UNCLASSIFIED

OAK RIDGE NATIONAL LABORATORY
 Operated By
 UNION CARBIDE NUCLEAR COMPANY

UCC

POST OFFICE BOX X
 OAK RIDGE, TENNESSEE

EXTERNAL TRANSMITTAL
 AUTHORIZED

ORNL
 CENTRAL FILES NUMBER

CF-57-7-31

DATE: July 8, 1957
 SUBJECT: THE ECONOMICS AND HAZARD POTENTIAL OF WASTE DISPOSAL
 TO: Distribution
 FROM: E. D. Arnold

COPY NO. 66

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States nor the Commission, nor any person acting in behalf of the Commission

A. makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights, or

B. assumes any liability with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting in behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, or the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

Paper Presented at ANS Meeting
 Pittsburgh, Pennsylvania
 June 10-12, 1957

Declassified June 10, 1957 in letter (Ref. D:RJT)
 H. F. Carroll to E. J. Murphy

NOTICE

This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

UNCLASSIFIED

020-001

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

UNCLASSIFIED

-2-

THE ECONOMICS AND HAZARD POTENTIAL OF WASTE DISPOSAL

E. D. Arnold
Chemical Technology Division
Oak Ridge National Laboratory

ABSTRACT

The two most important considerations in the disposal of radioactive wastes are safety and economy. All other steps in the waste disposal complex must be tuned to accomplish these two goals. In general, the hazardous waste in the nuclear power complex affect (1) the cost of the nuclear power reactor fuel cycle, (2) the general environment since disposal must exclude radioactivity from the environment for over 500 years, (3) the costs and/or methods of waste treatment including fission product utilization, (4) the methods of shipping, (5) the location of chemical processing plants and waste disposal sites, (6) the methods of disposal best suited for a particular type of waste or site location, and (7) potential public damage and third-party liability.

UNCLASSIFIED

226 002

UNCLASSIFIED

-3-

THE ECONOMICS AND HAZARD POTENTIAL OF WASTE DISPOSAL

INTRODUCTION

The choice of any ultimate disposal scheme for radioactive wastes requires two answers - economics and safety. In all cases the disposal of wastes must be economical as well as offering protection to the present and future generations from the dangers of atomic radiation. Thus, from the broadest sense, these are the two goals for which waste treatment and disposal development programs must aim. The disposal of radioactive wastes can no longer be considered as a problem incidental to reactor evaluation - something for George to do - but must now be considered as an integral part of the nuclear power complex, the aim of which is extraction of economical electricity.

ECONOMICS OF WASTE DISPOSAL

It is probable that nuclear power must be produced for less than 8 mills per kilowatt-hour to be competitive in the United States. Of this, approximately 1.6 mills must be allowed for the entire fuel cycle, with only 0.8 mills available for both chemical processing and treatment and disposal of the radioactive wastes. In large processing plants the chemical processing can possibly be accomplished for 0.65 mills (including inventory and fuel shipping) which thus leaves possibly 0.15 mills for the entire waste disposal scheme. Not only must this figure of 0.15 mills/kwh cover the cost of ultimate disposal, but it must cover also all costs of preparation of these wastes for final ultimate disposal. In addition, it also must cover the treatment and/or disposal of high-, intermediate-, and low-level wastes which exist as solids, liquids, and gases.

Using these criteria, the estimated allowable unit volumetric cost for waste treatment and disposal are indicated in Fig. 1. This plot indicates the allowable costs as a function of irradiation level and volume of waste per unit of uranium processed.⁽¹⁾ For example, at an average irradiation level of 4000 Mwd/t and 800 gals of high-level waste per ton uranium,

26 003

UNCLASSIFIED

UNCLASSIFIED
ORNL-LR-DWG 7625-A

FIG. 1. ALLOWABLE WASTE DISPOSAL COST AS A FUNCTION OF BURNUP AND PROCESS WASTE VOLUME

620 004

UNCLASSIFIED

-5-

a total waste cost of \$5.00 per gallon of high-level waste can be allocated to pay for treatment and disposal of all wastes associated with the process. Allocating waste disposal costs on the per unit of high-level liquid waste basis is fictitious since the total allowable cost must cover all waste treatment and disposal steps. What this really means is \$4000/ton uranium processed can be allocated for all waste treatment and disposal operations.

