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LOW-LEVEL RADIOACTIVE WASTE
MANAGEMENT CONFERENCE

17th Annual

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of Energy

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Radioactive Waste

Management

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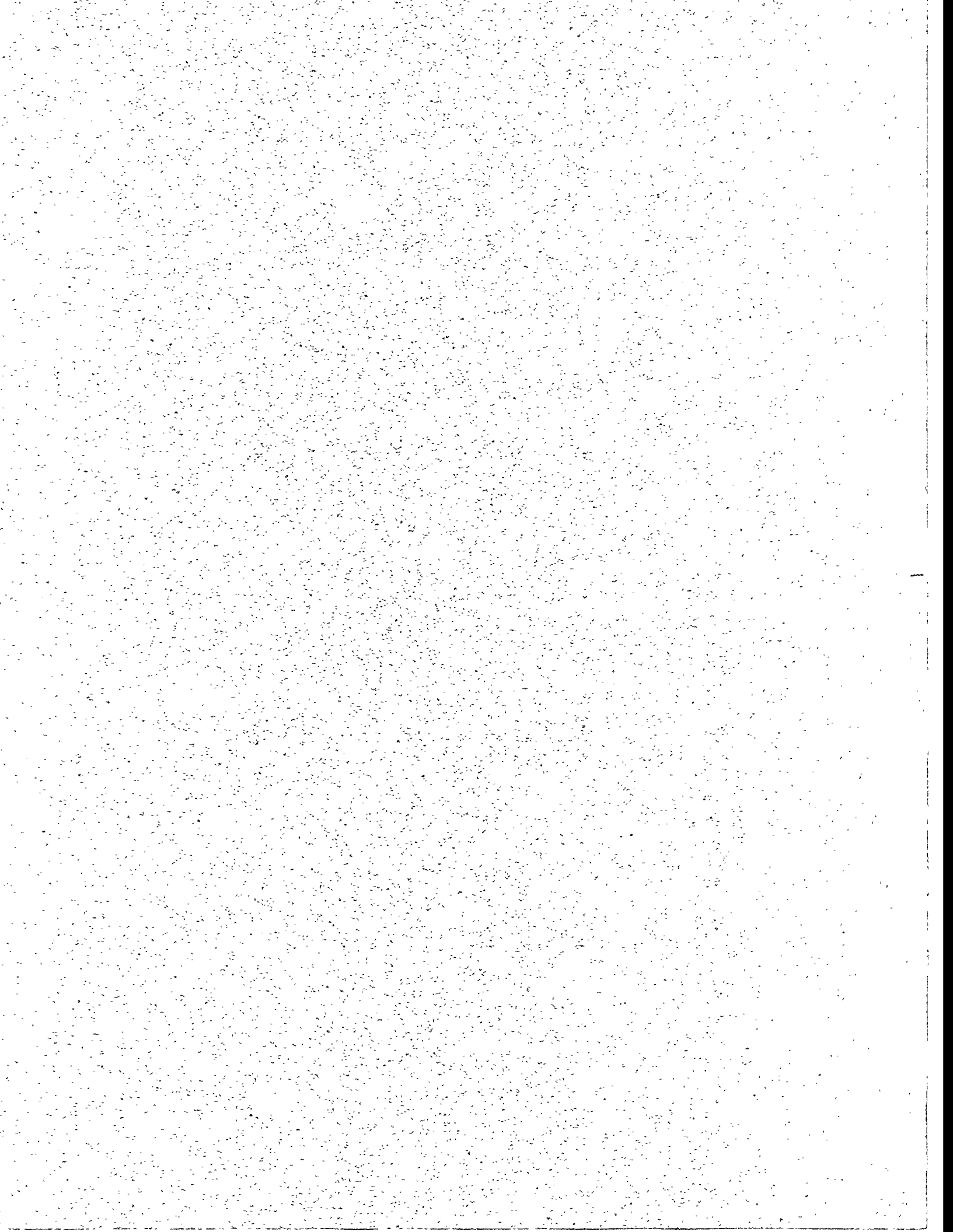
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INEL
P.O. Box 1625,
Idaho Falls, Idaho
83415-2420
(208) 526-0234
Fax: (208) 526-9165

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**17th ANNUAL U.S. DEPARTMENT OF ENERGY
LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT
CONFERENCE PROCEEDINGS**

**Phoenix, Arizona
December 12-14, 1995**

**Idaho National Engineering Laboratory
National Low-Level Waste Management Program**

Work performed under
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MASTER

COMMITTEE

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Project Manager

Sandra M. Birk, Idaho National Engineering Laboratory

Administrator

Donna R. Lake, Idaho National Engineering Laboratory

Technical Specialists

Idaho National Engineering Laboratory

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Department of Energy

Terry L. Plummer

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Edward O'Donnell**

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Texas Low-Level Radioactive Waste Disposal Authority

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University of Idaho

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Environmental Resources Management

R. John Starmer

Rogers & Associates Engineering Corp.

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Donald E. Wood

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PANEL DISCUSSION

This panel will cover the Nuclear Regulatory Commission's (NRC) proposed radiation limits in the *Branch Technical Position on Low-Level Radioactive Waste Performance Assessment* and the Environmental Protection Agency's (EPA) draft regulation in Part 193. Representatives from NRC and EPA will discuss the inconsistencies in these two regulations. DOE and state representatives will discuss their perspective on how these regulations will affect low-level radioactive waste performance assessments.

Panel Members:

William P. Dornsife
Pennsylvania Department of Environmental Resources
(717) 787-2480

H. Ben Hull
U.S. Environmental Protection Agency

Andrew C. Campbell
Nuclear Regulatory Commission
(301) 415-6897

Gregory J. Duggan
DOE-Headquarters, EM-332
(301) 903-7140

RESULTS AFTER 10 YEARS OF FIELD TESTING
LOW-LEVEL WASTE FORMS USING LYSIMETERS

J. W. McConnell, Jr., R. D. Rogers, J. D. Jastrow,^a
W. E. Sanford,^b I. L. Larsen,^b and T. M. Sullivan,^c
Idaho National Engineering Laboratory
P.O. Box 1625
Idaho Falls, Idaho 83415
(208) 526-6198

ABSTRACT

The Field Lysimeter Investigations: Low-Level Waste Data Base Development Program is obtaining information on the performance of radioactive waste forms. Ion-exchange resins from a commercial nuclear power station were solidified into waste forms using portland cement and vinyl ester-styrene. These waste forms are being tested to: (a) obtain information on performance of waste forms in typical disposal environments, (b) compare field results with bench leach studies, (c) develop a low-level waste data base for use in performance assessment source term calculations, and (d) apply the DUST computer code to compare predicted cumulative release to actual field data. The program, funded by the Nuclear Regulatory Commission (NRC), includes observed radionuclide releases from waste forms in field lysimeters. The purpose of this paper is to present the experimental results of two lysimeter arrays over 10 years of operation, and to compare those results to bench test results and to DUST code predicted releases. Further analysis of soil cores taken to define the observed upward migration of radionuclides in one lysimeter is also presented.

INTRODUCTION

The objective of the Field Lysimeter Investigations: Low-Level Waste Data Base Development Program is to expose waste forms to the physical, chemical, and microbiological environment of typical disposal sites; to monitor release and movement of radionuclides from those waste forms; and to compare the results with short-term laboratory leach test results. This program, funded by the NRC, has been operating lysimeters for 10 years to obtain information on the performance of radioactive waste forms in a disposal

-
- a. Argonne National Laboratory, Argonne, IL 60439.
 - b. Oak Ridge National Laboratory, Oak Ridge, TN 37831.
 - c. Brookhaven National Laboratory, Upton, NY 11973.

environment and to investigate waste form stability per requirements of Title 10, Code of Federal Regulations Part 61, "Licensing Requirements for Land Disposal of Radioactive Wastes." The experiment measures the releases of radionuclides from the waste forms and subsequent transport through soil columns to sampling locations within the lysimeters. This study was developed to field test waste forms composed of solidified ion-exchange resins from EPICOR-IIId prefilters used in cleanup of Unit 2 of the Three Mile Island Nuclear Power Station.¹ Resins used in the study are significant because they have high loadings of radionuclides and are the type used by the nuclear industry.

The U.S. Nuclear Regulatory Commission (NRC) has enacted regulations that link low-level radioactive waste acceptance criteria to the long-term satisfactory performance of the disposal facility. Under 10 CFR 61, commercially generated low-level radioactive waste is classified as Class A, B, or C. Class B and Class C wastes must be stabilized into waste forms or placed in containers designed to remain stable for a minimum of 300 years. To verify the 300-year stability, the NRC recommends the use of short-term standardized tests with the intention that such tests would provide information relevant to near-surface disposal performance objectives. Those tests, which were initially published in the NRC Branch "Technical Position on Waste Form,"² have been revised in Revision 1 of the Technical Position.³

A central requirement for disposing low-level radioactive waste is the need for a detailed understanding of the waste form behavior because the radionuclide source from those wastes is the driving force behind the disposal site performance. A major requirement in any site licensing is the performance assessment, which is used to evaluate the proposed disposal site. Assumptions regarding the radionuclide release from buried waste forms have a direct bearing on the outcome of the performance assessment. This has resulted in a very real need to obtain accurate data on the long-term field performance of these wastes.

d. References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendations, or favoring by the United States Government or any agency thereof.

The purpose of this paper is to present the experimental results of the two instrumented lysimeter arrays over 10 years of operation. The paper gives an update, which includes further discussion of the upward migration of ^{137}Cs and ^{134}Cs in one unit of the Oak Ridge National Laboratory array. Also, cumulative fractional release (CFR) of radionuclides from the waste forms is compared to bench leach test cumulative fractional releases from similar waste forms and to predictions of the Disposal Unit Source Term (DUST) code.

EXPERIMENT DESCRIPTION

Wastes used in the experiment include a mixture of highly loaded, nuclear-grade, synthetic, organic ion-exchange resins from EPICOR-II prefilter PF-7 and a mixture of organic-exchange resins and an inorganic zeolite from prefilter PF-24. Solidification agents employed to produce the 4.8 x 7.6-cm cylindrical waste forms used in the study were portland type I-II cement and vinyl ester-styrene (VES). Seven of the waste forms were stacked end-to-end and inserted into each lysimeter to provide a 1-L volume. The PF-7 waste contained 89% of the radionuclide activity as ^{137}Cs , while PF-24 contained 94% ^{137}Cs . The PF-7 waste also contained 5% ^{90}Sr , and PF-24 contained 1% ^{90}Sr . There were also measurable amounts of ^{134}Cs , ^{60}Co , and ^{125}Sb found in those wastes. Details on waste-form descriptions, formulations, and technical position testing are given in References 1 and 4. A listing of lysimeter waste form and fill material types are given in Reference 5.

Ten lysimeters were used in this study: five at Oak Ridge National Laboratory (ORNL) in Tennessee and five at Argonne National Laboratory-East (ANL-E) in Illinois (see

Reference 5). Each lysimeter is a 0.91×3.12 -m right-circular cylinder divided into an upper compartment that contains fill material, waste forms, and porous cups, and a lower compartment for collecting leachate (Figure 1). Four lysimeters at each site are filled with soil; a fifth, used as a control, is filled with inert silica oxide sand. The lysimeters at ANL-E contain soil indigenous to the site, while the ORNL lysimeters contain soil taken from Savannah River Laboratory in South Carolina. The soil columns are 2.21 m deep.

Porous cup soil-water samplers and the leachate collection compartment comprise the water sampling components of each lysimeter (Figure 1). Incoming precipitation moves downward through the soil column to the waste form, then on to cups 3 and 1, and finally to the leachate collector at the bottom. Moisture entering the soil at the edge of the lysimeter encounters cups 5, 4, or 2 as it moves downward. Samples of moisture are withdrawn from the cups and the collector. See Reference 5 for details.

Monitoring of the lysimeters at ANL-E and ORNL began with the collection of liquid samples in September 1985 (3 months from the time of placement) and has continued with sample collection on approximately a quarterly basis thereafter. Samples of liquids were taken from locations near the waste forms and from the leachate collectors to track the migration of radionuclides. The water samples were analyzed for ^{90}Sr and gamma-producing nuclides. Testing results are presented in Reference 6 as well as in this paper.

Weather Data

Diagram illustrating the experimental apparatus for studying the leachate flow pattern in a landfill cell. The apparatus consists of a vertical soil column (90.9 cm ID) with various instrumentation and components.

Key Components and Instrumentation:

- Route moisture-cup tubing as required-5 places
- Soil surfaces
- Route detector cables as required-3 places
- 149.0 cm
- Solidified resin waste forms (7)
- 108.5 cm
- 77.9 cm
- 51.2 cm
- 28.8 cm
- 1.3 cm
- Moisture/temperature probe-3 places
- Filter fabric
- Leachate collector

Dimensions and Vertical Distances:

- 90.9 cm ID
- To pump
- 10.2 cm
- 312.1 cm (Total height)
- 91.4 cm
- 22.9 cm
- 38.1 cm

Plan View Details (Top Left):

- 270°
- 20 cm-3 places
- 180°
- 90°
- 0°
- C, B, A
- 5
- 2
- 3
- 1
- 4

Other Labels:

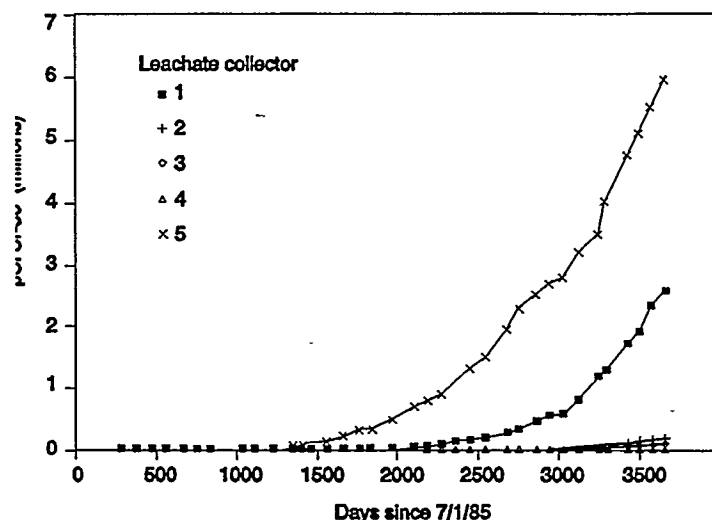
- Soil column
- Pump line
- Access tube
- Moisture cup-5 places
- River stone filter
- Screen
- Zero elevation reference for all instrument elevations

Radionuclide Data

5

observed in all the number 3 cups (22.4 cm below the waste form in the soil column) at both ANL-E and ORNL.

At both ORNL and ANL-E, recovery of ^{90}Sr in cups 3 and the leachate collectors indicates that a more predictable waste form



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Figure 2. ORNL cumulative ^{90}Sr collected in lysimeter leachate collectors.

performance is emerging (Table 1). Recovery of ^{90}Sr in the ORNL cups is comparable for those soil lysimeters containing the cement waste forms and one of the two containing VES waste forms. However, the other cup at ORNL and both cups at ANL-E, which contain the VES waste forms, are recovering more ^{90}Sr compared to the cement waste forms. These

Table 1. Percent of total ^{90}Sr and ^{137}Cs inventory per lysimeter released to moisture cups and leachate water through July 1995.

Lysimeter number	Solidification agent	Percent of total inventory of ^{90}Sr released				Percent of total inventory of ^{137}Cs released			
		Moisture cups		Leachate collectors		Moisture cups		Leachate collectors	
		ANL-E	ORNL	ANL-E	ORNL	ANL-E	ORNL	ANL-E	ORNL
1	Cement	1.4E-4	9.7E-4	3.7E-5	1.4E-2	— ^a	—	—	1.7E-6
2	Cement	4.4E-4	7.8E-4	7.0E-5	4.6E-3	1.1E-6	—	—	1.4E-7
3	VES	6.9E-3	1.3E-3	1.6E-3	2.9E-4	—	—	—	1.4E-6
4	VES	1.5E-3	3.3E-4	2.2E-4	4.8E-4	—	—	—	3.8E-7
5	Cement	2.7E-4	8.8E-4	2.3E-2	1.8E-1	2.7E-4	1.3E-6	—	4.3E-4

a. Percent released is essentially equal to zero.

data indicate that releases from the cement waste forms are generally less than from VES waste forms.

Movement of ^{90}Sr into the leachate collectors of the soil lysimeters is not following any pattern; however, movement into control lysimeter collectors is much greater than that of the other lysimeters, thus providing evidence of the moderating effect of soil (versus the inert sand) in those lysimeters. During the past several years, leachate collector water from the control lysimeters at each site has contained amounts of ^{90}Sr at least an order of magnitude larger than releases from the soil lysimeters⁶ (Figure 2 and Table 1). The difference in release represents how the environment at the two sites affects the movement of ^{90}Sr released from the waste forms. The higher release of ^{90}Sr from the ORNL control lysimeter waste form reflects the nearly 50% higher rainfall experienced at that site over that seen at ANL-E.

Gamma-producing nuclides continue to occur with regularity at both sites (Table 1). However, only waste forms at ORNL are releasing detectable amounts of ^{137}Cs to the leachate waters (Table 1). It is not possible to make a comparison of ^{137}Cs releases from cement and VES waste forms due to the small releases.

Table 2 is a comparison of CFRs from field testing EPICOR-II waste forms in lysimeters to releases from bench-leach-testing similar waste forms as reported in References 4 and 6. Lysimeter releases are at least two orders of magnitude less for ^{90}Sr in soil and at least five orders of magnitude less for ^{137}Cs in soil. Release of ^{90}Sr in the sand-filled lysimeter is only one or two orders of magnitude less than bench test results.

Table 2. Cumulative fractional releases from lysimeter field testing compared to those from bench leach testing.^{4,6}

Test type	Prefilter number	Solidification agent	Radionuclide	Cumulative fractional release		
				Demineralized water	Soil	Sand
Bench	7	VES ^a	⁹⁰ Sr	4.5E-2	—	—
Bench	7	Cement ^a	⁹⁰ Sr	7.8E-2	—	—
Bench	7	VES ^a	¹³⁷ Cs	4.0E-2	—	—
Bench	7	Cement ^a	¹³⁷ Cs	9.0E-2	—	—
Bench	7	VES	¹³⁷ Cs	2.1E-3	—	—
Bench	7	Cement	¹³⁷ Cs	4.8E-2	—	—
Bench	24	VES	¹³⁷ Cs	3.0E-4	—	—
Bench	24	Cement	¹³⁷ Cs	2.3E-2	—	—
Field, ANL-E	7	VES	⁹⁰ Sr	—	1.6E-5	—
Field, ANL-E	7	Cement	⁹⁰ Sr	—	3.7E-7	2.3E-4
Field, ANL-E	24	VES	⁹⁰ Sr	—	2.2E-6	—
Field, ANL-E	24	Cement	⁹⁰ Sr	—	7.0E-7	—
Field, ORNL	7	VES	⁹⁰ Sr	—	2.9E-6	—
Field, ORNL	7	Cement	⁹⁰ Sr	—	1.4E-4	—
Field, ORNL	24	VES	⁹⁰ Sr	—	4.8E-6	—
Field, ORNL	24	Cement	⁹⁰ Sr	—	4.6E-5	1.8E-3
Field, ORNL	7	VES	¹³⁷ Cs	—	1.4E-8	—
Field, ORNL	7	Cement	¹³⁷ Cs	—	1.7E-8	—
Field, ORNL	24	VES	¹³⁷ Cs	—	3.8E-9	—
Field, ORNL	24	Cement	¹³⁷ Cs	—	1.4E-9	4.3E-6

a. Waste forms were irradiated before test.

Upward Migration of Radionuclides at ORNL

Both ¹³⁷Cs and ⁹⁰Sr were discovered at the surface of lysimeter ORNL-5 during a routine gamma survey of the lysimeter's surface in December 1990. More activity was found near the center than at the edges. Surface samples were obtained from the center of the lysimeter for analysis. The analytical results showed significant activities of cesium and strontium, suggesting some type of an active deposition mechanism. There remained a

question, however, concerning the source of the radionuclides. In August of 1992, samples were again taken and analyzed for ^{137}Cs and ^{134}Cs . The results were similar to

the previous sampling. A comparison was made between the ratio of ^{137}Cs and ^{134}Cs measured in the two surface samples (264 and 242) and the ratio calculated to be in the buried waste form (252). The contamination of cesium came from the waste form.

