMATE
(CONTINUATION SHEET)

WORK ORDER NUMBER:

BILL OF MATERIAL NO:

CATEGORY: Land Improvements

BILL OF MATERIAL SHEET 2 OF 2

DRAWING OR OTHER SOURCE

TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL			LABOR				
							UNIT COST	TOTAL	HOURS UNIT	HOURS TOTAL	RATE	CFT	TOTAL
1	2 7	8 10	11 34	35 46	47 50	51 56	57 64			65 72	73 78	79 80	
		5.	Access road & area paving	1500	sy		3.60	5400			.91		1365
			6" crushed stone base w/1-1/2"										
			Asphalt wear surface										
			(18' roadway x 200 ft. - 100' x										
			100' staging area)										
						Subtotal		16543					6450
						Misc.	.15	2457			.15		950
						FPPC Direct		19000					7400
						OH & P	.34	6500			.26		2100
				General cont.		FPPC Total		25500					9500
			TOTAL					5400					1365

UCN-11257 (1 10-77)

LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF

For Computer Estimates Only

CODE NO. 1 3000

SUBPROJECT 1

ACCOUNT NO. 1

PARTICIPANT 7 FPPC

JOB TITLE AND BUILDING 9 Anaerobic Digestion of Cellulosic Wastes

SUBTITLE 41 Building Costs

WORK ORDER NO. 9

CATEGORY (LAND IMP. BLDG. ADD. ETC.) 9 Building Cost

CONSTRUCTION BY 9 FPPC

LEVEL OF ESTIMATE 9 Preliminary

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE 37830

COST ESTIMATE

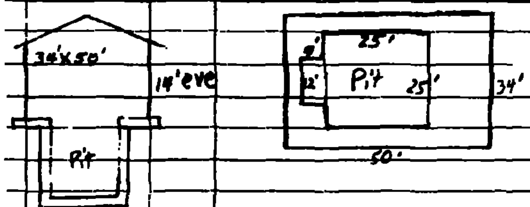
BILL OF MATERIAL NO. 41

BILL OF MATERIAL SHEET 1 OF 3

PROJECT ENGINEER 41 Terry Donaldson

PRINCIPAL ENGINEER 41

DRAWING OR OTHER SOURCE 1



TYPE	ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL UNIT COST	MATERIAL TOTAL	LABOR HOURS UNIT	LABOR HOURS TOTAL	LABOR RATE	CFT	LABOR TOTAL
1 2 7	8 10	11 38	39 46	47 50	51 56 57 64			65 72	73 78	79,80	
	1.	Foundation excavation: Pit 25' × 25' x 16' dp - grade beam 3' x 2' x 160' (3/4 yd. back hoe - hand trimmed - no haul - bulldoze to perimeter - see sketch	434	cy	2 03	881			3 09		402
	2.	Reinforced conc grade walls 12" tk - form inside face only	58	cy	96 00	5568			135 00		7830
	3.	Slab on grade (pit floor & bldg. fl. inc. grade beams avg. 8" tk - med. reinforcing trowel finish.	56	cy	68 00	3808			48 00		2688
		TOTAL				10,257					10920

UCN-S1255 (1 10-77) | LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF

JOB TITLE AND BUILDING: Anaerobic Digestion of Cellulosic Waste

COST ESTIMATE
(CONTINUATION SHEET)

WORK ORDER NUMBER:

BILL OF MATERIAL NO:

CATEGORY: Building Costs

BILL OF MATERIAL SHEET 2 OF 3

DRAWING OR OTHER SOURCE

TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL	MATERIAL UNIT COST	MATERIAL TOTAL	LABOR HOURS UNIT	LABOR HOURS TOTAL	LABOR RATE	CFT	LABOR TOTAL
1	2 7	8 10	11 38	35 46	47 50	51 56	57 64			65 72	73 78	79 80	
		4.	Pre-engineered steel building	1700	sf		6.00	10,200			4.00		6800
			insulated sandwich - enamel										
			surface inside & out - 34 x 50'										
			w/14' eave height. Installed on										
			item 3 slab.										
			Door 3 x 7 ' HM	1	ea		310.00	310			59.00		59
			Door 10' x 10' roll up (man)	1	ea		640.00	640			125.00		125
			Windows 3' x 3' sliding	4	ea		111.00	444			35.00		140
			Gutter - eave type	100	lf		2.05	205			.92		92
			Downspout	30	lf		.74	22			1.04		31
			Precast splash block	2	ea		10.00	20			5.00		10
		5.	Lighting - HPS 400 watt fixtures	8	ea		260.00	2080			19.00		392
		6.	Lighting panel - 24 ckt	1	ea		255.00	255			240.00		240
		7.	Lighting transf 480/120-240-1Ø	1	ea		530.00	530			260.00		260
			15 kva										
		8.	Comb exit & emergency lt. battery	2	ea		330.00	660			39.00		78
			operated - twin - 25w sealed beam -										
			NiCd battery										
			TOTAL					15,366					8,227

UFN-51751 (10-77)

LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF

JOB TITLE AND BUILDING: Anaerobic Digestion of Cellulosic Waste

COST ESTIMATE
(CONTINUATION SHEET)

WORK ORDER NUMBER:

BILL OF MATERIAL NO.:

CATEGORY: Building Costs

BILL OF MATERIAL SHEET 3 OF 3

DRAWING OR OTHER SOURCE:

TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL	MATERIAL UNIT COST	MATERIAL TOTAL	LABOR HOURS UNIT	LABOR HOURS TOTAL	LABOR RATE	CFT	LABOR TOTAL
1	2 7	8 10	11 38	39 46	47 50	51 56	57 64			65 72	73 78	79 80	
		9.	Switch 15A - 125V SPST	2	ea		25.00	50			35.00		70
			in fs conduit w/ss cover										
		10.	Duplex conven outlet 20A 125V	8	ea		35.00	280			35.00		280
			in fs conduit w/ss cover										
		11.	Steam unit heater - suspension	4	ea		300.00	1200			38.00		152
			mtd - propeller fan - thermostat										
			controlled										
		12.	Grounding system - bldg. & elect.	1	lot		1200.00	1200			300.00		300
			sys.										
						Subtotal		28,053					19,949
						Misc	.15	3,847			.15		2,951
						FPPC Direct		31,900					22,900
						OH & P	.34	10,800			.26		6,100
				Gen. cont.		FPPC Total		42,700					29,000
			TOTAL					2,730					802

UCN-5175T (1 10-73) | LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF

For Computer Estimates Only

CODE NO.	1 6000
JOB TITLE AND BUILDING	9 Anaerobic Digestion of Cellulosic Wastes
SUBTITLE	41 Special Facilities
SUBPROJECT	1
WORK ORDER NO.	9
BILL OF MATERIAL NO.	41
ACCOUNT NO.	1
CATEGORY (LAND IMP., BLDG. ADD., ETC.)	9 Special Facilities
BILL OF MATERIAL SHEET	1 OF 4
PARTICIPANT	7
CONSTRUCTION BY	9 FPPC
PROJECT ENGINEER	41
LEVEL OF ESTIMATE	9 Preliminary
PRINCIPAL ENGINEER	41 Terry Donaldson
DRAWING OR OTHER SOURCE	1

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE 37830

COST ESTIMATE

TYPE	ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL UNIT COST	MATERIAL TOTAL	HOURS UNIT	HOURS TOTAL	LABOR RATE	CFT	LABOR TOTAL
	1.	Chute - fan shapped 15' w @ top to 4' enclosed into bldg. (Dumpster unloading) w/ sorting/loading table inside bldg. 304 ss - 12 ga min with integrating scale pan	1	ea	5800 00	5800			250 00		250
	2.	Wet shredder, disposer American Delph. Model DWS 100 -D-25 inc. controls - rated 2000#/hr @ 50#/cu ft. shredder motor 10HP 480/3Ø - disposer motor 24 HP 480/3Ø - 3" discharge 1-1/2" water inlet 30 GPM ∿ 1900 lbs. net wt.	1	ea	31000 00	31000			3100 00		3100
	3.	Homogenizer mixer direct driven - 7-1/2 HP - 3" flanged inlet & outlet - 1/2" water inlet - w/ 2000 gal. mix tank	1	ea	6850 00	6850			750 00		750
		TOTAL				43650					4100