Since the costs allocated to waste disposal itself must include the costs for disposal of wastes of all levels and physical states, a complete analysis of all waste types and associated disposal technique is necessary. Although disposal of high-level liquid wastes constitute the major problem, the other disposal problems cannot be ignored. If the costs for disposal of all gases and solids as well as intermediate- and low-level liquids are considered, then this figure of \$5.00 per gallon for the high-level waste would be substantially reduced.

The final choice of an ultimate disposal method must be based on overall economics for the entire nuclear power complex. Included in the overall economics would be the cost of insurance premiums for protection against the possibility of the creation of a public hazard.

RADIOACTIVE WASTE BUILDUP AND POSSIBLE HAZARDS

Let us first define three terms which we shall use throughout this paper.

(1) Relative Hazard - The relative hazard of any radioisotope as compared to another is directly proportional to the quantity of material present, inversely proportional to its biological tolerance as measured by the maximum permissible concentration in air or water; and finally inversely proportional to its half-life. This relationship may be expressed mathematically by the following equation:

$$\text{Relative hazard} = \frac{N_1 \lambda_1}{3.7 \times 10^{10} \frac{\text{d/sec}}{\text{curie}}} \bigg/ \text{MPC} \quad (1)$$

where N_1 = the number of atoms of a specific radionuclide existing at any instant per gram of fissionable material as charged to a reactor.

026 005

UNCLASSIFIED

UNCLASSIFIED

-6-

λ_1 = radioactive decay constant, sec^{-1} .

MPC = maximum permissible concentration as given in references (2)(3) for water or air, which is a reflection of the biological tolerance.

In the consideration of the long-term accumulation and storage of radioactive wastes, this relative hazard can be used to define a more useful quantity, which we shall call potential hazard. Relative hazards, in conjunction with an estimate of the buildup rate of nuclear power and the counterbalancing natural decay of fission products and parasitically produced heavy elements, defines the integrated hazard which results from the total quantity of radionuclides produced in any time interval. Potential hazard is more carefully defined below.

(2) Potential Hazard - The potential hazard due to radioactive elements in a given system is determined by the total accumulation of activity divided by the MPC. Thus, the value of the potential hazard is really the quantity of air or water (depending upon the basis used) necessary to dilute the total accumulation of each isotope to biological tolerance.

Thus

$$\text{Potential hazard} = \frac{A_1}{\text{MPC}}$$

where

$$A_1 \text{ (curies)} = 8.012 \times 10^5 \lambda_1 y_1 \left\{ \frac{\alpha - \gamma}{\lambda_1} \left[1 - e^{-\lambda_1 t} \right] + \frac{\gamma}{\lambda_1 + \beta} \left[e^{\beta t} - e^{-\lambda_1 t} \right] \right\} \quad (2)$$

where α , β , γ are constants for an assumed equation used to estimate nuclear power buildup, such as that proposed by Lane⁽⁴⁾. For our work we have used Lane's estimated buildup equation in which the constants are:

$$\alpha = 2000$$

$$\beta = \ln 1.09$$

$$\gamma = 23,200$$

620 006

UNCLASSIFIED

UNCLASSIFIED

-7-

A_1 thus gives the total accumulated quantity of any radionuclide existing in the entire reactor complex of reactor, decay cooling systems, chemical plant, and waste systems.

(3) Absolute hazard - The absolute hazard associated with a waste system cannot be defined by any mathematical relationship at this time since only rough estimates have been made and a particular waste disposal method or site has not been established. However, the absolute hazard will depend on how much of the potential hazard (accumulated activity) can be released, what is the probability of release, what is the mechanism of release, how many people will be exposed by what mechanism, and what effects will the direct radiation and residual contamination have on biological systems exposed.

An estimate of the potential hazard associated with radioactive wastes must start with an estimate of the buildup of the over-all nuclear power complex. Table I summarizes the results of the buildup of nuclear power in the United States and the resulting wastes from such an economy.⁽¹⁾ This table gives the buildup of nuclear power, processing capacity and waste volumes and activity all based on the buildup predictions of J. A. Lane,⁽⁴⁾ which is somewhat lower than those of W. K. Davis⁽⁵⁾ and others.

Table II lists the total accumulated activities of important isotopes in various units of the nuclear power complex by 2000 A.D. The assumption was made that the nuclear power complex would consist of one thousand 700 Mw reactors, twenty chemical plants of 9 tons natural uranium capacity per day each, and 6 ultimate waste disposal sites. This table indicates that the total activity of Sr^{90} in the combined waste system is 24 times that in all of the reactors with each site containing 4000 times as much as each reactor. These ratios only apply for the year 2000 A.D., at which time the waste system has been accumulating long-lived activities from all reactors (after chemical processing) since 1960. For any year prior to 2000 A.D. the ratios would be less.