On January 31, 1994, two cores of sand 80 cm long were collected from lysimeter 5, one from the side of the lysimeter near the wall, and the other from the center of the lysimeter directly above the buried waste form (located approximately 100 cm below the sand surface). These sand cores were sectioned into 5-cm segments. Radiocesium and strontium activity were measured for each segment (Table 3). The analyses show that ^{137}Cs was present throughout the length of the cores (Table 3). There are three peaks in the cesium content.

During the sectioning of the center core, it was noticed that there was a fine plant root present throughout the depth of the core. The root material was extracted from each segment and counted (Table 3). ^{137}Cs activity was associated with the root, and the peaks in the root data occurred at the same depths as the peaks in the sand activity. There were higher concentrations of ^{137}Cs associated with the root than with the sand. Data from analysis of segments 1 and 2 suggest that the activity in the sand is not evenly distributed. This could be a result of the root being involved in the transport process. There was some ^{137}Cs found in all segments of the core collected from the side of the lysimeters; however, it was present

Table 3. Cesium and strontium analyses for sand segments from the center (core c) and side (core s) and root fragments from the center of ORNL lysimeter 5.

Segment #		Depth (cm)	Sand					Plant root	
			Segment dry weight (g)		¹³⁷ Cs (pCi/g)		⁹⁰ Sr (pCi/g)	Sample weight (g)	¹³⁷ Cs (pCi/g)
Core c	Core s		Core c	Core s	Core c	Core s	Core c		
— ^a	1	76.5-71	—	126.11	—	0.26	—	—	—
1	2	71.5-66	100.68	139.80	598.1	0.20	1.5	0.0134	18,900
1	—	71.5-66	17.08	—	704.5	—	—	—	—
1	—	71.5-66	17.16	—	660.8	—	—	—	—
2	3	66.5-61	118.92	120.32	1,303.4	0.22	3.5	0.0172	20,660
2	—	66.5-61	17.48	—	2,241	—	—	—	—
2	—	66.5-61	20.37	—	1,550	—	—	—	—
3	4	61.5-56	121.53	131.40	356.7	0.19	2.0	0.0301	20,480
3	—	61.5-56	19	—	400.7	—	—	—	—
3	—	61.5-56	14.85	—	376	—	—	—	—
4	5	56.5-51	115.25	109.76	490.2	0.24	2.1	0.0234	22,540
5	6	51.5-46	117.07	115.29	403.3	0.17	2.7	0.0216	27,520
6	7	46.5-41	125.28	141.24	1,594	0.19	7.6	0.0224	27,360
7	8	41.5-36	129.06	113.21	37,283.1	0.40	14.1	0.0220	81,970
8	9	36.5-31	121.14	124.99	551.2	1.14	1.5	0.0302	13,620
9	10	31.5-26	116.32	117.30	866.6	38.9	3.5	0.0196	10,150
10	11	26.5-21	122.86	135.38	5,484.2	6.1	7.6	0.0463	21,580
11	12	21.5-16	117.94	108.01	2032.4	2.6	16.0	0.0256	5,990
12	13	16.5-11	125.78	104.74	1,513	3.5	0.5	0.1049	3,850
13	14	11.5-6	94.99	117.22	711.7	9.0	0.2	0.0615	5,940
14	15	6.5-0	150.30	142.25	715.2	53.6	0.6	0.3105	8,570

a. No measurement was taken at this location.

in activities three to four orders of magnitude less than those from the center core. A large peak occurred at 26.5 to 31.5 cm, roughly the same depth as in the center core upper peak.

The ^{90}Sr analysis results show that there is significant strontium throughout the entire depth of the center core (Table 3). Peaks occur in the distribution at the same depths as for cesium in both the sand and roots. This suggests that the transport of strontium and cesium upward may be caused by the same mechanism. The predicted ratio of ^{137}Cs to ^{90}Sr is 440, while the measured average ratio was 460. This similarity in the ratios is further evidence that both are performing similarly. Strontium and cesium behave very differently chemically, suggesting that the process of migration is more physical than chemical, such as evaporation enhanced by transpiration through the root. The fact that the sand has a very low cation-exchange capacity is probably the reason that the physical aspect of migration is so evident. ORNL scientists performed gamma-radiation surveys of gravimetric soil cores collected annually, and determined that soil-filled lysimeters are not experiencing upward migration of radionuclides. Further study is planned.

SOURCE TERM MODELING OF LYSIMETER RELEASES

The Disposal Unit Source Term (DUST)⁷ code was used to model the release of the radionuclides ^{137}Cs and ^{90}Sr from the lysimeter waste forms. DUST is a one-dimensional code that accounts for waste form radionuclide leaching release.

This paper examines the release of ^{90}Sr from cement waste forms in the inert, sand-filled lysimeter 5 at ORNL, which was chosen because releases from the soil lysimeters were substantially lower; therefore, the data were not yet sufficient to model. ORNL-5 contained resin waste from PF-24 in cement. The diffusion coefficient value measured in

laboratory testing of these waste forms was $9.6\text{E-}10\text{ cm}^2/\text{s}$ for ^{90}Sr in portland cement.⁶ The Darcy velocity⁶ was $3.6\text{E-}6\text{ cm/s}$. The soil bulk density value⁵ was 1.60 g/cm^3 . Moisture content was calculated using the effective soil porosity and the fraction of saturation values found in Reference 6. The dispersivity and distribution coefficient (K_d) have not been measured for ^{90}Sr in this sand; therefore, they were estimated based on data in References 8 and 9 and by fitting the model predictions to the data. The cumulative activity in the leachate after 9 years of operation was used to compare to DUST predictions, and represented a CFR of about 0.0012 of the ^{90}Sr in lysimeter 5 at ORNL (Table 8 of Reference 6).

As shown in Figure 3, the actual data for ^{90}Sr from ORNL lysimeter 5 are compared with the DUST code predictions of releases with zero dispersive flux BC in case 1 using $K_d = 24$ and dispersivity = 8.5 cm. Also shown are predicted releases of case 2 using $K_d = 10$ and dispersivity = 0.6 cm. The predicted release shows a good fit to the actual data after initial stabilization of the test data. The lack of measured sand dispersivity and K_d necessitates obtaining cumulative release data over a longer term. However, a K_d analysis of these lysimeter soils and sands is now being performed to provide that important information.

CONCLUSIONS

The radionuclide that has appeared in the highest concentrations at both sites is ^{90}Sr , although ^{137}Cs is observed regularly in the leachate of all ORNL lysimeters. A comparison of total ^{90}Sr found in leachate of the control lysimeters shows that environmental effects have

resulted in a much higher release at ORNL. The data indicate that portland cement and VES waste forms have comparable releases of ^{90}Sr .

^{137}Cs , ^{134}Cs , and ^{90}Sr are present throughout the upper 80 cm of the inert sand in ORNL lysimeter 5 directly

above the waste form. The

ratio of $^{137}\text{Cs}/^{134}\text{Cs}$ indicates that the radionuclides are from the buried waste form and not from an outside source and were transported vertically upward by some physical mechanism such as evaporation enhanced by transpiration by a plant root.

DUST-predicted cumulative release of ^{90}Sr from ORNL lysimeter 5, which was plotted over the first 9 years of data collection, show a reasonable fit to the field data. The accuracy of the DUST modeling study was limited, however, by the lack of measured sand dispersivity and distribution coefficient. Those K_d values for lysimeter soils and sand are now being measured.

Testing has been terminated on this experiment. Planning is under way to exhume the waste forms for examination and to perform radiochemical analysis of soils to obtain nuclide

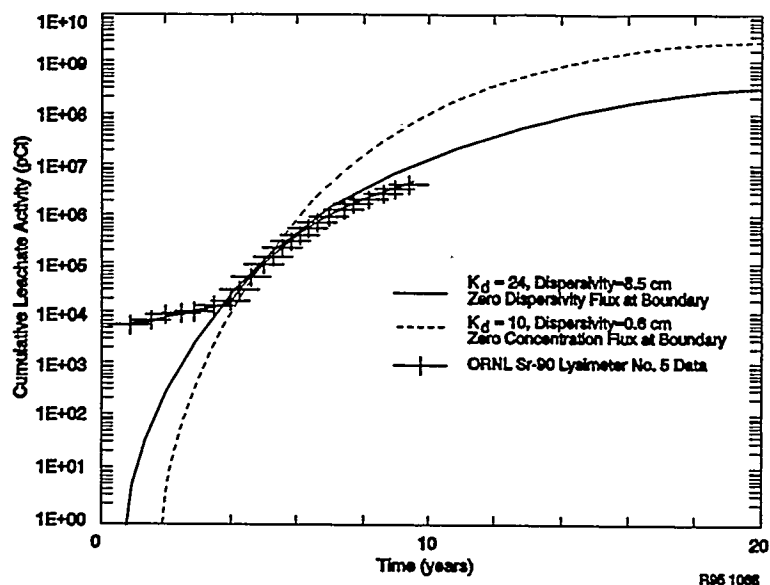


Figure 3. Cumulative release of ^{90}Sr in ORNL lysimeter 5 over 9 years, compared with DUST predictions using two sets of estimated K_d and dispersivity values over 20 years.

distribution information. The utility of this reliable source of data will be demonstrated through that analysis and application of those data to source term models such as DUST. NRC planning recommends that this experiment be augmented by an experiment examining solidified decontamination wastes and activated metals from commercial nuclear power stations.

ACKNOWLEDGMENTS

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SOURCE TERM MODEL EVALUATIONS FOR THE LOW-LEVEL
WASTE FACILITY PERFORMANCE ASSESSMENT

Man-Sung Yim
North Carolina State University
Raleigh, NC 27695-7909

and

Sol-II Su
North Carolina State University
Raleigh, NC 27695-7909

ABSTRACT

The estimation of release of radionuclides from various waste forms to the bottom boundary of the waste disposal facility (source term) is one of the most important aspects of LLW facility performance assessment. In this work, several currently used source term models are comparatively evaluated for the release of carbon-14 based on a test case problem. The models compared include PRESTO-EPA-CPG, IMPACTS, DUST and NEFTRAN-II. Major differences in assumptions and approaches between the models are described and key parameters are identified through sensitivity analysis. The source term results from different models are compared and other concerns or suggestions are discussed.

INTRODUCTION

The estimation of release of radionuclides from various waste forms to the bottom boundary of the waste disposal facility ("source term") is one of the most important aspects of LLW facility performance assessment. Especially with the newly proposed EPA's 40 CFR Part 193 standards which will become applicable to DOE low-level radioactive waste (LLW) management, the understanding of the levels of conservatism in different source term models and their impacts on the overall performance assessment will become very important. In this work, several currently used source term models are comparatively evaluated based on a test case problem. These models include PRESTO-EPA-CPG, IMPACTS, DUST and NEFTRAN-II. The test case problem is based on a hypothetical waste facility in a humid permeable environment with the inventory distributions in different waste streams estimated using the shipping manifest information from the Barnwell LLW site. The source terms are

analyzed for the maximum annual release of carbon-14 which is one of the key radionuclides in LLW facility performance assessment.

KEY FEATURES OF SOURCE TERM MODELS

Impacts

IMPACTS is a computer methodology developed by U. S. NRC to support the 10 CFR Part 61 compliance activities [U.S. NRC, 1981] and calculates radiological impacts resulting from a LLW disposal site. IMPACTS has been adopted in many LLW disposal facility licensing activities.

The leaching model of IMPACTS [Oztunali, 1986] is very simple and assume that the leaching from waste occurs through a surface wash mechanism which is represented by the so-called, waste form and package factor. This waste form and package factor is the product of several parameters such as annual volume of percolated water, waste leachability/accessibility multiplier, fraction of a specific radionuclide transferred from disposed waste to leachate due to contact of water at saturation, and fractional saturation for unsaturated flow. No attempt is made to describe the post-leaching dilution of radionuclides within the disposal unit. The code has a built-in library for most of the parameters used and the user needs to specify the information on the location of the site, the waste streams, the waste processing scenarios, and disposal technologies.

PRESTO-EPA-CPG

PRESTO-EPA series codes (mainly, PRESTO-EPA-CPG for critical group health effects calculation and PRESTO-EPA-POP population health effects) evolved from Oak Ridge's PRESTO code and have been used for EPA's 40CFR193 rulemaking activities [U. S. EPA, 1988]. The source term models in PRESTO-EPA series codes are essentially the same.

In PRESTO-EPA [Rogers, 1987], the annual precipitation of water into the waste disposal units are internally calculated based on a simplified water flow balance model. Inputs for this calculation include information on soil properties, engineered cap geometry, daily mean temperatures, and hourly precipitation changes during one year. Radionuclide leaching can be modeled for up to 40 radionuclides using one option for the leaching among three available options, i.e., chemical exchange (surface rinse) release, solubility limited release, and constant release fraction approach. Given the heterogeneity (waste types and forms) of LLW in a disposal unit with majority of activities residing in resins, filters, and dry active wastes, it is recommended to use the chemical exchange release option for source term analysis of LLW facilities^a. The source term is calculated as the amount of inventory release divided by the effective volume of water in the disposal unit. The chemical exchange model is empirical in nature where the sorption effect in leaching is described by adjusting the effective volume of water using a constant partition factor (K_d) of waste. The effective volume of water accounts for the post-leaching dilution of leachates within the disposal unit.

Dust

DUST is a code developed specifically for LLW source term analysis by Brookhaven National Laboratory (BNL) supported by U. S. NRC [Sullivan, 1991; Sullivan, 1993]. The methodology is very similar to BNL's earlier BLT approach [Sullivan, 1989].

The code has the capability to describe the details of waste characteristics including the waste types, forms, and containers and different leaching mechanisms associated. Different container lifetimes can be assigned to individual waste containers. The code can handle only one radionuclide for each simulation.

In estimating the release of radioactivity from the waste form, three processes can be simultaneously modeled in DUST: surface rinse with partitioning, diffusion, and dissolution

a. In the test case problem for C-14, 60.5% of the inventory is contained in dewatered resins and filters. Therefore, using the surface rinse option is adequate as the best estimate case for PRESTO-EPA.

release. The solubility limit is always applied to these 3 options. The surface rinse model is based on a mass balance approach using the linear isotherm. The diffusional release model is based on the analytical solution of diffusion equation either for cylindrical or rectangular geometry with the zero concentration boundary condition. The dissolution release assumes time-independent dissolution process with a constant dissolution rate. The code can also describe the influence of localized container failures on release. The relative contributions of each leach mechanisms must be specified for each waste containers modeled. After estimating the leaching, the code calculates the dilution of released radioactivity due to dispersion or mixing by the moving stream of water flowing past containers. This dilution is determined by solving the advection and dispersion transport equation which is coupled to the leach rate calculation. Water infiltration into disposal units needs to be provided as input by the user. The code allows the description of time dependent changes in infiltration.

NEFTRAN-II

NEFTRAN [Olague, 1991] was developed as part of a performance assessment methodology for storage of high-level nuclear waste in unsaturated zone. NEFTRAN source term model has been used for NRC's test case analysis of LLW performance assessment.

The model assumes that the waste are uniformly distributed throughout the pore space within the disposal unit after the container failure. Leaching of radionuclides is described by using either a constant leach rate approach or a solubility limited approach. The leach-rate based option is described by either linear leaching or exponential leaching and can be combined with solubility limit option. The model cannot describe the sorption/partitioning effects. The leaching model is coupled with the near-field flow and transport to describe post-leaching dilution. The code allows the use of distributed velocity inputs, thus the changes in water infiltration with time can be accepted.

SENSITIVITY ANALYSIS OF KEY PARAMETERS

Sensitivity analyses are performed to identify major parameters in each computer models through the calculation of sensitivity coefficients. The sensitivity coefficient, a_i , represents the percentage change in the estimated source term (Ci/yr) that results from a percentage change in an input parameter.

$$a_i = \frac{dS/S}{dX_i/X_i}$$

where S = estimated maximum release rate of C-14 (Ci/yr)
 X_i = i_{th} input parameter

In this study, source term represents the release rate of C-14 from a hypothetical disposal unit. Major input parameters used for the selected test case problem are shown in Table 1. The inventory distribution of C-14 in different waste streams was estimated based on the shipping manifest information at the Barnwell LLW site [Chem Nuclear, 1994]. Since each code has different input requirements, most parameters listed do not appear for all the codes. The analyses were performed based on the best estimate capabilities of each computer code as described in the table.

Tables 2 shows the estimated sensitivity coefficients of major parameters in the source term analysis. As expected, IMPACTS source term model is very sensitive to every parameters used for the calculation of the waste form and package factor. In the case of PRESTO-EPA-CPG, annual precipitation of water into the disposal unit which is internally calculated is the most important parameter. Other parameters of importance are the Kd of waste material, density of waste, and hydraulic conductivity within the disposal unit. Some parameters which are only used in PRESTO-EPA-CPG source term model are also found to be important. These are the fraction of waste impacted by chemical exchange leaching and the release fraction of trash.

In DUST, Darcy velocity is found to be the most important parameter. The K_d of soil, density of waste, and the depth of the disposal unit were also important. The K_d of waste did not show expected sensitivity for the range of parameter variation (5% used) in contrast to other models. However, if the K_d value (5 mg/l used for the test case) was increased to a larger value (K_d of 100), the source term decreased somewhat significantly (about 50%).

In NEFTRAN, sensitivities of parameters critically depend on the option chosen for the leaching. In case of using the leach-rate option, the leach-rate is the only parameter of importance. In case of using the solubility-limited option, average pore velocity is the important parameter along with the solubility limit. The importance of solubility limit is dependent on the value of solubility limit used.

Table 1 Input Parameters for the Test Problem (C-14 Source Term)

facility surface area = $9.29\text{E}4 \text{ m}^2$
 nominal depth of the disposal unit = 10.7 m
 porosity of soil = 0.444
 density of soil = 1.6 g/cm^3
 density of waste = 1.331 g/cm^3
 (These inputs do not apply to IMPACTS)

All the inputs related to water infiltration are based on PRESTO-EPA results.

IMPACTS	PRESTO-EPA	DUST	NEFTRAN
The site located in the Southeast. annual infiltration= 0.03 m/yr (original & updated methodology) 0.1172 m/yr (from PRESTO-EPA) contact time fraction = 1.08E-3 (original) 0.2 (updated methodology) 0.05327 (in the current study) waste partition ratio (Mo) = 5.76E-3 (original & updated methodology) 0.15 (based on Kd of 5 ml/g) waste emplacement efficiency = 0.75 volumetric disposal efficiency = 5.7 m	leaching option = chemical exchange with immersed fraction beginning years of cap failure = 0 year ending years of cap failure = 300 years hydraulic conductivity of soil = 2.2 m/yr Kd of soil & waste = 5 (ml/g) number of years before waste containers begin failing = 0 year year that containers fail completely = 300 yr fraction of waste impacted by chemical exchange leaching = 1 release fractions = 1	leaching option = surface rinse for absorbing waste; diffusion for solidified waste; & dissolution for activated metals Darcy velocity= 5.86E-3 m/yr @ 15yr 1.758E-2 m/yr @ 45 yr 2.93E-2 m/yr @ 75 yr 4.102E-2 m/yr @ 105 yr 5.274E-2 m/yr @ 135 yr 6.446E-2 m/yr @ 165 yr 7.618E-2 m/yr @ 195 yr 8.985E-2 m/yr @ 230 yr 1.035E-1 m/yr @ 265 yr 1.172E-1 m/yr @ 300 yr 1.172E-1 m/yr @ 1000 yr dissolution rate = $1\text{E}-5 \text{ (yr}^{-1}\text{)}$ solubility limit of C-14 = $3\text{E}-11 \text{ (g/cm}^3\text{)}$ container lifetimes of carbon steel drum = 0 yr carbon steel liner = 5 yr HICs = 300 yr	leaching option = leach rate / solubility limit Average pore velocity = Darcy velocities from DUST/porosity leach rate = $1.76\text{E}-4 \text{ (yr}^{-1}\text{)}$ onset time of migration = 0 (yr) onset time of leaching = 0 (yr) solubility limit of C-14 = $3\text{E}-11 \text{ (g/cm}^3\text{)}$

Table 2 Sensitivity Coefficients of Parameters of Different Codes for the Selected Case Problem

	IMPACTS	PRESTO-EPA-CPG	DUST	NEFTRAN (leach rate)	NEFTRAN (solubility)
percolating infiltration	1.0	see precipitation	see darcy velocity	see average pore velocity	see average pore velocity
Kd of waste	-1.0	-0.88	0.0	n/a	n/a
water contact time	1.0	internally calculated	n/a	n/a	n/a
waste accessibility f	1.0	n/a	n/a	n/a	n/a
annual precipitation	see infiltration	2.02	see darcy velocity	see average pore velocity	see average pore velocity
waste emplacement efficiency	-0.95	n/a	n/a	n/a	n/a
volumetric disposal efficiency	-0.95	n/a	n/a	n/a	n/a
Kd of soil	n/a	0.0	-1.05	0.0	0.0
depth of disposal unit	n/a	-0.94	-1.05	0.0	0.0
soil, coeff of permeability	n/a	-0.94	see darcy velocity	see	0.0
density of waste	n/a	-0.88	-1.05	0.0	0.0
fraction under surface rinse	n/a	-0.97	n/a	n/a	n/a
release fraction, trash	n/a	0.29	n/a	n/a	n/a
solubility limit	n/a	option not used	0.0	0.0	0.99
Darcy velocity	see infiltration	see precipitation	1.18	0.0	1.0
Dispersivity of soil	n/a	0.0	0.0	n/a	n/a
average pore velocity	see infiltration	see precipitation	see darcy velocity	0.0	0.0 (1.0 for higher solubility)
leach rate of waste	n/a	not used	n/a	1.23	0.0
Diffusion coefficient	n/a	n/a	0.0	n/a	n/a

COMPARISONS OF SOURCE TERM PREDICTIONS

Using the computer codes selected, source term analyses are performed for the test case problem. Only the maximum release rates are compared in the study. The maximum release rates will eventually produce the peak in the dose assessment which will be paired with the regulatory limit. The comparisons are again based on the best estimate capabilities of each codes to describe the source term for LLW disposal facilities.