UCN-5125S (1 10-77)

LISTED BY	DATE	ESTIMATED BY	DATE	ESTIMATE SHEET
				OF

JOB TITLE AND BUILDING: Anaerobic Digestion of Cellulosic Wastes

COST ESTIMATE
(CONTINUATION SHEET)

WORK ORDER NUMBER:

BILL OF MATERIAL NO.:

CATEGORY: Special Facilities

BILL OF MATERIAL SHEET 2 OF 4

DRAWING OR OTHER SOURCE

TYPE	(2–7)	ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL	MATERIAL UNIT COST	MATERIAL TOTAL	LABOR HOURS UNIT	LABOR HOURS TOTAL	LABOR RATE	CFT	LABOR TOTAL
		4.	Digester tank 20' ø x 18' h conical bottom w/steam sparger/heater - 1/4" cs wall w/ intermediate external stiffners. (price as API tank) 41,000 gal. capy - total wt. 165 Tns w/demister vent in top	1	ea.		28000.00	28000		erected in place			
		5.	Mixer, Philadelphia Gear Model PTERS 08-vertical tank mounting w/stuffing box & shaft seal 140" lg shaft 60" ø 4 blade angular pitch impeller - 2 RPM shaft speed - 15 HPTEFC 480/3ø motor	1	ea.		12080.00	12080			720		720
		6.	Pump (digester transfer) 100 GPM @ 50' TDH - 5 HP 480/3ø mtr horizontal sewage pump	3	ea.		1500.00	4500			200		600
		7.	Chemical feeder/mixer unit calgon mod DP-6 - SD-C metering pump (0-20.8GPH) 1/4 HP mixer & 550 gal steel reinf. polyethlene tank	2	ea.		4403.00	8806			320		640
			TOTAL					53,386					1,960

LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF

UCN-5125T (1 10-77)

JOB TITLE AND BUILDING: Anaerobic Digestion of Cellulosic Wastes

COST ESTIMATE
(CONTINUATION SHEET)

WORK ORDER NUMBER:

BILL OF MATERIAL NO:

CATEGORY: Special Facilities

BILL OF MATERIAL SHEET 3 OF 4

DRAWING OR OTHER SOURCE:

ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL: UNIT COST	MATERIAL: TOTAL	LABOR: HOURS UNIT	LABOR: HOURS TOTAL	LABOR: RATE	LABOR: CFT	LABOR: TOTAL
8.	Hold up tank 4,000 gal API 9' ∅ x	1	ea.		3,500					
	9' Hw/cone top - manhole, ladder, level									
	indicator & fill & drain nozzles									
	Erect in place on conc. pad									
9.	6 sf Oliver vacuum filter with	1	ea.		8,000					500
	access									
10.	Dryer space for 3 drums	1	ea.		5,000					1,000
	155 cfm airflow									
11.	Low pressure process piping - 3" PVC	1	lot	3000.00	3,000					1,000
	w/PVC Ball valves									
12.	High pressure process piping	1	lot	4000.00	4,000					2,000
	(transfer line) 4" sch 40 A63									
	w/forged steel ball valves									
13.	Process water - 3" backflow	1	lot	5000.00	5,000					2,000
	Preventer & ∿ 200 lf of 1-1/2"									
	sch 40 A120 galv. pipe									
	TOTAL				28,500					6,500

UCN-8125T (1 10-73)

LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF

JOB TITLE AND BUILDING: Anaerobic Digestion of Cellulosic Wastes

COST ESTIMATE
(CONTINUATION SHEET)

WORK ORDER NUMBER:

BILL OF MATERIAL NO.:

CATEGORY: Special Facilities

BILL OF MATERIAL SHEET 4 OF 4

DRAWING OR OTHER SOURCE

TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL	MATERIAL UNIT COST	MATERIAL TOTAL	LABOR HOURS UNIT	LABOR HOURS TOTAL	LABOR RATE	CFT	LABOR TOTAL
1	2 – 7	8 – 10	11 – 38	39 – 46	47 – 50	51 – 56	57 – 64			65 – 72	73 – 78	79 80	
		14.	Steam pressure reducing station & dist. piping	1	lot			5,000					2,000
		15.	Process power - inc. motor control center w 6 size 2 comb starters & 3 100A 480V breakers	1	lot			9,000					3,000
		16.	Sump pump 50 GPM @ 120' manually started - 1-1/2 HP 480V 3 ø	1	ea.			1,200					250
		17.	Instrumentation					21,100					2,700
						Subtotal		161,836					20,510
						Misc.	15	24,164			15		3,090
				Sub. cont.		FPPC Direct		186,000					23,600
						OH & P	54	100,000			44		10,400
						FPPC Total		286,000					34,000
			TOTAL					36,300					7,950

UCN-5125T (1 10-77) | LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF

For Computer Estimates Only

CODE NO. 1 7000
JOB TITLE AND BUILDING 9 Anaerobic Digestion of Cellulosic Wastes
SUBTITLE 41 Outside Utilities

SUBPROJECT 1
WORK ORDER NO. 9
ACCOUNT NO. 1
CATEGORY (L AND IMP. BLDG. ADD. ETC.) 9
PARTICIPANT 7
CONSTRUCTION BY 9
LEVEL OF ESTIMATE 9

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE 37830

COST ESTIMATE

BILL OF MATERIAL NO. 41
BILL OF MATERIAL SHEET 1 OF 2
PROJECT ENGINEER 42
PRINCIPAL ENGINEER 41 Terry Donaldson

DRAWING OR OTHER SOURCE 1

TYPE	ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL	MATERIAL UNIT COST	MATERIAL TOTAL	LABOR HOURS UNIT	LABOR HOURS TOTAL	LABOR RATE	CFT	LABOR TOTAL
	1.	Extend underground water line to new bldg. ~ 300 LF 4" CI line w/block valve & post indicator.	1	lot		4800	4800			2000		2000
	2.	Extend steam line to new bldg. 3" A53 pipe underground w/ gilsolate insulation ~ 300'	1	lot		5500	5500			2000		2000
	3.	Electrical power										
	(a)	Pole 35' class 2 w/cross arms, hardware, down guy & dead end insulators	1	ea.		300	300			200		200
	(b)	Fused cut out 3P-15KV w/lightning arrestors 3P	1	lot								
	(c)	Pad mounted transformer 13.8KV/480V 3 Ø, 150 KVA w/Pri & sec. disconnects - inc primary Potheads	1	ea.		5175	5175			805		805
		TOTAL					15,775					5,005

UCN-9125S (1 10-77) LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF

JOB TITLE AND BUILDING: Anaerobic Digestion of Cellulosic Wastes

COST ESTIMATE
(CONTINUATION SHEET)

WORK ORDER NUMBER:

BILL OF MATERIAL NO.:

CATEGORY: Outside Utilities

BILL OF MATERIAL SHEET 2 OF 2

DRAWING OR OTHER SOURCE

TYPE		ITEM NO.	MATERIAL AND DESCRIPTION	QUANTITY	UNIT	MATERIAL	MATERIAL UNIT COST		MATERIAL TOTAL	LABOR HOURS UNIT	LABOR HOURS TOTAL	LABOR RATE		CFT	LABOR TOTAL
1	2 7	8 10	11 38	39 46	47 50	51 56	57	64			65 72	73	78	79 80	
		d.	Primary feeder - 2" rigid conduit	1	lot		900		900			500			500
			w/3c #2 15 KV cable w/pothead for												
			Pole mtg ~ 30' total												
		e.	Secondary feeder - 2" rigid cond.	1	lot		1500		1500			800			800
			underground conc. encased												
			3 #2/0 THWN & 1 #1 bare - trans.												
			to load ctr in bldg. ~ 50' total												
						Subtotal			18175						6305
						Misc.		15	2725				15		945
						FPPC Direct			20900						7250
				Sub. cont.		OH & P		54	11300				44		3150
						FPPC Total			32200						10400
			TOTAL						2400						1300

UCN-5125T (1 10 77) | LISTED BY | DATE | ESTIMATED BY | DATE | ESTIMATE SHEET OF