We must point out that this does not mean that the absolute long-term hazard associated with a waste site is 4000 times that of a reactor, but rather that the long-term hazard potential of one waste site may be many times that of a single reactor because of the greater quantities of the long-lived bio-

006 007

UNCLASSIFIED

UNCLASSIFIED

-8-

TABLE I

ESTIMATE OF WASTE CONDITIONS IN NUCLEAR POWER COMPLEX
(Slightly Enriched Uranium Irradiated to 4000 Mwd/ton)

	YEAR		
	<u>1970</u>	<u>1985</u>	<u>2000</u>
Nuclear Power (Heat Mw x 10^{-3})	33	180	700
Proc. Capacity (tons natural U or equivalent per day)	8.5	48	180
Volume of HA Waste (at 800 gals/ton U processed)			
Annual Vol. (gals/yr)	2.3×10^6	1.3×10^7	4.9×10^7
Accumulated Vol. from 1960 (gals)	1.1×10^7	1×10^8	6×10^8
Total Accumulated F.P. Activity from 1960 (curies)	1.7×10^{10}	1×10^{11}	3.8×10^{11}

UNCLASSIFIED

-26 008

UNCLASSIFIED

-9-

TABLE II

ACTIVITY LEVEL IN ANY ONE UNIT OF THE
NUCLEAR POWER COMPLEX BY 2000 AD

ACTIVITY (CURIES) IN A SINGLE UNIT

ISOTOPE	IN EACH OF 1000 REACTORS	IN EACH OF 20 CHEM. PLANTS		IN EACH OF 6 WASTE SITES
		DECAY	PROCESS	
Sr ⁹⁰	2.6×10^5	2.5×10^7	2.5×10^6	1.0×10^9
Cs ¹³⁷	2.2×10^5	2.2×10^7	2.2×10^6	8.8×10^8
Kr ⁸⁵	3.6×10^5	3.5×10^6	3.4×10^5	9.8×10^7
Pm ¹⁴⁷	1.1×10^6	1.1×10^8	1.0×10^7	1.0×10^9
Ba ¹⁴⁰	3.5×10^7	7.6×10^6	1.1×10^3	-
Am ²⁴¹	29	1.5×10^3	1.5×10^2	1.8×10^5
Pu ²³⁹ + Pu ²⁴⁰	3.8×10^3	3.8×10^5	3.8×10^4	4.7×10^4

UNCLASSIFIED

026 099

UNCLASSIFIED

-10-

logically dangerous materials contained. The immediate hazard from a waste accident would also be much less than the immediate hazard from a reactor accident, since there are no short-lived isotopes present in the waste system. It is these short-lived isotopes that are most lethal during the initial period as a result of an uncontrolled reactor excursion. Since a waste system will not contain within itself sufficient energy or other energy release mechanisms to disperse activity, as is the case with a reactor, the probability of release from a waste system is much less than the probability of release from a reactor. The magnitude of airborne release from a waste accident should be small compared to that from a reactor, since it would require an energy expenditure equivalent to several thousand pounds of TNT to vaporize the contents of a million gallon tank. Thus, the probable mechanism of release (the way the potential hazard becomes an absolute hazard) becomes one of liquid release, and the direct comparison of a probable waste accident to a probable reactor accident cannot be made.

One criterion for design of a successful ultimate disposal site will undoubtedly be that it should have a release probability of essentially zero. Probably the only significant release "mechanism" in a well-designed waste system would be sabotage or espionage. Waste sites can be located in isolated areas and the number of people or the value of the land affected will be small.

Figs 2 and 3 give the potential hazards, compared to maximum permissible levels, of the most important isotopes on water and air contamination bases. These plots indicate that after removal of Sr^{90} and Cs^{137} the transplutonics become the most important hazards.

WASTE TREATMENT

The purposes of waste treatment are twofold: (1) to prepare the wastes for safe and economical disposal, and (2) recover valuable fission products. Waste treatment processes for ultimate disposal must change or alter the chemical or physical characteristics to achieve complete compatibility with the ultimate disposal site and scheme. However, the treatment methods must be as simple and economical as possible in order to minimize the over-all treatment and disposal cost.