Among the parameters of source term, the infiltration of water into the disposal unit is found to be most important and the computer codes selected have different treatment to consider water infiltration. To make consistent comparisons, the estimated water infiltration changes from PRESTO-EPA were used to prepared comparable inputs for other codes. These are describe in Table 1.

Table 3 shows the results of predicted release rates (Ci/yr) of C-14 at the year of maximum release. With IMPACTS, both the original and the updated methodology of 1986 appear to predict very optimistic results (with the original methodology, 4 orders of magnitude lower than the DUST results). However, by using the case specific parameters for the fractional saturation (contact time fraction) and the partition ratio (K_d of waste), the test case problem shows that the IMPACTS results could be comparable to the DUST results.

With the surface rinse option, PRESTO-EPA-CPG predicts smaller source term (by a factor of 2 or 3) than that of DUST. When the leach rate estimated from DUST results is used with the release fraction option, PRESTO-EPA-CPG results are comparable to DUST results.

DUST appears to predict higher release rates for the best estimate test case problem among the codes used. This best estimate results did not change much even if the relative contributions of each leaching processes in each types of waste were assigned somewhat differently. One thing that makes direct comparison of DUST result with PRESTO-EPA source term is the difference in describing the container failures. In DUST, container lifetime

assigned was 0 year for carbon steel drums, 5 years for carbon steel liners, and 300 years for high integrity containers. Since this was not possible with PRESTO-EPA, it was assumed that the containers start failing at time 0 and completely fail after 300 years. This difference appears to make impacts on the estimated peak release. To make a more direct comparison of leaching model of DUST and PRESTO-EPA, a separate case with a single container lifetime of 100 years is analyzed. The results are shown in Table 4. DUST is shown to be much more conservative than PRESTO-EPA by a factor of 30 to 70 in this direct comparison.

For the leach-rate option calculation with NEFTRAN-II, the leach-rate used was estimated from the DUST results. This resulted in almost the same maximum release prediction from NEFTRAN-II as from DUST. The solubility limit option of NEFTRAN predicted very small releases.

Table 3 Comparisons of predicted maximum release rate of C-14 (Ci/yr) using different source term models			
IMPACTS	PRESTO-EPA-CPG	DUST	NEFTRAN-II
3.05x10 ⁻⁵ (original Methodology)	6.97x10 ⁻² (Best estimate; surface rinse with release fractions of 1 for all wastes)	1.52x10 ⁻¹ (Best estimate; surface rinse for DAW, resins; diffusion for solidified waste; dissolution for metals)	1.50x10 ⁻¹ (leach-rate limited, leach rate estimated from DUST results)
5.65x10 ⁻³ (updated '86 Methodology)	4.41x10 ⁻² (surface rinse with default release fractions for non- absorbing wastes)	1.53x10 ⁻¹ (surface rinse for all wastes)	5.74x10 ⁻⁶ (leach-rate & solubility limited, both linear leach & exponential leach)
1.53x10 ⁻¹ (Best estimate; fractional saturation & partition ratio adjusted for the given problem)	1.41x10 ⁻¹ (release factor option)	1.14x10 ⁻³ (dissolution for all wastes)	5.74x10 ⁻⁶ (solubility limited)

Table 4 Direct Comparison of DUST and PRESTO-EPA-CPG for the Maximum C-14 release rate (Ci/yr) (using a single container lifetime of 100 years for all the waste; all other inputs remain the same as in Table 1)		
PRESTO-EPA-CPG with surface rinse option	DUST with surface rinse option	DUST with the best estimate option (surface rinse for absorbing waste; diffusion for solidified waste; dissolution for metals)
6.71×10^{-2} (peak at 300 years)	4.76 (peak at 133 years)	2.01 (peak at 300 years)

DISCUSSIONS

IMPACTS source term results are very sensitive to all the parameters used for the calculation of waste form/package factor. However, this results can not directly compared with the results of other computer models due to the differences in the input and the model structures.

In using PRESTO-EPA-CPG for source term modeling, predicting the accurate annual precipitation of water into the disposal unit is found to be very important. The source term predictions made by PRESTO-EPA-CPG needs to be interpreted based on the accuracy of its infiltration modeling.

For the use of DUST, inputting right values of Darcy velocity during the history of a site is very important. However, the code is somewhat limited since it can only consider 10 different Darcy velocities with step changes to describe the expected continuous variations. Among the models reviewed, DUST is the only model with mechanistic descriptions of the leaching processes of diffusion and dissolution. This becomes important if the majority of radionuclide inventory is contained in cemented waste or activated metals.

NEFTRAN source term model is very sensitive to changes in two parameters; leach rate for the leach-rate option and solubility limit for the solubility limit option. For several important radionuclides in LLW performance assessment such as carbon-14, iodine-129, technetium-99, and chlorine-36, solubility limit can hardly be determined. Thus solubility limit option of NEFTRAN is not recommended for the source term analysis of these radionuclides. For the use of leach-rate option, NEFTRAN requires good prior estimation of leach rate. This practically means a more detailed source term model, such as DUST, needs to be run before NEFTRAN is used.

All of the source term reviewed adopts the use of linear isotherm approach using a single partition factor (K_d). However, this linear isotherm approach cannot describe the inherent nonlinear characteristics of sorption, especially at higher concentrations and cannot describe the possible changes in background water chemistry. These issues need to be investigated for the performance assessment of waste facilities for a very long time period.

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**THE ROLE OF A DETAILED AQUEOUS PHASE SOURCE RELEASE MODEL
IN THE LANL AREA G PERFORMANCE ASSESSMENT**

Erik L. Vold, R. Shuman, Diana K. Hollis,
Patrick Longmire, E. Springer, K. Birdsell
Los Alamos National Laboratory
(505) 665-8205

ABSTRACT

A preliminary draft of the Performance Assessment for the Los Alamos National Laboratory (LANL) low-level radioactive waste disposal facility at Area G is currently being completed as required by Department of Energy orders. A detailed review of the inventory data base records and the existing models for source release led to the development of a new modeling capability to describe the liquid phase transport from the waste package volumes. Nuclide quantities are sorted down to four waste package release categories for modeling: rapid release, soil, concrete/sludge, and corrosion. Geochemistry for the waste packages was evaluated in terms of the equilibrium coefficients, K_{ds} , and elemental solubility limits, C_{sl} , interpolated from the literature. Percolation calculations for the base case closure cover show a highly skewed distribution with an average of 4 mm/yr percolation from the disposal unit bottom. The waste release model is based on a compartment representation of the package efflux, and depends on package size, percolation rate or Darcy flux, retardation coefficient, and moisture content.

GEOCHEMICAL EFFECTS ON THE BEHAVIOR OF LLW RADIONUCLIDES IN SOIL/GROUNDWATER ENVIRONMENTS

Kenneth M. Krupka and R. Jeffrey Serne
Pacific Northwest National Laboratory
P.O. Box 999, Mail Stop K6-81
Richland, Washington 99352
(509) 376-4412 km_krupka@pnl.gov

ABSTRACT

Assessing the migration potential of radionuclides leached from low-level radioactive waste (LLW) and decommissioning sites necessitates information on the effects of sorption and precipitation on the concentrations of dissolved radionuclides. Such an assessment requires that the geochemical processes of aqueous speciation, complexation, oxidation/reduction, and ion exchange be taken into account. The Pacific Northwest National Laboratory (PNNL) is providing technical support to the U.S. Nuclear Regulatory Commission (NRC) for defining the solubility and sorption behavior of radionuclides in soil/ground-water environments associated with engineered cementitious LLW disposal systems and decommissioning sites. Geochemical modeling is being used to predict solubility limits for radionuclides under geochemical conditions associated with these environments. The solubility limits are being used as maximum concentration limits in performance assessment calculations describing the release of contaminants from waste sources. Available data were compiled regarding the sorption potential of radionuclides onto "fresh" cement/concrete where the expected pH of the cement pore waters will equal to or exceed 10. Based on information gleaned from the literature, a list of preferred minimum distribution coefficients (K_d 's) was developed for these radionuclides. The K_d values are specific to the chemical environments associated with the evolution of the compositions of cement/concrete pore waters.

BACKGROUND

The U.S. Nuclear Regulatory Commission (NRC) is currently completing a test case modeling exercise to assist with the development and evaluation of guidance for performance assessment of LLW disposal systems. A summary of this modeling exercise was presented at this conference in 1994¹ and elsewhere.^{2,3} The test case involves a hypothetical, below-ground, concrete vault LLW disposal system located on a sub-humid coastal plain. The source term model¹ used for the test case considers the percolation of water into the concrete vaults and the release of radionuclides from the LLW waste by either rinse, diffusion, or

dissolution mechanisms. The LLW waste form and inventory data were based on those from the "Richland '89" data.⁴

Because large amounts of cementitious material are present as various components of the disposal vault system, interactions between the infiltrating water and the concrete are expected to have a strong buffering effect on the chemical environment in and near the disposal vault system. An objective of our PNNL study was to assess suitable ranges of radionuclide solubility limits and distribution coefficients needed for calculating radionuclide release from the concrete-buffered chemical environment associated with disposal vaults considered in NRC LLW test case analysis. The radionuclides considered in our study included americium, inorganic carbon, chlorine, iodine, lanthanide elements, niobium, nickel, neptunium, plutonium, radium, strontium, technetium, thorium, and uranium. The scope of this paper is limited to our results for the solubility and adsorption of uranium. All of the results from our literature reviews and solubility calculations are described in detail elsewhere.⁵

CHEMICAL ENVIRONMENT OF CEMENT/WATER INTERACTIONS

Cementitious materials have several important uses in LLW disposal facilities, including waste forms, backfill, and construction materials. Therefore, the long-term behavior of hydrated cements and their constituent phases in natural ground waters is important to understanding the potential release of radionuclides from LLW disposal systems. The composition of hydrated cement generally consists of 40-50 wt% calcium silicate hydrogel (C-H-S);^a 20-25 wt% portlandite [$\text{Ca}(\text{OH})_2$]; 10-20 wt% ettringite [$\text{Ca}_6\text{Al}_2\text{O}_6(\text{SO}_4)_3$], monosulfate [$\text{Ca}_4\text{Al}_2\text{O}_6\text{SO}_4$], and ferric phases; 10-20 wt% pore solution; 0-5 wt% minor components, such as NaOH, KOH, and $\text{Mg}(\text{OH})_2$.⁶ The chemical reactions associated with the hydration of cement are described in detail by others.^{7,8,9}

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- a. Researchers in cement science use a convention to abbreviate names of cement phases. This terminology uses abbreviations for components in the cement phases, such as C $\equiv$ CaO, S $\equiv$ SiO₂, A $\equiv$ Al₂O₃, F $\equiv$ Fe₂O₃, and H $\equiv$ H₂O. The formula of a cement phase is expressed as the appropriate stoichiometric combination of these initials, such as C₃AH₆ for Ca₃Al₂(OH)₁₂ [hydrogarnet].

The composition of pore water that evolves during the degradation of cement in water has been studied extensively in the laboratory (see review in Krupka and Serne⁵). The dissolution of the C-H-S and portlandite phases, which may constitute as much as 75 wt% of the cement, have an important role in buffering the pH of the pore fluids. As ground water reacts with the cement, dissolution of the alkali hydroxide phases, present in relatively minor amounts, results initially in high pH values of approximately 13.5. As these phases are consumed in the cement, the pore fluid pH is then buffered near 12.5 by the dissolution of free portlandite in the cement. Eventually the portlandite is depleted and the pore fluid pH decreases to approximately 10.5 where it is controlled by the incongruent dissolution of the C-S-H hydrogel. When the dissolution of C-S-H is complete, the pH of the cement pore fluid will continue to decrease to a value buffered by the host ground water. This pH change will also be affected to a limited extent by the dissolution of any calcite that precipitated at the high pH conditions during the early stages of cement dissolution. The rate at which the pH of the pore solution changes from 13.5 to that of the ground water will depend on the physical properties (e.g., fractures, porosity, etc.) of the cementitious materials, rate of infiltration, chemistry of the infiltrating solution, and related hydrologic properties of the disposal system. For radioactive waste disposal systems being considered in the United Kingdom, studies¹⁰ indicate that the pH of the near-field pore water would remain above 10.5 for several hundred thousand years.

SOLUBILITY LIMITS

Conservative concentration limits based on equilibrium solubility constraints were calculated for several radionuclides for pore-water conditions considered in the NRC LLW performance assessment test case.⁵ The calculations are designed to address geochemical considerations that determine radionuclide solubility limits for the high pH conditions associated with cementitious systems.

Conceptual Model

The initial conditions for the geochemical evolution of the source term assumes that the composition of the leachate migrating from the disposal vault is controlled by the dissolution of the cement hydrate phases (i.e., "cement buffered" case) and characterized by pH values from 12.5 to 10.5. These conditions correspond to the initial stages of water infiltration into the LLW disposal system. In the final stages of the source-term evolution, the leachate composition is assumed to be controlled by reactions with soils and therefore equivalent to the local ground-water composition (i.e., "ground-water buffered" case). This case would correspond to an advanced state of degradation of the LLW disposal system when the availability of reactive concrete phases is insufficient to affect pore fluid compositions. The ground water infiltrating the disposal vaults has the following average composition in the test case: pH 5.8, Eh 500 mV, alkalinity (as CaCO_3) 14.1 ppm, Ba 0.2 ppm, Ca 4.0 ppm, Cl 3.0 ppm, F 0.07 ppm, Fe 0.118 ppm, K 1.3 ppm, Mg 0.4 ppm, Mn 0.052 ppm, $(\text{NO}_3 + \text{NO}_2)$ 0.6 ppm, Na 3.2 ppm, PO_4 0.1 ppm, SO_4 2.6 ppm, silica (as SiO_2) 5.8 ppm, and Sr 0.1 ppm.

The radionuclide concentration limits were calculated at fixed pH values at 0.5 pH-unit increments over the range of pH and redox (Eh) conditions defined by the cement buffered (pH = 12.5 and Eh = +200 mV) and ground-water buffered (pH = 5.8 and Eh = +500 mV) conditions. The Eh values used for the solubility calculations were assumed to vary linearly as a function of pH according to the equation:

$$\text{Eh (mV)} = -44.78 \text{ pH} + 760.$$

As a conservative limit, dissolved carbonate concentrations in the leachate were calculated between pH values of 5.8 and 8.0 by assuming equilibrium with 0.003 atm CO_2 (gas).¹¹ For pH values greater than 8.0, dissolved carbonate concentrations were calculated by assuming equilibrium with the solubility of calcite (CaCO_3). Calcite is known to precipitate as a result of reactions occurring with the dissolution of cement.^{12,13,14,15} The concentrations of dissolved calcium were also fixed in the pH range from 8.5 to 12.0 by assuming the leachate is equilibrium with the solubility of calcite. At pH 12.5, the leachate

was assumed to be in equilibrium with the solubilities of both calcite and portlandite $[\text{Ca}(\text{OH})_2]$. The solubility of portlandite is known to control the pH of hydrating cement at 12.5. To simplify the model calculations, the concentrations of the other dissolved, non-radionuclide constituents in the leachate were fixed at the concentrations specified for the ground-water composition listed. This assumes that the ground water is the major source for dissolved fluoride, chloride, nitrate/nitrite, sulfate, and phosphate. It should be noted that cement contains measurable quantities of sulfate and minor amounts of chloride phases that could increase the concentrations of these species in the pore fluids. Because the cement pore fluids at the outer edge of a vault will be diluted by infiltrating ground water, it was assumed that the leachates leaving the facility would have a moderate to low ionic strength.

MINTEQA2 Geochemical Model

The radionuclide solubilities and associated aqueous speciation equilibria were calculated using the chemical equilibria code MINTEQA2 (Version 3.11) obtained from the Center for Exposure Assessment Modeling at the U.S. Environmental Protection Agency (EPA) in Athens, Georgia. The MINTEQA2 code and its predecessor versions have been described by others.^{16,17,18,19} The MINTEQ calculations include aqueous speciation, solubility and saturation state (i.e., saturation index), adsorption, oxidation-reduction, gas phase equilibria, and precipitation/dissolution of solid phases. The thermodynamic database used to calculate radionuclide solubilities includes the EPA MINTEQA2 database augmented for aqueous species and solids containing the radionuclide elements of interest using database supplements provided by D. Turner [Center for Nuclear Waste Regulatory Analyses (CNWRA), Southwest Research Institute, San Antonio, Texas] and revisions added during the course of our study.

Solubility Limits for Dissolved Uranium

The concentration limits for the dissolved radionuclides were calculated using appropriate solubility-controlling solid(s) selected from those in the MINTEQ thermodynamic database. The solids were chosen based on phase-stability information given in published

studies and knowledge of the geochemistry of radionuclide aqueous systems. Two solubility controls, schoepite $[\text{UO}_2(\text{OH})_2 \cdot \text{H}_2\text{O}]$ and uranophane $[\text{Ca}(\text{H}_3\text{O})_2(\text{UO}_2)_2(\text{SiO}_4)_2 \cdot 3\text{H}_2\text{O}]$, were considered in calculating concentration limits of dissolved uranium. Concentration limits based on schoepite are highly conservative. Schoepite is known to precipitate readily in low-temperature aqueous systems at laboratory time scales and result in high concentrations of dissolved uranium.²⁰ In natural low-temperature aqueous systems, the presence of alkali and/or alkaline earth ions at high pH conditions results in the precipitation of alkali/alkaline earth uranyl compounds that control the solubility of uranium at concentrations lower than those resulting from equilibrium with schoepite.

Uranophane is known to exist in uranium-loaded C-S-H gel mixtures and thus may be realistic solubility control for dissolved uranium. Calculation of its solubility, however, may be more susceptible to uncertainties in conceptual models and available thermodynamic data. Atkins et al.^{21, 22} have investigated uranium interactions with $\text{Ca}(\text{OH})_2$ and C-S-H using a range of uranium loadings and equilibration periods of 21 to 75 days. Solid phases in the resulting mixtures were characterized by X-ray diffraction and analytical electron microscopy. Three uranium-containing phases were identified in these mixtures. These phases, which included uranophane, a hydrated calcium uranyl oxide $[\text{Ca}_2\text{UO}_5 \cdot (1.2-1.5)\text{H}_2\text{O}]$, and becquerelite $[\text{CaU}_6\text{O}_{19} \cdot \text{H}_2\text{O}]$, could be possible solubility controls for uranium in cement-buffered systems. A source of thermodynamic data for the hydrated calcium uranyl oxide phase and becquerelite was not identified.

The concentrations calculated for dissolved uranium are listed in Table 1. The model results indicate that dissolved uranium would exist primarily in the +6 valence state, and uranyl carbonate and hydroxyl species would dominate the speciation of dissolved uranium at these pH/Eh conditions. At $\text{pH} > 10$, the hydrolysis species dominate the aqueous speciation of dissolved uranium. In addition to pH and Eh, the calculated solubilities of dissolved uranium are sensitive to the concentrations of dissolved carbonate as a result of strong complexation. Moreover, the concentrations of dissolved calcium and silica are additional factors affecting the uranium concentrations based on equilibrium with uranophane.