UNCLASSIFIED

005 010

FIG.2. EFFECT OF DECAY TIME AFTER 1990 ON BIOLOGICAL HAZARD OF ACCUMULATED
WASTE(1960-1990) BASED ON AIR CONTAMINATION

FIG.3. EFFECT OF DECAY TIME AFTER 1990 ON BIOLOGICAL HAZARD OF ACCUMULATED
WASTE (1960-1990) BASED ON WATER CONTAMINATION

UNCLASSIFIED

-13-

Recovery of fission products may offer an economic return from the sale of several of the long-lived isotopes. Isolation of certain of the long-lived FP's such as Cs and Sr will provide the additional advantage of making the gross waste less hazardous. Table III gives a very rough estimate of possible costs and credits for recovery of fission products from wastes from a large processing plant.

STORAGE

The purpose of waste storage in tanks is to allow decay of radioactivity for a period of 5-10 years at which time the waste can be economically shipped and/or ultimately disposed. The economics of storage is linked to shipping as mentioned below. The costs for interim storage tanks would range between \$0.25-\$2.00 per gallon (with some cases being greater than \$2.00/gallon) depending upon the size and type of service or usage.

The criteria for an interim storage system can be listed as follows:

- (1) Allow safe and economical storage of wastes prior to disposal.
  - (2) Heat removal and off-gas systems must be safe, efficient, and economical.
  - (3) The wastes must be stored and maintained as a solution in order to allow easy removal at time of shipment or disposal or in case of a leak.
  - (4) The corrosion rates must be low so frequent replacement is unnecessary.
- A cost of 5-10¢/gal-year can be tolerated, i.e., a tank which costs \$2.00 per gallon should last 20-40 years.

SHIPPING

From the standpoint of economics alone, radioactive liquid wastes can be shipped from a processing plant to an ultimate disposal site for distances up to 1000 miles one-way. As waste is cooled, the cost of storage increases and the cost of shipping decreases by virtue of having to ship less shield weight. The optimum cooling time will depend on the irradiation history of the fuel, the cost of storage and the cost of shipping. The lower the irradiation level the shorter the optimum decay time. The shipping cost per gallon for disposal at a site 500 miles from the processing plant might be approximately \$0.90 by truck and \$1.30 by rail for 2000-day cooled waste at 800 gals/ton uranium

UNCLASSIFIED

000 013

UNCLASSIFIED

-14-

TABLE III

FISSION PRODUCT ECONOMICS

Basis: Solvent Extraction Plant for Power Reactor Fuels with Complete Facilities

Capacity = 6 tons Nat. U/day + 25 kg Enr. U/day

Total Plant Investment	$\$78 \times 10^6$
Total Plant Oper. + Amort.	$\$24 \times 10^6/\text{yr}$
Waste Disposal Investment	$\$6.5 \times 10^6$
F. P. Recovery Investment	$\$3.5 \times 10^6$
Waste Disposal Oper. + Amort.	$\$2.3 \times 10^6/\text{yr}$
F. P. Recovery Oper. + Amort.	$\$1.7 \times 10^6/\text{yr}$
Total Waste System Oper. + Amort.	$\$4.0 \times 10^6/\text{yr}$
Value of Fission Products	$\$13.0 \times 10^6/\text{yr}$
(at $\$0.10/\text{c}$ Cs ¹³⁷ or Sr ⁹⁰ , $\$0.05/\text{c}$ Kr ⁸⁵ , $\$0.001/\text{c}$ TRE)	

UNCLASSIFIED

20 014

processed. By taking a broader outlook on waste shipping philosophy, this cost could possibly be reduced to ~15¢ per gallon by using more economical barge shipping (river distance = twice road distance). However, this philosophy puts additional restrictions on the location of the ultimate disposal site as well as the chemical processing plant. Another interesting point which should be mentioned is the possible use of an overland pipeline. If one compares the large number of possible truck shipments (14,000) involved during 1980 with the diameter of a pipe carrying the same volume of waste (2"), then the pipeline possibility appears attractive. Of course, a double concentric pipe arrangement with monitoring, pumping and cooling stations will be necessary. An elaborate pipeline system might easily be the safest shipping method, and further study and development of this possibility is justified.

Fig. 4 indicates the optimum decay time prior to shipment as well as the total cost of shipping plus interim storage as a function of decay time and shipping distance for the conditions of: (1) storage cost = 4.1¢/gal-yr, (2) 250 gal. of liquid in spherical carrier of 4 ft. I.D., (3) 800 gals waste/ton uranium processed, and (4) 10,000 Mwd/t irradiation. (1)

However, the big question mark over the philosophy of shipping radioactive liquid wastes is the hazard involved. Thus the four methods of shipping - rail, road, barge, pipeline - must be evaluated from both the economic and hazard standpoint. In fact, the hazard potential may really be a measure of the true cost because of possible insurance premiums involved. The present average accident rate for the trucking industry is high - 1 per 100,000 vehicle miles. In 1980 when 14,000 shipments of say 1000 miles per round trip will be involved, then approximately 70 accidents (on the basis of pure statistics alone) involving full carriers will occur. This number of accidents could inadvertently release 4 million curies of activity to the environment at random locations throughout the country. Of course this analysis assumes that each accident results in a spill of the entire contents of a carrier. This assumption is probably far from reasonable since a statistical analysis of accident data covers all types of truck accidents, both major and minor.

UNCLASSIFIED
ORNL-LR-DWG 9555-A

FIG.4. COMBINED SHIPPING AND STORAGE COST AS A FUNCTION OF COOLING TIME

UNCLASSIFIED

-17-

LOCATION

There are many factors affecting the location of both the waste disposal sites and the chemical processing plant. The shipping problem can easily dictate the choice of locations. If the hazard involved with shipping of liquid wastes is too great and if the most economical disposal method is disposal of liquids in underground formations, then it may be advisable to locate the processing plant at the waste disposal site. However, location of a processing plant in an isolated spot could easily create increased costs for processing. From the standpoint of economics alone, the best location of the chemical processing plant depends upon the relative geographical density of power reactors, the shipping distance and cost for fuel elements and the shipping distance and cost for waste.

Using unpublished work by the author, a group in the ORNL-MIT Practice School⁽⁶⁾ investigated the optimum location of the first processing plant with a waste disposal site picked at Hutchinson, Kansas. The optimum location appeared to be Terre-Haute, Indiana. The optimization was based on the sum of fuel shipping costs, waste storage plus waste shipping. The total unit cost for this minimum was \$5450/ton of spent fuel elements. However, if the processing plant were located at Hutchinson, the total cost would be increased to \$5940/ton - only ten percent. (Fuel element shipping represented 80-90% of the total cost.) The best location for the first processing plant appears to be southern Indiana, both with and without consideration of a waste disposal site.

However, a final decision about optimum locations for both waste disposal sites and processing plants cannot be made until further investigation of processing methods and costs, waste disposal techniques, shipping methods, and hazards are made.

LIABILITY

The most important aim of an eventual over-all waste disposal scheme is complete protection to the present and future generations at a cost commensurate with competitive nuclear power. Unless a waste disposal scheme is sound in terms of public safety, the cost of insurance premiums could be prohibitive.

UNCLASSIFIED

017

UNCLASSIFIED

-18-

With our present knowledge and from preliminary considerations as discussed in this paper we suggest that the evaluation of the hazards involved in the over-all waste disposal complex are possibly as important as the evaluation of hazards resulting from a single reactor disaster. Such an evaluation should include at least the following parameters: (1) probability of accident, (2) probability of release, (3) pattern and mechanism of distribution, (4) exposure of people and the effects of exposure on people, (5) deposition on land, (6) possible water contamination. All of these must be considered in the evaluation of potential liability for those groups who must process fuel and dispose of waste.

UNCLASSIFIED

C20 018

UNCLASSIFIED

-19-

REFERENCES

- (1) Zeitlin, H. R., Arnold, E. D. and Ullmann, J. W., "Economics of Waste Disposal", Nucleonics, Vol. 15, No. 1, Pgs. 58-62, (Jan. 1957).
- (2) National Bureau of Standards Handbook 52, "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water".
- (3) Morgan, K. Z. and Ford, M. R., "Developments in Internal Dose Determinations", Nucleonics 12(6): 32-39 (1954)(revision of paper presented at the American Industrial Hygiene Conference, Los Angeles, April 23, 1953).
- (4) Lane, J. A., Nucleonics 12, No. 10, 65 (1954).
- (5) Davis, W. K., "Atomic Power -- Big New Field for Builders", Engineering News Record, p. 154, (April 21, 1955).
- (6) Wolff, R. W. and Rekemeyer, P. C., MIT Engineering Practice School, Memorandum EPS-X-295, KP-255, (Jan. 18, 1957).

026 019

UNCLASSIFIED

1-19