Table 1. Calculated Solubilities of Dissolved Uranium.

pH	Eh (mV)	Schoepite as Solubility Control	Uranophane as Solubility Control
		-----mol/l-----	
5.8	500	1.5×10^{-5}	3.9×10^{-6}
6.5	470	3.9×10^{-5}	7.7×10^{-7}
7.0	450	1.1×10^{-4}	3.2×10^{-7}
7.5	420	3.9×10^{-4}	4.8×10^{-7}
8.0	400	1.1×10^{-3}	4.4×10^{-6}
8.5	380	2.9×10^{-4}	4.2×10^{-8}
9.0	360	2.6×10^{-4}	3.4×10^{-8}
9.5	340	2.6×10^{-4}	3.9×10^{-8}
10.0	310	2.8×10^{-4}	4.5×10^{-8}
10.5	290	3.8×10^{-4}	4.4×10^{-8}
11.0	270	7.8×10^{-4}	7.9×10^{-8}
11.5	250	2.3×10^{-3}	2.8×10^{-7}
12.0	220	7.5×10^{-3}	1.4×10^{-6}
12.5	200	3.0×10^{-2}	4.0×10^{-7}

Results of our solubility calculations bracket the experimental data reported in the literature. Ewart et al.²³ experimentally determined the concentrations of dissolved uranium resulting from the equilibration of cement-equilibrated waters that were oversaturated with dissolved uranium. The experiments involved the addition of sufficient U(VI) chloride solutions to cement equilibrated waters to obtain an initial concentration of 5×10^{-5} M dissolved uranium. The pH of the resulting mixtures was adjusted with sodium hydroxide or hydrochloric acid. Concentrations of dissolved uranium predicted using the solubility of schoepite are several orders of magnitude greater than their experimental values. The solubility of uranophane, on the other hand, is in good agreement with the experimental values for pH values greater than 10.5, and significantly underestimates the concentrations at lower pH values. Ewart et al.²³ also modeled possible solubility controls for their experimental results, and noted that the solubility of schoepite overestimated uranium concentrations relative to their observed values.

RADIONUCLIDE SORPTION OF RADIONUCLIDES ON CEMENT/CONCRETE

The proper selection and use of distribution coefficients (K_d 's) that are most germane to the physicochemical system (e.g., cement-containing disposal vault) being modeled is an important concern to the technical defensibility of performance assessment calculations. The most common approach to quantifying adsorption is the use of K_d which is also often referred to as the distribution ratio, R_d . This constant is defined as the concentration of contaminant adsorbed on the solid per mass divided by the concentration of contaminant in solution per volume. The derivation and assumptions underlying the use of K_d in classical ion exchange literature have been discussed in detail by others.^{24,25}

Literature Review

We conducted a literature review of studies pertaining to radionuclide adsorption on cement and concrete materials. Our review of sorption information focused on the geochemical conditions associated with "fresh" cement/concrete where the cement pore waters will have $\text{pH} \geq 10$. Many factors⁵ lead to significant variability in reported K_d 's for the adsorption of radionuclides onto cement and concrete. Thus the proper selection of a K_d for a specific application will require judicious selections from the available literature. The adsorption measurements described in the literature are consistent on the qualitative adsorption (retardation) behavior of the radionuclides included in our review. That is, all sorption studies basically agree on which radionuclides are strongly retarded by cement paste (e.g., actinides, lanthanides, transition metals, inorganic carbon); moderately retarded by cement paste (e.g., radium, strontium, technetium); and not significantly retarded by cement paste (e.g., chlorine, cesium, iodine).

Tabulation of K_d 's for cementitious materials typically show considerable scatter (e.g., a factor of two difference in some studies) which could be misconstrued as inconsistency in sorption behavior. Because cement is usually studied in its freshly cured state, unusually large variations in reported K_d 's should be expected. At this point of the cement evolution, hydration reactions are continuing and alkali and OH^- ions are still

leaching in significant quantities into the pore waters. Moreover, the resulting cement hydration minerals are not thermodynamically stable relative the geochemistry of most surface and ground waters.

From the perspective of hydrologic transport or performance assessment calculations, one must consider the fact that cement and concrete are a very impermeable yet very porous media. The major transport pathway through cement or concrete may in fact be through fractures or other defects that are more amenable to advective flow of water and more reactive to chemical weathering. The weathering products along these flow paths will exhibit different adsorption tendencies compared to the bulk cement hydration gel minerals. Several investigators^{26,27,28} have discussed the potentially beneficial phenomenon of carbonate plugging or armoring. Carbonate precipitation might close up fractures that form in monolithic cement and concrete structures and thereby further retard the already slow diffusion of most radionuclides through the hardened cement paste.

Categorization of K_d Values for Radionuclide Adsorption on Cement

The convention of Bradbury and Sarott²⁶ for the three physicochemical environments that all cements progress through was used to categorize K_d 's for radionuclide adsorption onto cement/concrete. These include the following: 1) *Environment I*, which occurs immediately after the cement hardens and is wetted by infiltrating water and where cement pore water is characterized as having a high pH of > 12.5 , high ionic strength, and high concentrations of K and Na; 2) *Environment II*, where the soluble alkali salts are all dissolved and the cement pore water pH is controlled at 12.5 by the solubility of $\text{Ca}(\text{OH})_2$; and 3) *Environment III*, where the solubility C-S-H gel now controls the pH of the cement pore fluid, the ionic strength of the cement pore fluid is low, and its pH is ~ 10 or less. Each environment was split into an oxidizing and a reducing subenvironments, because some radionuclide elements may be present in chemically different forms depending on their redox-influenced valence state. We use the terms "oxidizing" and "reducing" to refer to the valence states of the specific radionuclide contaminant of interest.

The K_d 's of most radionuclides present in an Environment III cementitious system were assigned values of one-tenth of those K_d 's selected for radionuclides associated with Environment II following the convention of Bradbury and Sarott.²⁶ This assumption is necessary because laboratory data are not available for the sorption of radionuclides on severely weathered cements. Bradbury and Sarott reason that most of the very high surface area C-S-H gel has been removed in severely weathered cement. The remaining solid phase, silica, has significantly less surface area and adsorption capacity for trace contaminants compared to the C-S-H gel.

Adsorption of Uranium on Cementitious Materials

The Swedish studies^{29,30} present the most data for the adsorption of uranium onto cements or concretes. Uranium was added as the oxidized form U(VI) to the simulated cement pore waters. For the seven types of concretes and the weathered concretes, the K_d 's for uranium ranged from 350 to 13,000 ml/g. The average K_d was ~ 1000 , and the median value was 1400 ml/g. Although the behavior of uranium in aqueous systems is known to be sensitive to redox conditions, there was no significant increase in the uranium K_d measured in the experiments that used concrete containing blast furnace slag, an expected reductant.

Numerous investigators^{8,31,32} have studied the incorporation of U(VI) into cementitious waste forms. Under these conditions, the release of uranium is reduced significantly over the release of many other potentially soluble contaminants. Plausible solubility- and adsorption incorporation processes for U(VI) into the C-S-H gel are described by these investigators.

Based on the results of our review, it should be adequate to consider the adsorption of uranium, in either of its +6 or +4 valence states, as being readily retarded within the pore waters of cements and concretes where high pH conditions and relatively high concentrations of dissolved calcium exist. For this reason, the K_d 's selected for uranium on concrete and cement in Environments I and II are 1000 and 2000 ml/g for oxidizing and reducing conditions, respectively. For Environment III, assuming the one-tenth default convention,

uranium K_d values of 100 and 200 ml/g are selected for oxidizing and reducing conditions, respectively.

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RECENT IMPROVEMENTS TO THE SOURCE1 AND SOURCE2 COMPUTER CODES

Alan S. Icenhour and M. Lynn Tharp
Oak Ridge National Laboratory
105 Mitchell Road
Post Office Box 2008
Oak Ridge, Tennessee 37831-6495
(423) 576-5315

ABSTRACT

Performance assessments of low-level radioactive waste (LLW) disposal facilities often involve the use of computer codes to describe radionuclide releases from a waste form and the subsequent transport of radionuclides through the environment. The SOURCE1 and SOURCE2 computer codes are used to calculate radionuclide release rates (i.e., source terms) for LLW disposal facilities. These codes have been used to evaluate the source terms for Oak Ridge National Laboratory performance assessments. SOURCE1 is applicable to tumulus-type facilities, while SOURCE2 can be applied to silo, well-in-silo, well, and trench-type facilities. In addition to the calculation of radionuclide release rates, both SOURCE1 and SOURCE2 calculate the degradation of engineered barriers. This paper provides an overview of these codes and a description of recent improvements to the codes. Major improvements include incorporation of a new advective transport model into SOURCE1 and SOURCE2, development of a new model for SOURCE1 that calculates the degradation and failure of the tumulus pad and leachate collection system, improvement of routines for controlling water infiltration inputs, expansion of options for obtaining output summaries, and restructuring of SOURCE1 and SOURCE2 for sensitivity and uncertainty analyses. The status of code verification efforts is also presented.

INTRODUCTION

Performance assessments of low-level radioactive waste (LLW) disposal facilities often involve the use of computer codes to describe radionuclide releases from a waste form and the subsequent transport of radionuclides through the environment. The SOURCE1 and SOURCE2 computer codes calculate radionuclide release rates (i.e., source terms) for LLW disposal facilities.¹ These codes have been used to evaluate the source terms for Oak Ridge National Laboratory (ORNL) performance assessments. SOURCE1 is applicable to tumulus-type facilities, while SOURCE2 can be applied to silo, well-in-silo, well, and trench-type

facilities. In addition to the calculation of radionuclide release rates, both SOURCE1 and SOURCE2 calculate the degradation of engineered barriers. This paper provides an overview of these codes and a description of recent improvements to the codes. Major improvements include incorporation of a new advective transport model into SOURCE1 and SOURCE2, development of a new model for SOURCE1 that calculates the degradation and failure of a tumulus-type concrete pad and leachate collection system, improvement of routines for controlling water infiltration inputs, and expansion of options for obtaining output summaries. In addition, summarized results from sensitivity analyses as well as the status of code verification efforts are presented.

OVERVIEW OF SOURCE1 AND SOURCE2 COMPUTER CODES

The SOURCE1 and SOURCE2 computer codes, collectively called the SOURCE computer codes, are used to estimate the source term (i.e., radionuclide release rate) for various types of waste disposal facilities. SOURCE1 simulates radionuclide releases from tumulus-type disposal facilities. SOURCE2 simulates radionuclide releases from silo, well, well-in-silo, and trench-type disposal facilities. Both codes simulate the degradation of engineered barriers (e.g., concrete and metal containers) as a function of time. The estimated degradation is incorporated into the calculation of the radionuclide release rate.

Radionuclide release rates from waste disposal facilities are a function of the integrity of the waste (or waste form) and the engineered barriers used in construction of the facility. When intact, these barriers minimize the contact of water with the waste, thereby minimizing releases of radionuclides. As the barriers deteriorate, over time, water can more readily contact the waste and mobilize radionuclides, thereby accelerating releases to the environment. The SOURCE codes simulate the long-term performance of engineered barriers currently in place at waste disposal facilities. Changes in the material properties of the barriers caused by chemical attack and physical stress are modeled. Specifically, concrete barriers are simulated to degrade as a result of sulfate attack, calcium hydroxide leaching, and corrosion of steel reinforcement. Linear corrosion models are used to simulate the degradation of metal barriers. Projected material properties are considered in structural

and cracking analysis of a disposal facility. These analyses are performed to assess the ability of a disposal facility to bear the loads placed upon it. As the ability to bear design loads is compromised and structures crack or fail, rates of infiltration of water through the waste are increased.

The SOURCE computer codes consider two mechanisms through which waste radionuclides are released into the environment: advection (bulk flow driven by hydraulic pressure differences) and diffusion (nuclide movement driven by concentration differences). The calculated total release rate resulting from advection and diffusion is compared with the rate of release dictated by the solubility limit of the nuclide in water. If the solubility limit is exceeded, the release rate is adjusted to the solubility-limited rate. As a disposal facility degrades, the percolation rate of water through the waste increases. Thus, except for cases constrained by solubility, advective releases will increase with degradation and, in general, dominate the total release.

The output of the SOURCE codes includes summaries, as a function of time, of the (a) results from the barrier degradation and failure analyses and (b) calculated contaminant release rates. The generation of a source term with these codes requires more than 100 input parameters to describe the physical and chemical characteristics of the disposal facility and waste type under consideration.

A detailed discussion of the SOURCE computer codes (including a description of the types of facilities modeled, engineered barrier degradation, radionuclide transport models, and input data requirements) can be found in refs. 1 and 2.

NEW ADVECTIVE TRANSPORT MODEL

A new advective transport model was incorporated into the SOURCE codes to better simulate the time dependence of the radionuclide inventory in the disposal facility. This analytical model was developed based on work presented in ref. 3. A detailed derivation of the model can be found in ref. 2.

The total radionuclide release during a time step is calculated by the following formula:

$$L = \frac{\lambda_L}{\lambda_L + \lambda_d} Q_0 [e^{-(\lambda_L + \lambda_d)t_1} - e^{-(\lambda_L + \lambda_d)t_2}] \quad , \quad (1)$$

where

- L = mass of radionuclide leached because of advection (g),
- λ_L = leach rate constant (s^{-1}),
- λ_d = radioactive decay constant (s^{-1}),
- Q_0 = initial mass of radionuclide in the waste (g), and
- t_1, t_2 = the bounds of the time period of interest (s).

The leach rate constant, λ_L , is given by

$$\lambda_L = \frac{q}{W\theta R_d} \quad , \quad (2)$$

where

- q = water infiltration rate (cm/s),
- W = waste thickness (cm),
- θ = relative saturation (i.e., volume of water in waste/volume of waste) (dimensionless),
- R_d = retardation factor (dimensionless).

Finally, the retardation factor, R_d , can be calculated by the following equation:

$$R_d = 1 + \frac{\rho_b}{\theta} K_d \quad , \quad (3)$$

where

- ρ_b = bulk density of waste (g/cm^3) and
- K_d = distribution coefficient (mL/g).

In ref. 2, comparisons were made between the new advective transport model and the original model in the SOURCE codes. To perform these comparisons, a number of simulations were conducted using the SOURCE1 and SOURCE2 codes. These simulations allowed for examination of various radionuclides, half-lives, distribution coefficients, radionuclide inventories, and types of disposal. In general, the two advective models produced similar results with the original model predicting a slightly higher cumulative radionuclide release than the new model. A detailed description of the advective model comparisons can be found in ref. 2.

DEGRADATION MODELS FOR CONCRETE PAD AND LEACHATE COLLECTION SYSTEM

The tumulus-type disposal facility in use at ORNL has both a steel-reinforced pad on which disposal vaults are placed and a leachate collection system. The leachate collection system collects water that infiltrates through the waste and reaches the concrete pad. Hence, as long as the pad and collection system are intact and perform correctly, any radionuclide releases from the waste should be captured and not released to the environment. Routines that simulate the degradation and failure of the concrete pad and the leachate collection system have been developed and incorporated into the SOURCE1 code.

Concrete Pad Degradation Model

The SOURCE1 code predicts the performance of concrete vaults in a tumulus-type disposal facility. However, the original version of SOURCE1 did not account for the presence of a reinforced concrete pad under the vaults. This pad, while intact, should divert water to the leachate collection system. To incorporate the performance of the concrete pad into SOURCE1, a compressive failure model was assumed. Failure was estimated by calculating the reinforcement ratio.⁴ The reinforcement ratio is defined by

$$\rho = \left(\frac{A}{b} \right) \frac{1}{d} \quad , \quad (4)$$

where

ρ = reinforcement ratio (dimensionless),

- $\frac{A}{b}$ = cross-sectional area of steel reinforcement per unit width of slab (m),
and
d = effective depth of steel (distance from the top of the slab to the center of the steel reinforcement) (m).

The reinforcement ratio at which compressive failure may occur is called the *limiting reinforcement ratio* and is given by⁴

$$\rho_{lim} = \frac{\epsilon'_c}{\epsilon'_c + \epsilon_y} 0.85\beta_1 \frac{f'_c}{f_y} \quad , \quad (5)$$

where

- ρ_{lim} = limiting reinforcement ratio (dimensionless),
 ϵ'_c = ultimate concrete strain (for this application, taken as 0.003) (dimensionless),
 ϵ_y = yield strain of steel (dimensionless),
 β_1 = a factor used in the equivalent rectangular stress diagram for concrete at the ultimate load (dimensionless),
 f'_c = specified compressive strength of concrete (MPa), and
 f_y = specified yield strength of steel reinforcement (MPa).

The yield strain of the steel reinforcement can be calculated by

$$\epsilon_y = \frac{f_y}{E_s} \quad , \quad (6)$$

where

- E_s = modulus of elasticity of steel (for this application, taken as 200,000 MPa) (MPa).

The value of β_1 is determined as follows:⁴

$$\beta_1 = 0.85 \text{ for } f'_c \leq 30 \text{ MPa or}$$

$$\beta_1 = 0.85 - 0.08 \left(\frac{f'_c - 30}{10} \right) \text{ for } f'_c > 30 \text{ MPa} .$$

The values of the reinforcement ratio and the limiting reinforcement ratio are evaluated at annual time steps in SOURCE1. These two values are compared, and when the reinforcement ratio exceeds the limiting value, the pad is said to have failed hydraulically. Failure of the pad will allow leachate to pass through it. Values of both ρ and ρ_{lim} will change because of the degradation of the concrete. The concrete is simulated to degrade by using the sulfate attack and calcium hydroxide leaching subroutines in SOURCE1. Corrosion of reinforcing steel was not considered because the rates of sulfate attack and calcium hydroxide leaching was judged to greatly exceed the rate of degradation resulting from corrosion. Sulfate attack results in the spalling off of the concrete cover on the reinforcing steel. Hence, as the effective depth of the steel decreases, the reinforcement ratio increases. Leaching of calcium hydroxide from the concrete pad results in reduced concrete strength. Therefore, as the compressive strength of the concrete decreases, the limiting reinforcement ratio decreases. Both of the concrete degradation mechanisms result in a decrease of the margin between the reinforcement ratio and the limiting reinforcement ratio, ultimately resulting in pad failure.

Leachate Collection System Degradation Model

Water that reaches an intact concrete pad of a tumulus-type facility will be diverted to a leachate collection system. This system consists of piping, valves, collection sumps, and monitoring equipment. Ideally, with a properly functioning system, all leachate will be collected, and no release of radionuclides to the environment will occur.

As with the concrete pad, the original version of the SOURCE1 code did not simulate the performance and degradation of the leachate collection system. A model has subsequently been developed that describes the functionality fraction of the collection system

as a function of time. The functionality fraction is defined as the ratio of the amount of radionuclide in the collected leachate to the total radionuclide release from the disposal vaults and can vary from 0 to 1. With a value of 1, the leachate collection system is fully functional, and no radionuclides are released to the environment. A zero value indicates a fully degraded system which allows all leached radionuclides to be released to the environment.

The initial functionality fraction and the length of the institutional control period are input parameters to the SOURCE1 code. The functionality fraction degrades linearly to zero from the beginning of the simulation until the end of the institutional control period. The degradation of the collection system is assumed to result from piping and valve leaks or failures, flow obstructions within the system, leakage or overflow of collection sumps, degraded monitoring equipment, etc. At the end of the institutional control period, no maintenance of the collection system is assumed to occur. Hence, no credit is taken for the collection system after the end of institutional control. Additionally, if the concrete pad is predicted to fail hydraulically before the end of institutional control, the functionality fraction is set to zero at the time of pad failure.

VARIATION OF WATER INFILTRATION INPUT

In the original version of the SOURCE codes, only one set of water infiltration values could be input. This set consisted of 12 values of water infiltration data (1 value for each month in the year) that were used for each year of the simulation. Because simulations are typically performed for 1000-year or greater periods, water infiltration would certainly vary with time. The SOURCE codes were modified to allow for variation of water infiltration data. The one set of infiltration values in the input data file was replaced with the name of a file which contains multiple sets of infiltration data. Each set corresponds to a defined time period during the disposal facility performance simulation. For example, six such periods have been defined by ORNL for tumulus-type disposal facilities: (1) the active-use period during which vaults are placed on the tumulus pad, (2) the capping period during which the facility is covered with an engineered cap, (3) the cap decline period during which the cap

weathers and degrades, (4) the grass cover period during which the facility is covered with grass and vegetation, (5) the forest succession period during which small trees and bushes begin to grow on top of the facility, and (6) the forest cover period during which the disposal facility is completely covered by trees. Representative water infiltration values can be developed for each of these periods, and with the modifications to the SOURCE codes, these values can be applied during the appropriate time period.

ADDITION OF OUTPUT FILES

The original version of the SOURCE codes contained three output files. One file provided a summary of input data and of engineered barrier degradation. Another file provided, as a function of time, calculated radionuclide releases that recharge to groundwater. The third file provided, also as a function of time, calculated radionuclide releases that flow laterally in the shallow storm-flow region. To provide more information from each simulation, five new output files were created for SOURCE1, and three new output files were created for SOURCE2. A summary of the input and output file structure for SOURCE1 and SOURCE2 is presented in Tables 1 and 2, respectively. These tables list the filename extension, function of the file, and output control variables. The output control variables are used to select which, and at what frequency, output files are written during a simulation.

The output files now available for the SOURCE codes provide a wide variety of data for a source term simulation. Additionally, the output files have been structured to allow for use of the output data by both spreadsheet and graphing software. These types of software applications aid in quality assurance checks and interpretation of simulation results.

SENSITIVITY ANALYSES

To provide more insight into input data needs, extensive sensitivity analyses have been performed on the SOURCE codes. These analyses were conducted for a variety of radionuclides and disposal facilities to cover the spectrum of situations expected to be

encountered in a performance assessment. Sensitivity analyses were performed on the SOURCE codes using the Latin Hypercube method. The PRISM computer code⁵ was used to implement this random sampling technique. A summary of the results of the sensitivity analyses is presented in Table 3, with a more detailed description of the sensitivity analyses provided in refs. 2 and 6. The sensitive parameters and their rank of importance varied by disposal technology, radionuclide, and year of simulation.

Once sensitive parameters are identified, input data collection efforts can be focused on selecting the most probable values of these parameters and the information required to describe their statistical distribution. These efforts result in a range of uncertainty for each sensitive parameter. Then, through an uncertainty analysis, the overall uncertainty in simulation results can be established.

Table 1. File structure for SOURCE1

Name ^a	Function	Output control variables ^b
<i>filename.inp</i>	Input: Model parameters	
Specified in <i>filename.inp</i> Example: water_tum1.dat	Input: Water infiltration values	
<i>filename.con</i>	Output: Summary of input information and concrete analysis	iprint, iprn3, ifrq3
<i>filename.h2o</i>	Output: Beginning year, ending year, monthly water infiltration values	iprint
<i>filename.rch</i>	Output: Year, water flow rate, recharge component of radionuclide release	iprn1, ifrq1
<i>filename.1at</i>	Output: Year, water flow rate, lateral component of radionuclide release	iprn2, ifrq2
<i>filename.sum</i>	Output: Year, radionuclide inventory, total leach rate, cumulative leached	iprn4, ifrq4
<i>filename.lch</i>	Output: year, advection component, diffusion component, total leach rate	iprn5, ifrq5
<i>filename.vt1</i>	Output for intact vaults: Year, radionuclide inventory, advection component, diffusion component	iprn6, ifrq6
<i>filename.vt2</i>	Output for cracked vaults: Year, radionuclide inventory, advection component, diffusion component	iprn7, ifrq7

a. The filename selected by the code user is common to input and output files. The type of file and its contents are identified by the three-character extension.

b. The output control values determine if data are written to a particular file and at what frequency:

iprint = 0: input data written to file

iprint = 1: input data not written to file

iprn1 through iprn7 = 0: data written to file

iprn1 through iprn7 = 1: data not written to file

The values of ifrq1 through ifrq7 determine how often data are written to a file. Example: For iprn1 = 0 and ifrq1 = 50, data are written to *filename.rch* every 50 years of the simulation.

Table 2. File structure for SOURCE2

Name ^a	Function	Output control variables ^b
<i>filename.inp</i>	Input: Model parameters	
Specified in <i>filename.inp</i> Example: water_th.dat	Input: Water infiltration values	
<i>filename.con</i>	Output: Summary of input information and concrete analysis	iprint, iprn3, ifrq3
<i>filename.h2o</i>	Output: Beginning year, ending year, monthly water infiltration values	iprint
<i>filename.rch</i>	Output: Year, water flow rate, recharge component of radionuclide release	iprn1, ifrq1
<i>filename.1at</i>	Output: Year, water flow rate, lateral component of radionuclide release	iprn2, ifrq2
<i>filename.sum</i>	Output: Year, radionuclide inventory, total leach rate, cumulative leached	iprn4, ifrq4
<i>filename.lch</i>	Output: year, advection component, diffusion component, total leach rate	iprn5, ifrq5

a. The filename selected by the code user is common to input and output files. The type of file and its contents are identified by the three-character extension.

b. The output control values determine if data are written to a particular file and at what frequency:

iprint = 0: input data written to file

iprint = 1: input data not written to file

iprn1 through iprn5 = 0: data written to file

iprn1 through iprn5 = 1: data not written to file

The values of ifrq1 through ifrq5 determine how often data are written to a file. Example: For iprn1 = 0 and ifrq1 = 50, data are written to *filename.rch* every 50 years of the simulation.

Table 3. Summary of SOURCE1 and SOURCE2 sensitive parameters

Sensitive parameters ^a	Source term code ^b	
	SOURCE1	SOURCE2
Density of earthen cover (g/cm ³)	X	
Density of waste (g/cm ³)	X	X
Moisture content of waste (unitless)		X
Sulfate diffusion coefficient in concrete (m ² /s)	X	X
Time for complete corrosion of metal waste containers (year)	X	
Saturated hydraulic conductivity of the soil under the disposal facility (cm/s)	X	X
Saturated hydraulic conductivity of concrete (cm/s)	X	X
Radionuclide distribution coefficient in waste (mL/g)	X	X
Radionuclide inventory ^c (g/disposal unit)	X	X
Radionuclide diffusion coefficient in concrete (m ² /s)	X	X
Concentration of sulfate inside vault (mol/L)	X	X
Concentration of sulfate in groundwater (mol/L)	X	X
Containment area per unit (m ²)	X	X
Initial functionality fraction of leachate collection system (unitless)	X	
Time for complete corrosion of corrugated steel liners (year)		X
Time for complete corrosion of cast iron pipe (year)		X

a. Sensitive parameters are those which contribute at least 3 %, during a simulation, to the release rate calculation.

b. Items marked with an "X" indicate that the item is a sensitive parameter for the computer code.

c. For SOURCE1, inventory units are expressed as grams per tumulus vault. For SOURCE2, inventory units are expressed as grams per silo, well, or trench, as appropriate.

SUMMARY

The SOURCE1 and SOURCE2 codes are used to calculate the source term for performance assessments of ORNL LLW disposal facilities. These codes simulate the degradation of engineered barriers and the release of radionuclides. Recent major improvements and modifications to the SOURCE codes including incorporation of a new advective model, development of SOURCE1 models for degradation of a tumulus-type concrete pad and leachate collection system, addition of a water infiltration input-data file, and expanded output files and output options have been effected. Additionally, sensitive parameters for both SOURCE1 and SOURCE2 have been summarized.

In parallel with the SOURCE code improvements, an effort was undertaken to verify the computer codes. This effort involved the development and execution of a verification plan for both SOURCE1 and SOURCE2. This plan consisted of a detailed review of the algorithms used in the codes, a review of code structure and programming, and a comparison of different advective models. In addition, tools such as sensitivity analyses and graphical representation of output were used to evaluate the performance of the SOURCE codes. Improvements and revisions to the SOURCE1 and SOURCE2 codes, as well as summary of verification efforts, will be incorporated into a revision of the SOURCE code user's manual.⁷

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COMPARISON OF RESRAD WITH HAND CALCULATIONS

Paul D. Rittmann
Westinghouse Hanford Company H6-30
Post Office Box 1970
Richland, WA 99352 USA
(509) 376-8715

ABSTRACT

This report is a continuation of an earlier comparison (*Benchmarking of Computer Codes and Approaches for Modeling Exposure Scenarios*, DOE/LLW-188) done with two other computer programs, GENII and PATHRAE. The dose calculations by the two programs were compared with each other and with hand calculations. These hand calculations have now been compared with RESRAD Version 5.41 to examine the use of standard models and parameters in this computer program. The hand calculations disclosed a significant computational error in RESRAD. The Pu-241 ingestion doses are five orders of magnitude too small. In addition, the external doses from some nuclides differ greatly from expected values. Both of these deficiencies have been corrected in later versions of RESRAD.

INTRODUCTION

The U.S. Department of Energy (DOE) has established a Performance Assessment Task Team to integrate the activities of the sites that are preparing performance assessments for disposal of new low level radioactive waste. One activity of the team is to compare the computer programs which are being used at the sites to assess potential human exposures. The first programs examined¹ were GENII² and PATHRAE.³ The two computer programs were compared with each other and with hand calculations. The hand calculations were necessary to understand differences between the computed results from the two programs.

The third program examined was RESRAD Version 5.41.⁴ The computed results from RESRAD were also compared with hand calculations and a few irregularities were noted. First among these is an error in the calculations of the Pu-241 ingestion dose from vegetation grown on contaminated soil. Subsequent versions of RESRAD have eliminated this error and generally improved the calculations.

The following sections describe the hand calculations are described first, along with the parameters used in these calculations. The RESRAD program is then described and the RESRAD results are compared with the hand calculations.

HAND CALCULATION MODELS AND PARAMETERS

Two exposure scenarios are frequently used to evaluate the impacts of low-level waste disposal. The first is intrusion by an unsuspecting individual who drills a water well through the waste site and later grows a garden on the exhumed material. For the purposes of comparison, a unit concentration in the surface soil was assumed. The second scenario assumes the radionuclides in the waste have migrated into the groundwater. An individual drills a water well near the disposal site and uses contaminated water for domestic needs as well as watering the grass and hay fed to a cow. For the purposes of comparison, a unit concentration in the well water was assumed. The methods used to calculate the doses are described below. Refinements for radioactive decay were not included, since the nuclides of importance have long decay half lives.

Doses from an Initial Soil Concentration

The typical waste intrusion scenario includes doses that result from gardening activities on contaminated soil. Dose pathways include external dose from the soil, inhalation of resuspended dust, and ingestion of garden produce. The computer programs were compared with hand calculations starting with each nuclide at a soil concentration of $1 \mu\text{Ci}/\text{m}^3$. The hand calculated doses are shown in Table 1.

The external dose accumulated during the first year is the product of the soil concentration, the time of exposure, and the external dose rate factor. The exposure duration was taken to be one year. The external dose rate factors are taken from Federal Guidance Report Number 12⁵ for soil with a 15 cm depth of contamination. The tabulated dose rate factors use a higher soil density than was assumed in the hand calculations. The tabulated

values were adjusted upward by the factor 1.067 to compensate for this. Equation 1 summarizes this calculation. Appropriate unit conversion factors must be applied.

$$\text{External Dose} = (\text{Soil Conc})(\text{Exposure Time})(\text{Dose Rate Factor}) \quad (1)$$

The inhalation dose is the product of the soil concentration, the volume of soil inhaled during the year of exposure, and the inhalation dose factor.⁶ The volume of soil inhaled is based on an average mass loading of 0.1 mg/m³ and a total of 8500 m³ air inhaled during the year. The volume of soil inhaled is calculated by dividing the mass of soil inhaled by the assumed soil density, 1.5 g/cc. Equations 2 and 3 summarize this calculation.

$$\text{Volume of Soil Inhaled} = (0.1 \text{ mg/m}^3)(8500 \text{ m}^3)/(1.5 \text{ g/cc}) = 0.567 \text{ cc} \quad (2)$$

$$\text{Inhalation Dose} = (\text{Soil Conc})(\text{Soil Volume Inhaled})(\text{Inhalation Dose Factor}) \quad (3)$$

The ingestion dose from contaminated garden vegetables is the product of the nuclide concentration in the vegetable at the time of harvest, the quantity of the vegetable consumed, and the ingestion dose factor.⁶ The concentration of nuclides in vegetables is based on root uptake from the soil into the edible portions of the plants. The transfer of contamination from soil to the plants by mechanical means (rain splash) is not considered. Soil-to-plant concentration ratios^{7,8} are used to estimate the plant concentration. These concentration ratios are based on the dry weight of the plants and must be adjusted downward to include the water in the plants at the time of consumption. Equations 4, 5, and 6 summarize the calculation of ingestion dose from garden produce.

$$\text{Leafy Concentration} = C_s \cdot DW_v \cdot B_v \quad (4)$$

$$\text{Grain Concentration} = C_s \cdot DW_r \cdot B_r \quad (5)$$

$$\text{Ingestion Dose} = [\text{Leafy} \cdot Q_v + \text{Grain} \cdot Q_r] \cdot DF_{\text{ing}} \quad (6)$$

where,

C_s = Soil concentration, 1 $\mu\text{Ci/m}^3$. The hand calculations assume this remains constant during the year of exposure. There is no radioactive decay or leaching from the surface layer of soil.

DW = Ratio of dry weight of a plant to the wet weight. For leafy vegetables DW_v is 0.066, while for grains DW_r is 0.187. These somewhat low values are hard-coded into PATHRAE and were chosen for ease of comparison.

B = Ratio of the concentration of a nuclide in a plant to the concentration in the soil. Dry weights of the soil and plants are used. The B_v is for leafy vegetables, while the B_r is for non-leafy vegetables. Values for H-3 and C-14 are taken from Reference 8. Values for the other nuclides are taken from Reference 7.

Q = Quantity of a vegetable that is eaten. For leafy vegetables, Q_v is 20 kg, while for grains Q_r is 172 kg.

DF_{ing} = Dose received from the ingestion of a unit amount of activity. Values are taken from Reference 6.

Table 1. Hand Calculated Doses from Contaminated Soil

Nuclide	External	Inhale	Ingest	Total
H-3	0.00E+00	5.36E-05	1.69E+00	1.69E+00
C-14	8.91E-03	1.19E-03	1.52E+01	1.52E+01
Co-60	8.97E+03	8.50E-02	1.09E+00	8.97E+03
Ni-59	0.00E+00	7.37E-04	6.70E-02	6.77E-02
Se-79	1.23E-02	5.04E-03	1.16E+00	1.18E+00
Sr-90	1.53E+01	1.35E-01	2.65E+02	2.80E+02
Tc-99	8.29E-02	4.25E-03	1.32E+01	1.33E+01
I-129	8.58E+00	1.02E-01	8.43E+01	9.30E+01
Cs-137	2.00E+03	1.81E-02	8.92E+00	2.01E+03
Pb-210	3.96E+00	1.21E+01	3.92E+02	4.08E+02
Ra-226	6.25E+03	4.48E+00	1.25E+01	6.27E+03
U-238	7.87E+01	6.80E+01	5.66E+00	1.52E+02
Np-237	6.90E+02	2.78E+02	2.95E+02	1.26E+03
Pu-239	1.88E-01	2.89E+02	1.46E+00	2.91E+02
Pu-241	1.23E-02	5.67E+00	2.93E-02	5.71E+00
Am-241	2.90E+01	2.95E+02	1.15E+01	3.35E+02

NOTE: Units are rem/y per $\mu\text{Ci}/\text{m}^3$ in the surface soil.

Doses from Contaminated Irrigation Water

Contaminated irrigation water could come from groundwater or surface water. The typical irrigation scenario includes ingestion doses from drinking water, garden produce, beef, and milk. The soil becomes contaminated from application of the irrigation water. Plants become contaminated through root uptake and direct deposition on the foliage by the overhead irrigation system. The animal products become contaminated when the cows eat contaminated produce and drink contaminated water. Inhalation and external doses were not computed because the calculation would differ little from what was computed previously for contaminated soil. The hand calculated doses are shown in Table 2.

The ingestion dose from drinking untreated water during the first year is the product of the water concentration, the volume of water consumed, and the ingestion dose factor. The annual volume of water consumed is taken to be 730 L. Equation 7 summarizes this calculation. Appropriate unit conversion factors must be applied.

$$\text{Drinking Water Dose} = (\text{Water Conc})(\text{Water Consumed})(\text{Dose Factor}) \quad (7)$$

The ingestion dose from vegetables irrigated with contaminated irrigation water is the product of the nuclide concentration in the vegetable at the time of harvest, the quantity of the vegetable consumed, and the ingestion dose factor. The radioactivity accumulating in the soil contributes to the contamination of vegetables by root uptake. Transfer of contamination from soil to the plants by mechanical means (rain splash) is not considered. Most of the contamination in the plants comes from direct deposition of the radioactivity on the plants by the overhead irrigation system. Equations 8 and 9 summarize this calculation.

$$\text{Plant Conc} = \frac{C_w \cdot I \cdot DW \cdot B}{\text{Density} \cdot \text{Thick}} + \frac{C_w \cdot I \cdot F_{\text{dep}} \cdot \text{Trans} \cdot [1 - \text{Exp}(-L_w \cdot T_{\text{gro}})]}{T_{\text{irr}} \cdot \text{Yield} \cdot L_w} \quad (8)$$

$$\text{Ingestion Dose} = [\text{Leafy} \cdot Q_v + \text{Grain} \cdot Q_r] \cdot DF_{\text{ing}} \quad (9)$$

where,

- Cw = Water concentration, 1 $\mu\text{Ci/L}$. The hand calculations assume this remains constant during the year of exposure. There is no radioactive decay or ingrowth of progeny nuclides.
- I = Irrigation applied during the year, 36 inches (91.4 cm). This is converted to liters per square meter with the factor 25.4 L/m² per inch of water.
- DW = Ratio of dry weight of a plant to the wet weight. For leafy vegetables DWv is 0.066, while for grains DWr is 0.187. These somewhat low values are hard-coded into PATHRAE and were chosen for ease of comparison.
- B = Ratio of the concentration of a nuclide in a plant to the concentration in the soil. Dry weights of the soil and plants are used. The Bv is for leafy vegetables, while the Br is for non-leafy vegetables. Values for H-3 and C-14 are taken from Reference 8. Values for the other nuclides are taken from Reference 7.
- Density = Soil density of the surface layer, 1500 kg/m³.
- Thick = Thickness of soil that the deposited activity contaminates, 0.15 meters. This is a customary tilling depth for gardening and farming activities.
- F_{dep} = Interception fraction, i.e., the fraction of the activity in the applied irrigation water which remains on the plant surfaces. It is assumed that F_{dep}=0.25 for both leafy vegetables and grains.
- Trans = Translocation factor, i.e., the fraction of the activity deposited on plant surfaces that ends up in the edible portions of the plant. For leafy vegetables this is 1.0, while for grains this is 0.1.
- Lw = Weathering removal constant, $\text{Ln}(2)/(14 \text{ days}) = 18.084$ per year. If radioactive decay were included, the decay constant of the nuclide would be added to the weathering constant.
- T_{gro} = Growing period of the crop. This is assumed to be 60 days for both leafy vegetables and grains.
- T_{irr} = Irrigation period is assumed to be 0.5 year. The activity from direct deposition depends on the rate at which the contaminated irrigation water is applied.
- Yield = Crop yield, kg/m². The greater the mass of foliage, the lower the average concentration in the foliage. This is assumed to be 2.0 kg/m² for both leafy vegetables and grains.

Leafy = The concentration of a nuclide in leafy vegetables. This is computed by substituting the leafy vegetable parameters into the "Plant Conc" formula.

Grain = The concentration of a nuclide in grains. This is computed by substituting the grain parameters into the "Plant Conc" formula.

Q = Quantity of a vegetable that is eaten. For leafy vegetables, Q_v is 20 kg, while for grains Q_r is 172 kg.

DF_{ing} = Dose received from the ingestion of a unit amount of activity.

Table 2. Hand Calculated Ingestion Doses from Contaminated Irrigation Water

Nuclide	Water	Vegetable	Beef	Milk
H-3	4.60E-02	1.73E-02	8.31E-02	8.01E-02
C-14	1.53E+00	3.27E-01	5.60E+00	2.51E+00
Co-60	1.90E+01	2.91E+00	4.02E+01	4.66E+00
Ni-59	1.46E-01	2.27E-02	9.32E-02	1.80E-02
Se-79	6.06E+00	9.33E-01	9.64E+00	2.98E+00
Sr-90	1.02E+02	1.72E+01	3.65E+00	2.11E+01
Tc-99	9.49E-01	2.25E-01	1.28E+00	1.74E+00
I-129	2.04E+02	3.17E+01	1.53E+02	2.53E+02
Cs-137	3.65E+01	5.63E+00	7.76E+01	3.14E+01
Pb-210	4.92E+03	7.54E+02	1.56E+02	1.51E+02
Ra-226	8.04E+02	1.23E+02	2.13E+01	4.43E+01
U-238	1.77E+02	2.71E+01	3.76E+00	1.30E+01
Np-237	2.85E+03	4.37E+02	1.67E+01	1.75E+00
Pu-239	3.14E+03	4.80E+02	1.66E-01	3.84E-02
Pu-241	6.28E+01	9.59E+00	3.32E-03	7.69E-04
Am-241	3.28E+03	5.02E+02	1.22E+00	1.61E-01

NOTE: Units are rem/y per $\mu\text{Ci/L}$ in the irrigation water.

Ingestion doses from consumption of beef or milk are the product of the beef or milk concentration, the quantity consumed, and the ingestion dose factor. The irrigator is assumed to consume 95 kg of contaminated beef and 110 L of contaminated milk each year.

The nuclide concentration in the beef or milk is proportional to the daily intake of radioactivity. Equilibrium transfer factors^{7,8} are used to relate the rate of intake of a nuclide to the steady-state concentration in beef or milk. The rate of intake of the nuclide depends on the cow's diet.

Both types of cattle are assumed to have the same diet for simplicity. They both drink 55 L of untreated water each day and consume 50 kg of fodder each day. The fodder is assumed to be 75 percent fresh grass and 25 percent stored grain. The concentration of a nuclide in grass is calculated using the "Plant Conc" formula (equation 8) with the leafy vegetable parameters and the following changes: the dry-to-wet ratio is 0.243, the growing period is 30 days, and the grass yield is 1.0 kg/m². The concentration of a nuclide in stored grain is calculated using the "Plant Conc" formula (equation 8) with grain parameters and the following changes: the dry-to-wet ratio is 0.68, the growing period is 30 days, and the grass yield is 1.0 kg/m². Equations 10, 11, and 12 summarize this calculation.

$$\text{Daily Intake} = C_w \cdot Q_w + \text{Fresh} \cdot (37.5 \text{ kg/d}) + \text{Stored} \cdot (12.5 \text{ kg/d}) \quad (10)$$

$$\text{Dose from Beef} = F_{\text{beef}} \cdot (\text{Daily Intake}) \cdot Q_{\text{beef}} \cdot DF_{\text{ing}} \quad (11)$$

$$\text{Dose from Milk} = F_{\text{milk}} \cdot (\text{Daily Intake}) \cdot Q_{\text{milk}} \cdot DF_{\text{ing}} \quad (12)$$

where,

C_w = Water concentration, 1 $\mu\text{Ci/L}$.

Q_w = Quantity of untreated water (50 L) that is consumed by the cow each day.

Fresh = The concentration of a nuclide in grass consumed by the cow. This is computed using the leafy vegetable parameters. The dry-to-wet ratio, the growing period, and the crop yield are different.

Stored = The concentration of a nuclide in stored grain consumed by the cow. This is computed using the grain parameters. The dry-to-wet ratio, the growing period, and the crop yield are different.

F_{milk} = Equilibrium transfer factor to relate the rate of intake of a radionuclide to the eventual steady-state concentration in milk. It is the ratio of the equilibrium concentration of a nuclide in the milk to the daily intake of the nuclide by the animal. For milk the units are Ci/L(milk) per Ci/day . In practice, the values are

tabulated using units of day/L. Values for H-3 and C-14 are taken from Reference 8. Values for the other nuclides are taken from Reference 7.

F_{beef} = Equilibrium transfer factor to relate the rate of intake of a radionuclide to the eventual steady-state concentration in beef. It is the ratio of the equilibrium concentration of a nuclide in the beef to the daily intake by the animal. For beef the units are Ci/kg(beef) per Ci/day. In practice, the values are tabulated using units of day/kg.

DF_{ing} = Dose received from the ingestion of a unit amount of activity.

RESRAD INPUT AND COMPARISON WITH HAND CALCULATIONS

Version 5.41 of the RESRAD program has internal dose factors from Reference 6. Two inhalation solubility classes were changed for these comparisons. Sr-90 was changed from Class Y to Class D, and Ni-59 was changed from elemental vapor to Class D. The ingestion dose factors were left unchanged. The soil-to-plant concentration ratios and the animal transfer factors were changed to be consistent with the hand calculations. For most nuclides, these default RESRAD parameters were reduced.

Doses from an Initial Soil Concentration

For input to RESRAD, the initial soil concentration of each nuclide was entered as 666.7 pCi/g. For a soil density of 1.5 g/cc this is the same as 0.001 Ci/m³. The soil concentration was reduced by a factor of 1000 because RESRAD reports dose equivalent in units of mrem rather than rem. Reducing the soil concentration by a factor of 1000 gives numeric results that are equivalent to the hand calculations. Two nuclides were not included in the RESRAD calculations. Se-79 is not available in RESRAD, and Pb-210 was not one of the original nuclides selected for comparison.

The soil distribution coefficients used by RESRAD were set to 100 cm³/g to minimize the migration of contaminants from the surface layer. The emanation constants for carbon

were set to zero to keep the C-14 in the surface layer. To eliminate particulate resuspension from soil to foliage, the "Mass loading for foliar deposition" term was set to zero.

The dose results from Version 5.41 of RESRAD were divided by the hand calculation results and are shown in Table 3. The external dose column shows significant departures from the hand calculations. RESRAD overestimates the external dose from the strong gamma-emitting nuclides (Co-60, Cs-137, Ra-226, and Np-237) by about 40 percent. The total dose is affected by the increase also. The RESRAD estimates for weak photon sources range from very close (Pu-241) to zero (Sr-90). The total dose is not affected by these differences because the external dose contributes little to the total dose for weak photon-emitting nuclides. Version 5.60 of RESRAD now uses the external dose rate factors in Reference 5. The hand calculations agree very well with the current version of RESRAD.

The inhalation doses are very close. The small difference is due to the area adjustment factor used in RESRAD. With the garden area set to 20,000 m² and the dilution length for airborne dust set to 1.0 m, the area adjustment factor is 0.993, which explains the consistent 0.7 percent difference.

Table 3. RESRAD Doses Divided by Hand Calculations for Contaminated Soil

Nuclide	External	Inhale	Ingest	Total
H-3	Both=0	0.993	0.009	0.009
C-14	RESRAD=0	0.993	1.081	1.080
Co-60	1.381	0.993	0.981	1.381
Ni-59	HandCalc=0	0.993	1.003	1.058
Sr-90	RESRAD=0	0.992	0.997	0.942
Tc-99	0.014	0.993	1.001	0.995
I-129	2.558	0.993	1.000	1.144
Cs-137	1.451	0.993	0.997	1.449
Ra-226	1.314	0.991	0.998	1.313
U-238	0.935	0.993	1.001	0.963

Np-237	1.431	0.993	0.998	1.234
Pu-239	2.590	0.993	0.997	0.994
Pu-241	1.008	0.993	2.4E-05	0.988
Am-241	1.098	0.993	0.999	1.002

The ingestion doses are very close for most nuclides. RESRAD uses special models for H-3 and C-14, which leads to the large differences. The RESRAD Version 5.41 result for Pu-241 is clearly in error. This was corrected in subsequent versions.

Doses from Contaminated Irrigation Water

For input to RESRAD, the soil concentrations were chosen to give a well water concentration of 1000 pCi/L for each nuclide. The soil distribution coefficients for each nuclide were set to zero to maximize the migration of contaminants from the surface layer. The emanation constants for carbon were set to zero to keep the C-14 in the surface layer. To eliminate particulate resuspension from soil to foliage, the "Mass loading for foliar deposition" was set to zero.

It was necessary to use two sets of soil-to-plant concentration ratios for the benchmark comparisons. The first set was the weighted combination used for vegetables while the second set was constructed based on the different weightings for the cow diet. Since both milk and beef cows consume the same relative amounts of fresh and stored feed, the one table was sufficient for both milk and beef cows. The dose results from RESRAD were divided by the hand calculation results and are shown in Table 4.

Table 4. RESRAD Doses Divided by Hand Calculations for Contaminated Water

Nuclide	Water	Vegetable	Beef	Milk
H-3	1.001	0.121	0.038	0.066
C-14	1.001	0.018	0.029	0.049
Co-60	1.000	0.933	0.557	0.561
Ni-59	1.001	0.932	0.575	0.575

Sr-90	1.000	0.861	0.516	0.517
Tc-99	1.001	0.625	0.403	0.403
I-129	1.000	0.934	0.573	0.573
Cs-137	0.999	0.936	0.571	0.572
Ra-226	1.185	1.122	0.705	0.636
U-238	1.001	0.947	0.578	0.578
Np-237	1.000	0.944	0.575	0.575
Pu-239	1.000	0.948	0.578	0.578
Pu-241	0.086	0.081	0.347	0.198
Am-241	0.999	0.946	0.577	0.577

The doses for water ingestion are in very good agreement with the hand calculations with two exceptions. RESRAD does not allow the activity of parent nuclides in the well water to decay during the year of pumping, but it does allow the daughter nuclides to accumulate. Thus, the dose for Co-60 does not change, while the dose for Ra-226 increases due to the ingrowth of Pb-210. The Pu-241 dose increases from a value five orders of magnitude too small to a value which is a factor of 8 too small by the ingrowth of Am-241. In the current version of RESRAD, this ratio turns out to be 1.086 rather than 0.086.

The doses for the other ingestion pathways show rather consistent differences. The first two nuclides, H-3 and C-14 use special models and should differ. The differences for other nuclides were traced to parameters in RESRAD that cannot be changed by the user. In RESRAD, the plant concentration from direct deposition on foliage is computed using the following unalterable parameters: the length of the growing period, the weathering constant, the interception fraction, the translocation factors, and the crop yield. Different parameters are used for the vegetable garden and the cow fodder. The calculated ratio between the RESRAD method and the hand calculations is 0.948, which is close to the ratios found in the Vegetable column. For the cow fodder, the ratio turns out to be 0.578. The ratios for beef and milk are very similar.

The ratios for Co-60, Sr-90, Tc-99, Ra-226, and Pu-241 differ from the expected ratios. Co-60 is decreased by radioactive decay. Ra-226 is increased by the ingrowth of Pb-210. Both Sr-90 and Tc-99 have significant root uptake contributions in the hand calculations. The hand calculations assume no leaching and the root uptake is calculated at the end of the irrigation season. In the RESRAD calculations, there was leaching, and RESRAD computes root uptake at the end of the growing season. Hence, the root uptake contribution is very small in RESRAD, and the dose ratios are less than expected. The Pu-241 dose is nearly zero, but the ingrowth of Am-241 gives the observed contributions. The current version of RESRAD gives Vegetable, Beef and Milk ratios for Pu-241 of 1.025, 0.923, and 0.776. Thus, the values shown for Pu-241 are based on the amount of Am-241 which has accumulated in the well water.

SUMMARY

Version 5.41 of RESRAD had an error in the calculation of ingestion dose from Pu-241. Since this pathway is typically not the main contributor to the total dose, the total doses should not be significantly affected. Calculations done with Pu-241 and earlier versions of RESRAD do not need to be redone. Since this error has been corrected, one can easily check for changes by using the current version of RESRAD on older input data.

Version 5.41 of RESRAD tended to overestimate external doses from strong gamma emitters by about 40 percent. Version 5.60 of RESRAD adopted an improved model for external dose calculations. Details of the comparisons of all three computer programs with the hand calculations are available in draft form.⁹

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Integration of Computational Modeling for the Los Alamos National Laboratory Low Level
Radioactive Waste Disposal Performance Assessment

E.L. Vold
Los Alamos National Laboratory,
CST-14, MS J595
Los Alamos, NM 87545
505-665-8205

K.H. Birdsell, E.P. Springer, D.K. Hollis
Los Alamos National Laboratory

R. Shuman
Rogers and Associates Engineering Corporation
Idaho Falls, ID

ABSTRACT

The preliminary Performance Assessment for the Los Alamos National Laboratory Low Level Radioactive Waste Disposal Facility at Area G is drawing to completion. The disposal site is located on the top of a finger mesa in the complex terrain of a semi-arid region which leads to considerable complications in the atmospheric and subsurface transport and in the requisite modeling. Infiltration and run-off are evaluated for the proposed disposal unit closure configuration. A new analytic source release model characterizes the disposal unit performance utilizing detailed source term characterization from the inventory data base. This analysis provides input to the subsurface modeling done by the sophisticated finite element transport code, FEHM, using realistic 2-D cross-sections of the geologic stratigraphy and the disposal units. Subsurface transport via lateral flow to intermittent alluvial waters in adjacent canyons is evaluated in addition to the usual deep aquifer. Vapor phase flow has been treated separately and calibrated to field data for tritium migration. Atmospheric transport is based on Gaussian dispersion with a correction for complex canyon terrain evaluated from on-going 3-D atmospheric transport studies. Indications to date are that the Performance Assessment objectives are met for all migration pathways.

INTRODUCTION

The preliminary draft of the Performance Assessment (PA) for the Los Alamos National Laboratory (LANL) Low Level Radioactive Waste (LLRW) disposal facility at TA54, Area G, was presented to the US Department of Energy (USDOE) Peer Review Panel in August, 1995¹. Panel comments were received and are being incorporated into the complete draft for submittal to the USDOE during 1996. The on-going effort has involved a team of LANL technical staff

and contractors including nine principle authors and more than a dozen additional contributors. This report summarizes the integration of the assessment teams, the technical data analyses, and the flow of the actual modeling effort.

The LANL disposal site at Area G is located on the top a narrow finger mesa averaging 300m wide, north to south, and about 30m above the adjacent canyons. The mesa is several kilometers long with the active disposal site occupying about 1 km west to east, and a proposed expansion area for future projected waste occupying another half km to the west of the present site. The mesa is composed of Bandelier tuff, which is a layered sequence of porous volcanic rock formed from volcanic ashes and flows².

The region is semi-arid, with about 14 in/year precipitation on average. The mesa top is about 300m above the saturated aquifer. The adjacent canyons have perched alluvial systems, while vertical moisture profiles observed on most core samples beneath the mesa show a very low moisture content (1-2%). Hydraulic conductivities of core samples are consistent with negligible liquid phase flow through much of the vertical profile^{3,4}. Vapor phase movement is expected to be significant for gas or vapor phase contaminants. The mesa top location, complex stratigraphy, and liquid and vapor phase movement make analyses of the subsurface transport a challenging modeling effort.

The release mechanisms expected from the site are summarized in a conceptual model in Fig.1. The liquid phase migration is indicated by the Darcy flux, q . Effort to date has focused on the downward movement to the aquifer, but movement may be lateral towards the mesa edge or even upward from the disposal unit if evaporative conditions prevail. These paths are currently under study. Biota translocation is projected to bring a small but steady transfer of contamination to the surface which is then available to the atmospheric path by resuspension and to canyon contamination and off-site exposure via the surface run-off path. Cliff retreat and surface erosion are predicted to uncover the remaining waste on the time scale of about 50,000 years, and surface erosion contributes to increasing the biota translocation during erosion. These issues have been analyzed in the preliminary draft PA. In this report, the discussion will focus on the groundwater and the atmospheric pathway assessments.

GROUNDWATER PATHWAY

A flow chart for the ground water pathway assessment is shown in Fig.2. Detailed numerical simulations followed the historical inventory and were used to generate scaling laws to apply to the future projected inventory. The inventory in the historical disposal units (pits and shafts which were active after the USDOE PA compliance order issuance in 1988) was screened to eliminate nuclides with half-lives less than five years. A second screen eliminated nuclides whose concentration in the waste was below the level that would be safe if conservatively ingested, i.e., the waste concentration leads to a concentration in leachate through the waste that would meet the PA dose objectives if ingested at the standard annual rate.

This screened inventory included 30 nuclides, with 15 being parents of decay chains. Based on information in the 'waste code' inventory data base on physical and chemical form, these 30 nuclides were sorted into four release categories defined in terms of the source release model parameters. This screened and categorized spreadsheet data base then contained concentrations (Ci/m³) and total historical inventory (Ci) information each sorted over 30 nuclides and over the four release form categories of rapid release, soil absorbed, concrete or sludge absorbed, and corrosion. This information is provided to the facility source release model.

Source Release Model

The source release model includes a compartmental description of the waste packages and disposal unit⁵. This description accounts for site parameters including waste type, waste form chemistry based on K_ds and elemental solubility limits by waste category, and infiltration and percolation characteristics. The average percolation rate through the facility of 4mm/yr was determined by detailed surface water balance simulations utilizing statistical precipitation data from the site⁶. Equilibrium sorption coefficients, K_d, and solubility limits, for waste forms in soil and in sludge, were derived from relevant literature values². With this data base, the compartment release model provides an analytic solution for the time dependent release from the waste package of non-solubility limited nuclides. An example in Fig.3 shows the compartment concentrations for the waste package solid phase contaminant concentration, C_s, the waste package liquid phase concentration, C_w, and the average disposal unit liquid phase concentration, C_a, for the case with K_d = 0, corresponding to the maximum release rates.

The elemental solubility limit must be applied to the sum of each nuclide contributing to the elemental concentration. Integration of this elemental concentration over the historical inventory of nuclides and multiple waste forms required the development of a numerical code. The output of this code is the time dependent efflux from the waste packages per nuclide (summed over release category), and this is distributed as a source term over each of the grid nodes within the disposal units in the 2-D unsaturated zone transport model.

Unsaturated Zone Transport

The unsaturated zone was modeled in detail using the FEHMN code⁷, which has been extensively applied to and undergone quality assurance in the Yucca Mountain Project⁸. A 2-D cross-section is modeled which incorporates the full stratigraphy and associated hydrologic transport properties summarized as van Genuchten-Maulem fits^{2,3}. The cross-section extends from the mesa top to the water table and from canyon to canyon. Infiltration rates were varied to find the best overall fit to field data on vertical moisture profiles. The best fit overall is 1 mm/yr net infiltration (Darcy flux), although a much lower and negligible vertical flux fits much of the data in the mesa top. On top of this, the 4mm/yr percolation rate derived for the disposal units was applied to the upper surface of five disposal units which were included in the cross-section. The resulting steady-state saturation distribution for the mesa perturbed by disposal operations is shown in Fig.4, and the increased moisture content of the disturbed disposal units is clear. The horizontal bands near the elevation of the canyon floors is due to the different hydrologic transport properties in the stratigraphy layers.

Nuclide transport is imposed on this flow field, under the assumption that the long term behaviour is adequately described by the steady state flow solution. A source release term for $K_d=0$ in the waste (rapid release) was input to the unsaturated flow model for varying values of K_d in the Bandelier tuff. This showed that values of $K_d > 0.3$, did not traverse the unsaturated zone within the 10,000 years compliance period. Analysis of these results showed that only 17 of the 30 inventory nuclides needed to be modeled further based on a comparison of nuclide half lives to the time for unsaturated zone transit.

The remaining 17 nuclides were modeled in detail through the unsaturated and saturated zones. An example is shown at successive times in Fig.5 for uranium. The very slow progress

for a small $K_d = 1.8$ is evident in the time scales. Only nuclides with K_d values approximately equal to zero in tuff, neptunium (with its non-secular equilibrium decay chain daughters, uranium and thorium) and carbon 14, reach the aquifer within the 10,000 year compliance period.

Transport to the saturated zone is conservatively approximated as transport to the top of a thick basalt layer, i.e., through the top one third of the total 300m to the aquifer (this can be seen in Fig.5 where the uranium contours 'flatten' or disappear at the basalt layer). Thus, no credit is taken for dilution or travel time through the basalt (and deeper Puye) layers, because there is little or no site-specific data available for these layers, and the basalts are expected to be highly fractured. This likely incorporates a very large conservatism which may need to be revisited if this leads to PA objectives being exceeded considering the Legacy Waste (disposed of prior to 1988) to be estimated in the 1996 PA report.

Saturated Zone Transport

The 17 nuclides and decay chain products are then treated in the aquifer dilution model. Saturated zone transport occurs on a time scale very short compared to unsaturated movement at Area G and is treated analytically by diluting the contaminant into the aquifer. Horizontal dispersion is negligible for the spatial scales of interest and the vertical dispersion is proportional to the dispersion length taken to be 0.1m. A simple boundary layer analysis leads to aquifer dilution factors of about 160 at the receptor well location 100m downstream. These concentrations drive the final dose assessment via the standard ground water dose pathways.

ATMOSPHERIC PATHWAY

The flow chart for the atmospheric transport assessment is shown in Fig.6. The actual PA calculations were done completely on spreadsheets, with analyses and results from several supporting technical studies incorporated in two main areas. One, the gas phase source release models were analytic solutions to diffusive flux transport equations, which were compared to detailed numerical results of the diffusive transport profiles in time and in spatial distribution through the disposal unit. Mesa subsurface diffusion was calibrated to field data for tritium⁹. Two, the expected atmospheric dispersion was corrected for the complex terrain effects from a

simple Gaussian estimate, based on site-specific data, on-going sophisticated modeling efforts and an assessment procedure to incorporate the complex terrain channeling effects into a predictive procedure for atmospheric dispersion.

Source Release Models

Atmospheric release source models were developed for the resuspension of surface contamination from the biota-erosion models, and for the diffusive release of gas or vapor phase contaminants, tritium, carbon 14, and radon. Site-specific resuspension values¹⁰ based on standard EPA wind erosion estimates were used to convert surface contamination levels to an airborne source release term. Extensive field data on tritium surface efflux¹¹ and on core sample tritium concentrations in the vicinity of the high level tritium disposal shafts was compared to 3-D simulations⁹ to derive an effective diffusion coefficient, conservatively applied to all vapor or gas phase movement in the Bandelier tuff.

One-dimensional (vertical) and time dependent numerical simulations for gas phase release examined the concentration and flux profiles in space through the disposal unit. The transport equations differed primarily only in their source terms. Radon emanated from the radium in the disposal unit which included listed inventory and decay radium from the uranium series. Carbon 14 was assumed released as a gas following the biodegradation of the estimated organic fraction of the total carbon inventory. The tritium release rate was determined empirically by comparison of the 3-D modeling to the field data.

Complex Terrain Dispersion

Data on wind flow and meteorologic conditions at Area G has been collected on six remote meteorological towers fielded in the Area G vicinity for over a year¹² to characterize the atmospheric transport in complex terrain at the site. Atmospheric dispersion is influenced by the complex terrain surrounding Area G, where the canyons can channel mesa top wind flow from several different directions leading to increased time averaged concentrations in the canyons upstream during the day or downstream during the night (estimated from Area G meteorological data to produce concentration increases by a factor of about 2.4 for the day or the night time

cases). Reduced wind velocities in the canyons relative to the mesa top (observed to be about a factor of 1.7 for the canyons surrounding Area G) proportionately increases canyon contaminant concentrations. Recirculating flow in deep canyons (not apparently present near Area G) could additionally increase canyon concentrations.

These factors indicate that critical receptor locations (minimum atmospheric dispersion) will be in the adjacent canyons assuming that mesa top flow is entrained in those canyons. This assumption is supported by the site field data and by the simulations completed to date. An example of a 3-D simulation done for a normalized source at a nearby mesa top location is shown in Fig.7¹³. The atmospheric dispersion and canyon channeling conditions are expected to be similar to that at Area G. The figure shows a morning time release which is carried to the north side canyon and then up canyon for a considerable distance before dispersing into the mesa top flow field. Once the airborne contaminant escapes the canyon flow and is entrained in the mesa top wind field, then the dispersion is greater than that in flat terrain due to the increased turbulence resulting from the 'rough surface' of the canyon systems.

Based on the site data, dispersion parameters were estimated for the up canyon and down canyon receptor locations, and combined with the release terms described above to generate the receptor location concentrations.

RESULTS

A set of standard dose pathways assumptions are used to convert the environmental concentrations, as described in the previous sections, to a dose rate. The dose results of the preliminary draft analyses (including the intruder scenarios not discussed in this paper) are summarized in Table I. The peak dose within the 10,000 year compliance time frame is shown for comparison to the PA dose objectives. In all cases, the PA dose objectives are met.

The peak dose for all time is also shown. These peak doses occur in the 80,000 to 600,000 year time frame depending upon the pathway and result from the ingrowth of daughter nuclides in decay chains especially the uranium series. The uncertainty associated with dose projections on these time scales is large.

Uncertainty associated with the 'mean dose estimates' summarized in Table I, is critical to interpreting the significance of the assessment and its implications for disposal operations and for supporting Waste Acceptance Criteria. The preliminary PA included extensive discussion of the uncertainty associated with the various 'pieces' of the environmental transport and assessment and also a preliminary review of the overall sensitivity of final results to the models and their data input. The existing and on-going uncertainty and sensitivity analyses and their implications for the waste site operations are presently being pulled into a unified framework for presentation in the draft PA to the USDOE in 1996.

**Table I A Comparison of projected doses for the 10,000-year compliance period
with DOE Performance Assessment (PA) Objectives**

E x p o s u r e Scenario	PA Objective (mrem)	Max. Dose (mrem)				
		Total Inventory	Historic Pits	Historic Shafts	Future Pits	Future Shafts
Groundwater	4	0.08	n/a	n/a	n/a	n/a
Atmospheric	10	7.9	n/a	n/a	n/a	n/a
All Pathways Groundwater	25	6.8	n/a	n/a	n/a	n/a
All Pathways Surface Water	25	0.0001	n/a	n/a	n/a	n/a
I n t r u d e r Construction	500	n/a	1.6	0.8	3.8	1.0
I n t r u d e r Agriculture	100	n/a	22	8.2	53	11
Intruder Post- Drilling	100	na/	0.2	1.5	0.3	3.4

Table I B Peak projected doses for time beyond 10,000 years

E x p o s u r e Scenario	Peak Dose (mrem)				
	Total Inventory	Historic Pits	Historic Shafts	Future Pits	Future Shafts
Groundwater	67	n/a	n/a	n/a	n/a
Atmospheric	500	n/a	n/a	n/a	n/a
All Pathways Groundwater	2.7	n/a	n/a	n/a	n/a
All Pathways Surface Water	35	n/a	n/a	n/a	n/a
I n t r u d e r Construction	n/a	24	5.5	55	13
I n t r u d e r Agriculture	n/a	310	69	690	160
Intruder Post- Drilling	na/	310	69	690	160

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Figures

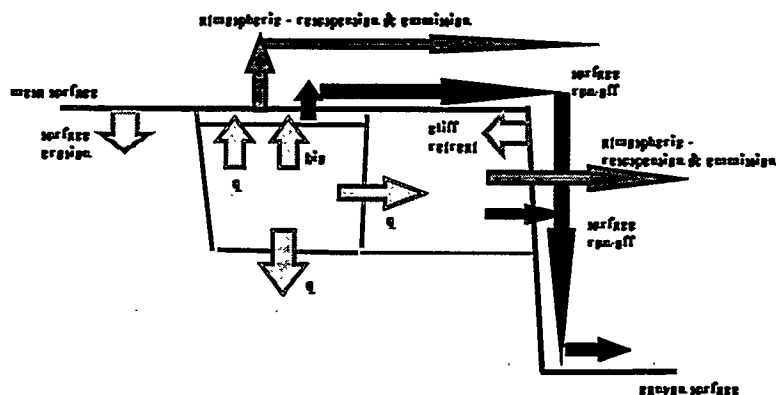


Fig.1 Conceptual model for source release mechanisms from the mesa top disposal site at Area G.

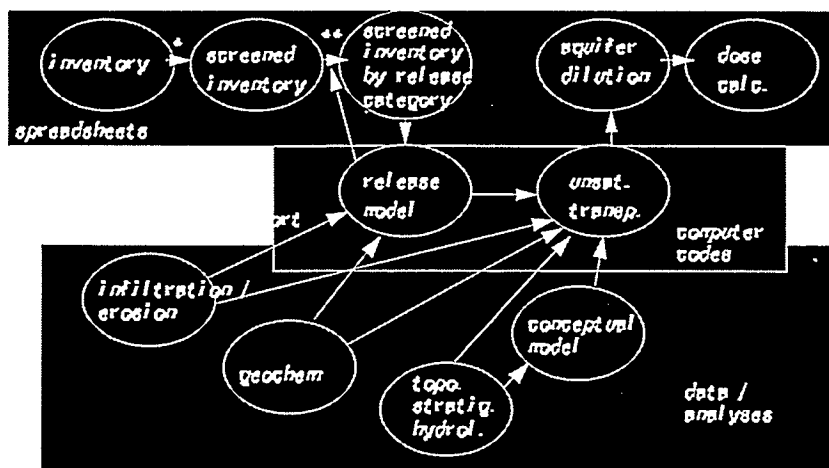


Fig. 2 Hydrogeologic transport calculations and data flow.

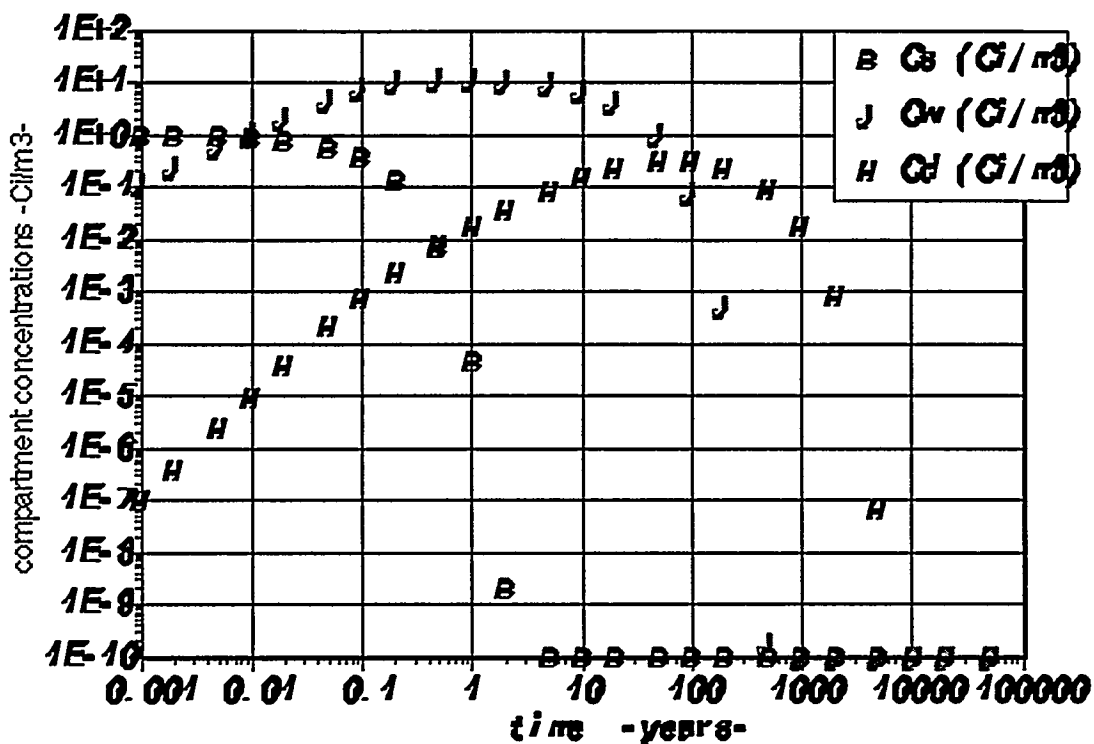


Fig.3 Compartment concentrations in the aqueous phase source release model for the base case conditions, with $K_d = 0$ in the waste form and in the disposal unit tuff, and with a rapid release characteristic time of 0.1 year. The model compartments, s, w, and d, are described in the text.

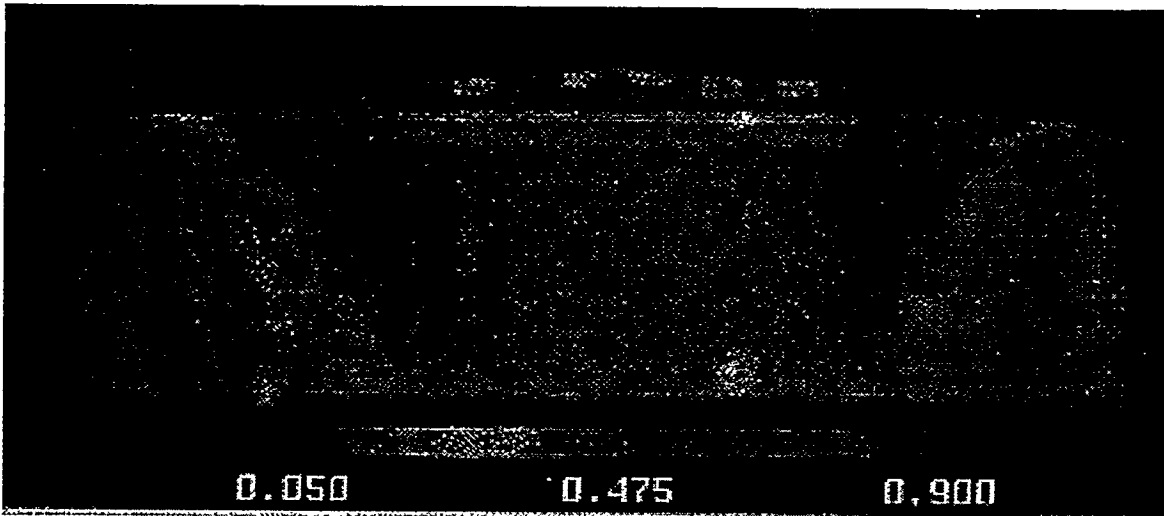


Fig. 4 The unsaturate zone results for saturation in the 2-D profile showing the mesa top and 5 representative disposal units. The saturation is fixed at the canyon surfaces to the left and right of the mesa.



time = 5000 yrs

time = 20,000 yrs

time = 50,000 yrs

time = 80,000 yrs

time = 100,000 yrs

Fig. 5 Representative transport results for a species with $K_d=1.8$ in the Bandelier tuff (uranium) shown at several times.

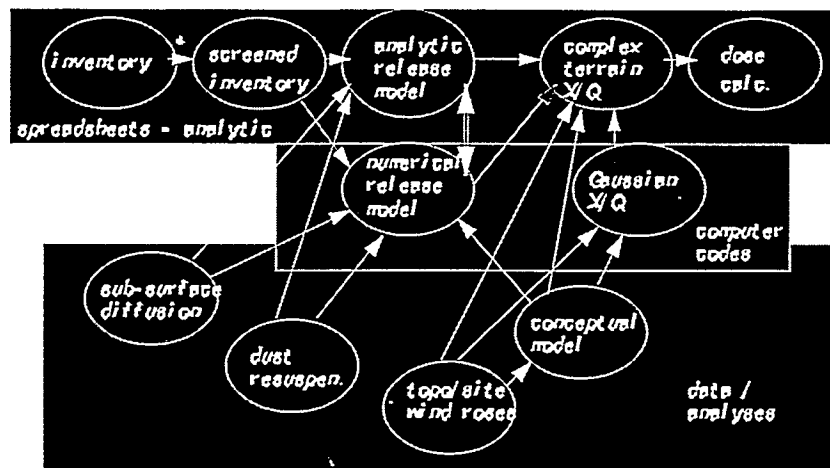


Fig. 6 Atmospheric transport and data flow for complex terrain dispersion.

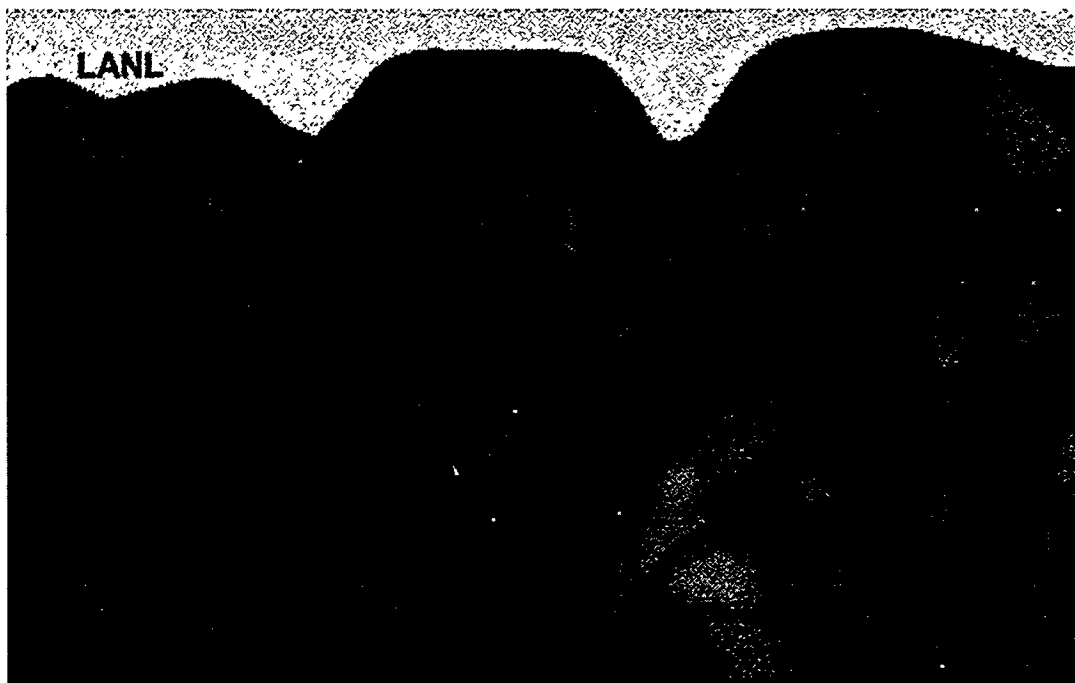


Fig. 7 Atmospheric dispersion simulation in Los Alamos complex terrain (ref: J. Bossert¹³). A normalized source is located at TA-21. Similar results are expected from Area G, TA-54.

TECHNICAL SUPPORT FOR THE EPA CLEANUP RULE ON
RADIOACTIVELY CONTAMINATED SITES

H. B. Hull, A. Newman, A. B. Wolbarst, M. Doehnert
Office of Radiation and Indoor Air
U.S. EPA (6603J)
Washington, D.C. 20460

and

J. Mauro, L. Ralston
S. Cohen and Associates
1355 Beverly Rd, Suite 250, McLean, VA 22101

ABSTRACT

The U.S. Environmental Protection Agency (EPA) is developing a radiation site cleanup regulation for the protection of the public from radionuclide contamination at sites that are to be cleaned up and released for public use. The regulation will apply to sites under the control of Federal agencies, and to sites licensed by the Nuclear Regulatory Commission (NRC) or NRC Agreement States. The agency is therefore conducting a comprehensive technical analysis aimed at developing information that will be used to support the rule. This presentation describes the regulation and the approach developed to determine how radiological health impacts and volumes of soil requiring remediation vary as functions of the possible cleanup dose or risk level.

INTRODUCTION

The United States Environmental Protection Agency (EPA) is responsible for protecting the public and the environment from exposure to ionizing radiation. As part of this responsibility, the Agency is developing a radiation site cleanup regulation which will establish a health-based cleanup standard to be attained at radioactively contaminated sites which are undergoing remediation to be released to the public.

This paper discusses recent technical and policy developments for the regulation. The information presented is preliminary in nature and is subject to change as the formal regulatory development process continues.

THE RADIATION SITE CLEANUP REGULATION

Purpose of the Regulation

EPA's goal in the development of the Radiation Site Cleanup Regulation is to establish clear, consistent, and protective health-based cleanup standards that are implementable. By doing so, the Agency will facilitate the cleanup of radioactively contaminated sites and promote the beneficial reuse of land (EPA 93). The Radiation Site Cleanup Regulation will not, however, mandate the cleanup of radioactively contaminated sites.

Responsibility of EPA

In developing the radiation site cleanup regulation, EPA plans to exercise its authority under the Atomic Energy Act (AEA), which sets forth the Agency's responsibility and authority to promulgate regulations to protect people and the environment from the harmful effects of ionizing radiation.

Applicability of the Regulation

The regulation will apply to sites contaminated with radioactive material that are under the control of a federal agency, such as the Department of Defense or Energy (DOE or DoD), and to sites licensed by the Nuclear Regulatory Commission or an "Agreement State". The regulation may also apply to Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)/Superfund sites as a potential applicable or relevant and appropriate requirement (ARAR). The cleanup standards will apply to an entire contaminated site, including exposures derived from radioactive materials in soils, ground water, surface water, and structures.

EPA may exempt NRC and Agreement State licensees from the cleanup regulation if the Agency finds that the decommissioning standards being developed by NRC are sufficiently protective of human health and the environment. This is in accord with a

Memorandum of Understanding (MOU) between EPA and NRC (57 FR 54127, November 16, 1992), which discusses how the agencies will avoid overlapping regulations.

Health-Based Dose Limit

The current staff draft of the proposed radiation site cleanup rule sets forth an overall individual dose limit for the site of 15 mrem/yr in excess of background radiation levels. This limit corresponds to a lifetime excess cancer risk level of approximately 3×10^{-4} over 30 years of exposure. A 3×10^{-4} risk is generally consistent with other environmental cleanup programs, as well as radiation protection standards.

In addition to the 15 mrem/yr standard, the rule proposes that the level of radioactivity at the site in any ground water that is a current or potential source of drinking water may not exceed either the individual Maximum Contaminant Levels (based on the Safe Drinking Water Act requirement) or background radiation levels, whichever is higher. The 15 mrem/yr standard may, in some instances, be obtained by implementing control measures (institutional controls, engineering controls) that prevent a radiation dose which exceeds the standard. This allows sites the flexibility of designating and accounting for, alternative land uses in cleanup actions. However, sites must demonstrate that doses would not exceed 75 mrem/yr above background if all controls were to fail.

TECHNICAL METHODOLOGY

In support of this rulemaking effort, EPA has conducted a comprehensive technical analysis of benefits and costs of alternative cleanup criteria. This paper presents the methodology used to determine how radiological health impacts and volumes of soil to be remediated vary as functions of the possible cleanup level. The analyses evaluate a set of typical sites that are considered representative of the universe of real sites to which this regulation will apply. For these "reference sites", the analytical work addresses: 1) the radiation doses and risks to an individual resulting from exposure, via all environmental pathways, to unit concentrations of radionuclides in soil; 2) the radionuclide soil

concentration, in units of pCi/g, that would have to be achieved in order to meet various possible individual dose or risk levels; 3) the quantity of soil that contains radioactivity in excess of any given radionuclide soil concentration; 4) the number of potential radiogenic cancers, and cancer deaths averted, by remediating the soil to the radionuclide soil concentration corresponding to the various individual dose or risk levels; and 5) the number of radiogenic health effects that might eventually occur among remediation workers and the general public because of the remediation process itself.

In order to quantify these health and cost impacts, EPA has developed and used a technical methodology (EPA 94) which can be summarized by the following steps:

- (1) Evaluate the magnitude of the cleanup problem. Identify and estimate the number of sites and approximate volumes of soil in the United States contaminated with radioactive materials.
- (2) Develop a set of models, scenarios, and assumptions that may be used to perform risk and dose assessments in support of the regulation.
- (3) Develop a set of reference sites that encompass the characteristics of the sites that may fall within the scope of the soil cleanup rule. A reference site is defined in terms of the radionuclide concentration contamination pattern and the environmental, hydrogeological, demographic, and land-use characteristics of the site.
- (4) Analyze the reference sites to determine: 1) the volumes of soil that must be remediated to achieve various levels of individual risk and/or dose; and 2) the number of potential radiogenic cancers averted, or caused, as a result of site cleanup to alternative risk-based cleanup goals.

In addition, EPA analyses supporting the rulemaking consider the issue of implementation. The analyses include the derivation of possible generic soil cleanup levels

that correspond to each of the alternative dose-based cleanup goals, and the evaluation of their practicality in light of the lower limits of detection of field and laboratory analytical techniques and the presence of variable natural and manmade background radiation.

Magnitude of the Cleanup Problem

Based on NRC, DOE, and DoD data, EPA has estimated that there are about 5000 sites known to be contaminated with radioactive materials in the United States. Included are sites on EPA's National Priorities List (NPL); sites under the authority of various Federal agencies, predominantly DOE and DoD; and sites licensed by the NRC and NRC Agreement States.

The identified radioactively contaminated sites have been placed into three major administrative categories: DOE, DoD, and NRC/Agreement State licensees. Most of the DOE sites fall under the DOE Environmental Restoration Program and are large, complex, and multi-functional facilities. These major sites encompass most of the contaminated soil that falls within the scope of the rule (DOE 94).

To facilitate the process of identifying and characterizing reference sites, a site categorization scheme was developed by EPA and representatives of DOE, DoD, and NRC. Eighteen functional categories were identified which cover the full range of sites containing radioactive materials. One of the eighteen categories is entitled "Entire Sites", and was created to account for large, unique, complex sites that cross functional category lines. Examples of such sites include the Hanford Reservation, Oak Ridge National Laboratory, the Savannah River Plant, and the Idaho National Engineering Laboratory.

Selection/Development of Pathways, Scenarios, and Models

Two sets of mathematical pathway models and exposure scenarios were selected/developed to perform risk and dose assessment in support of the rulemaking: those for assessing doses and risks to individuals assuming reasonable maximum exposure (RME)

conditions and those used to estimate the cumulative health impacts over time in the exposed populations (EPA 93). EPA also developed models and scenarios to compute risks to workers exposed during the remediation process.

Exposures and Risks to the RME Individual

The development of cleanup regulations for soil contaminated with radioactive materials must be based on potential radiation dose and/or risk to the public from all significant exposure scenarios, and pathways. The selection of exposure scenarios and pathways for deriving risks and dose involved a review of EPA guidance and standardized methodologies applicable to the performance of risk assessment. After the identification of the significant scenarios and pathways, potential candidate multimedia models were identified; EPA then selected specific pathway models for the analysis of reference sites.

The methodology for evaluating radiation-induced cancer risks was designed to be consistent and compatible with that used by EPA for evaluating cancer risks from non-radioactive hazardous chemicals. As such, the methodology generally follows the basic steps in the Superfund Remedial Investigation/Feasibility Study (RI/FS) process for baseline risk assessments, described in the EPA manual *Risk Assessment Guidance for Superfund/Human Health Evaluation Manual (RAGS/HHEM)* (EPA 89, EPA 91).

For the purpose of this rulemaking, EPA has evaluated three land-use scenarios: a rural residential scenario, a commercial/industrial scenario, and a suburban scenario. Pathways assessed by the rural residential scenario are:

- External radiation exposure from photon-emitting radionuclides in soil.
- Inhalation of resuspended soil and dust that contains radionuclides.
- Incidental ingestion of contaminated soil.

- Ingestion of ground water containing radionuclides transported from soil.
- Ingestion of home-grown produce (fruits and vegetables) contaminated with radionuclides taken up from soil.
- Ingestion of meat (beef) and milk containing radionuclides taken up by cattle grazing on contaminated plants (fodder).
- Ingestion of contaminated locally caught fish.

The suburban scenario makes use of the first five of these, and the commercial industrial employs the first four. Exposure assumptions differ among the three land use scenarios. Inhalation of radon (Rn-222 and Rn-220) and radon decay products from soil containing radium (Ra-226 and Ra-228) were also assessed.

Three pathway models were selected to perform the risk assessment calculations; DOE's RESRAD Version 5.19 (DOE 93), EPA PRESTO-CPG (EPA-87), and a code based upon an expanded version of EPA's RAGS/HHEM Part B equations. Following an analysis and comparison of the results, RESRAD was selected for the analysis of individual dose and risk at the reference sites.

Cumulative Population Impacts

To evaluate potential radiological impacts of a site on public health, it is not sufficient simply to derive the risks to the RME individual following cleanup. It is also necessary to derive the cumulative impacts to the population on and in the vicinity of the site. A simple cumulative population impacts model similar to the RAGS/HHEM equations was produced to assess cumulative population impacts. Alternative pathways were explicitly addressed in consideration of future land-use scenarios.

Development of Reference Sites

It is not feasible to assess fully all the sites that may fall within the scope of the rule because there are thousands of them, and many have highly complex contaminant, environmental, demographic, and ecological characteristics. Moreover, detailed site characterization data simply do not exist for most sites. Site characterization supporting the rulemaking was therefore limited to a representative sample of sites where characterization information is available.

Data on several hundred sites representing a broad range of administrative and functional categories were used to create a set of reference sites that are representative of: the major administrative categories of sites; the major functional categories of sites (e.g., weapons production and R&D facilities, fuel cycle facilities, materials licensees); the major facilities with unique characteristics (e.g., Hanford, Savannah River, Oak Ridge, etc.); the range of source characteristics (e.g., radionuclides, concentrations, depth and area of contamination, chemical and physical form); and the range of environmental settings (i.e., climatology, hydrogeology, demography).

For DOE facilities, EPA obtained data from Federal Facility Agreements, Records of Decision (RODs), and Remedial Investigation/Feasibility Studies (RI/FS) reports. For sites where RODs and RI/FS materials have not yet been completed, an attempt was made to obtain Preliminary Assessment/Site Investigation (PA/SI) reports; Environmental Audit Reports; Environmental Assessment Reports; Environmental Monitoring Reports; Environmental Data Packages; and Effluent Reports. Significant use was made of the DOE's Integrated Data Base (IDB). Data on DoD sites were obtained from similar sources. Data characterizing NRC licensed facilities came from site descriptions provided by the NRC in the preliminary draft of the Generic Environmental Impact Statement (GEIS) for the NRC rulemaking on decontamination and decommissioning, and documentation available on the NRC's Sites Decommissioning Management Program (SDMP).

Especially important and difficult to obtain, are soil volume versus radionuclide concentration curves. Sources of information include some RI/FS reports and a few aerial radiological survey reports.

Analysis of Reference Sites

Soil Cleanup Volumes for Reference Sites

EPA has calculated, for each reference site, the volume of soil that may need to be remediated at each site to ensure that no individuals will receive radiation exposures which could result in a lifetime cancer dose or risk exceeding the alternative risk-based cleanup goals ranging from .1 mrem/yr to 100 mrem/yr and 1×10^{-6} to 1×10^{-2} . A three-step process was used to estimate the volumes of soil at each reference site requiring remediation as a function of the cleanup levels:

Step 1 - Construct curves which relate the volume of soil as a function of contaminant concentration.

Step 2 - Determine the relationship between a given concentration of a radionuclide in soil and risks to individuals. This relationship was established for each radionuclide and each reference site and is defined as a site-specific dose or risk factor, which is expressed in units of dose or lifetime risk of cancer per pCi/g.

Step 3 - Using the site-specific risk factors and the site-specific soil volume versus contaminant concentration curves, determine the soil cleanup volume as a function of the dose or risk-based cleanup goals.

Radiological Impacts Due to Soil Cleanup

One of the benefits associated with site cleanup is the reduction in the cumulative exposure and associated health risks to the population residing on, or in the vicinity of, the

contaminated property following cleanup. For each reference site it is assumed that in the future, the site could be heavily populated, used extensively for farming, and that the groundwater is used extensively for domestic purposes.

The specific population exposure pathways addressed include:

- Direct radiation from living on contaminated soil,
- Inhalation of suspended dust,
- Exposure to indoor radon progeny,
- Ingestion of crops raised on contaminated soil, and
- Ingestion of contaminated groundwater

Cumulative population exposures and the adverse health effects attributable to these exposures were derived for each pathway and for time integration periods of 100, 1000, and 10,000 years. These alternative pathways and time periods were addressed explicitly for the consideration of future land-use scenarios and time periods of interest for the rulemaking.

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CONFIRMATORY/RELEASE SURVEY OF THE PROPERTY AT 71 PEARCE AVENUE
(FORMER EAD BUILDING) IN TONAWANDA, NEW YORK

Adela Salame-Alfie, Ph.D.
Robert Alibozek
New York State Department of Health
Bureau of Environmental Radiation Protection
2 University Place, Room 380
Albany, New York 12203
(518)458-6451

ABSTRACT

EAD Metallurgical, Inc., operated a facility in Tonawanda, New York, in which it utilized Americium 241 (Am-241) for the production of foil sources for use in smoke detectors. EAD was in operation between 1977 and 1983. By 1983, the company started losing money, and decided to relocate to Mexico. Before closing down its Tonawanda operation, however, it was required by the New York State Department of Labor (DOL) to decontaminate its facility to limits specified by DOL. No records of discharges to the sewer system were kept during this decontamination effort. Unsuccessful decontamination efforts by several EAD employees and contractors left the building contaminated, in particular the concrete floors and walls.

To determine the scope of work for the decontamination project, staff from the New York State Departments of Health (DOH) and Environmental Conservation (DEC) conducted a Characterization Survey of the facility in 1993. This survey identified contamination levels of Am-241 in excess of release limits throughout the building, in the soil outside the facility, in pipes for sewage and interior drainage, and in an 8 x 8 x 11 foot sump pit in the building.

DOH issued a request for proposals in early 1994 for the decontamination and subsequent decommissioning of the former EAD building, and NES/IES Inc. (NES) was awarded the contract to perform the remediation.

DOH's assignment was to provide an on-site presence to insure the completion of all agreed upon tasks, according to the terms of the contract and work plans submitted by NES. Additionally, the DOH staff acted as a liaison between NES, DOH, DEC and DOL central offices to review, comment and approve all changes or modifications to NES's approach to the decontamination efforts. The assigned staff was also responsible for conducting confirmatory sampling and surveys of all areas deemed releasable to DOL and DEC criteria by NES.

At the conclusion of the project, the property at 71 Pearce Avenue, including building and outside grounds was released for unrestricted use.

INTRODUCTION

EAD Metallurgical, Inc., operated a facility in Tonawanda, New York, in which it utilized Americium 241 (Am-241), a radioactive material, for the production of foil sources for use in smoke detectors. EAD was issued a license by the New York State Department of Labor (DOL) to possess and use radioactive materials. EAD discharged certain concentrations and quantities of Am-241 via the municipal sewer. Such disposal was not prohibited under 10 NYCRR Part 38 if done in accordance with the New York State Department of Environmental Conservation (DEC) regulations. Additionally, EAD was issued a permit to discharge certain quantities of Am-241 via monitored air releases by the DEC.

EAD was in operation between 1977 and 1983, during which time it apparently was quite successful, controlling 70% of the smoke detector foil market in the United States. However, by 1983, the company started losing money, and decided to relocate to Mexico. Before closing down its Tonawanda operation, however, it was required by DOL to decontaminate its facility to limits specified by DOL. This was carried out hastily, and unsuccessfully, by several EAD employees. Contrary to its radioactive materials license conditions and to the company's record-keeping practices during its years of operation, no records of discharges to the sewer system were kept during this decontamination effort. An inspection by DOL and subsequent investigations by DEC and State Department of Health (DOH), revealed that very high levels of Am-241 existed within the facility, in the sewer lines from EAD to the Tonawanda sewage treatment plant, in the Tonawanda sewage sludge incinerator equipment and other areas of the Sewage Treatment Plant and in the Town landfill.

Due to the nature and extent of the contamination and the circumstances surrounding the contamination, Governor Cuomo established a task force comprising representatives from DOH, DEC and DOL and the Attorney General's Office. Since 1985 the EAD Task Force

assisted the Town of Tonawanda in the cleanup of its sewage treatment plant and sewer lines contaminated with Am-241 caused by EAD using funds appropriated by NY State legislature for this purpose. A 1992 Court settlement resulted in funds provided to the State, with State assigned responsibility for the decontamination and decommissioning of the former EAD building and its surrounding property. A portion of these funds, \$1.08 Million, was appropriated to DOH for decontamination purposes. The DOH Bureau of Environmental Radiation Protection (BERP) was given the responsibility for the project. BERP worked with the other agencies comprising the Task Force on this project.

To determine the scope of work for the decontamination project, DOH and DEC staff conducted a Characterization Survey of the facility in 1993 [DOH93]. This survey identified contamination levels of Am-241 in excess of release limits throughout the building, in the soil outside the facility, in pipes for sewage and interior drainage, and in an 8 x 8 x 11 foot sump pit in the building.

DOH issued a request for proposals (RFP) in early 1994 for the decontamination and subsequent decommissioning of the former EAD building. Following review and evaluation of the submitted proposals, NES was awarded the contract to perform the remediation.

Under the terms of the contract, NES was responsible for performing the following tasks:

- Remove contaminated wall, floor, and ceiling surfaces
- Remove contaminated utilities (HVAC system, electrical wiring, and above and below ground piping).
- Remove and treat contaminated water to DEC release limits
- Excavate and remove the sump pit and contaminated soil
- Excavate and remove sub-floor contaminated soil
- Excavate and remove contaminated soil outside the building
- Remove vault and sump room concrete pad
- Remove and replace a section of the North wall in the sump room

- Package and ship all radioactive waste to Envirocare in Utah
- Perform a final release survey according to NUREG/CR-5849 [NRC93]
- Prepare a final report

BERP's assignment was to provide an on-site presence to insure the completion of all agreed upon tasks, according to the terms of the contract and work plans submitted by NES. Additionally, the BERP staff acted as a liaison between NES, DOH, DEC and DOL central offices to review, comment and approve all changes or modifications to NES's approach to the decontamination efforts. The assigned staff was also responsible for conducting confirmatory sampling and surveys of all areas deemed releasable to DOL and DEC criteria by NES. This sampling and survey included: all "clean" waste to be released, interior building surfaces, roof surfaces, soil affected by EAD operations, and water potentially contaminated by contact with affected soils and surfaces. The release limits agreed upon by the Task Force are given in Table 1. Other responsibilities included providing on-site verification that the B-25 boxes used for shipment of radioactive waste met the removable contamination limits established by the Department of Transportation (DOT) as set forth in 49 CFR, as well as the concentration limits set forth by Envirocare. To meet these objectives, all samples used to establish contamination levels or to confirm that NES had successfully met the established release limits were prepared for shipment, following chain of custody procedures, to the Department of Health's Wadsworth Center for Laboratories and Research (WCL&R) for an official analysis. Additionally, NES verified that the concentration limits had not been exceeded by taking two samples of representative waste streams from areas known to have elevated readings.

The DEC's Bureau of Radiation staff was responsible for confirming that the soil on the site grounds and beneath the floor slab, as well as the treated water, met the release criteria established by their department. To accomplish this task, DEC staff made periodic site visits to conduct surveys of areas under their jurisdiction. Samples obtained, however, were turned over to the DOH for analysis.

The DOL staff conducted a verification survey and collected wipe samples from the floors and walls.

CONFIRMATORY SURVEY

The objective of the confirmatory survey was to verify that the decontamination efforts of NES met all applicable release limits for residual radioactive contamination, as stipulated by the DOL and DEC (Table 1).

To facilitate the timely closure of exterior excavations, release of treated water to the sanitary sewer and avoid delays caused by weather problems, certain portions of the survey were conducted concurrently with decontamination activities. These areas included:

1. Exterior sewer line trench
2. Interior sewer line trench
3. Manufacturing area exterior roof
4. Office area exterior roof
5. Treated sump and flood water
6. Sump pit soil
7. Sub-slab soil
8. Exterior concrete slab excavations

Survey Methods

The confirmatory surveys consisted of different measurements using appropriate instruments, and sampling activities. These included:

- Surface alpha and gamma measurements
- Wipe or smear samples for removable alpha contamination
- Systematic and bias soil samples at 0-5 cm or 0-15 cm
- Roofing stone and tar

- Treated and untreated water
- Representative samples of "clean" debris
- One meter surficial gamma exposure rate measurements for outdoor locations
- Wipe samples of B-25 boxes for DOT contamination limits
- Representative background readings and samples in the Tonawanda area.

Instrumentation

Gamma measurements of surface and soil contamination were made by counting the 59.5 KeV photon associated with Am-241 decay using a Bicron 5 inch Sodium Iodide (NaI) FIDLER probe, Model GLLB, mated with a Ludlum #2221 single channel analyzer optimized to detect the Am-241 gamma. Typical four Pi (4π) efficiency for this detector system was about 13%. This probe was used in all indoor floor and sub-slab areas, trenches, roof surfaces, exterior soils (both on-site and off-site), lower wall surfaces, parking lots, "clean debris", and other areas to determine if there may have been contamination characteristic of Am-241, masked by a covering material, and thus undetectable by an alpha detector.

Alpha measurements were made using Eberline ESP-1 meters coupled with either Eberline AC- 3 or Ludlum 43-89 alpha scintillation probes for all but floor surfaces. Floors were surveyed using a Ludlum 239-F floor monitor with a Ludlum 2221 pulse rate meter. The confirmatory alpha measurements were only made on indoor surface and roof areas for this survey. However, Am-241 contamination was deemed to be present if the gamma measurements showed levels of approximately twice background. This was based on an initial correlation between the FIDLER reading and actual soil analysis developed by NES. Twice background equaled approximately 15 pCi/g, which is half the value of the release limit.

Since some areas had not been sampled/surveyed due to lack of access or time constraints during the characterization phase, it was necessary to survey more than the 10 percent recommended in NUREG/CR-5849 [NRC93] prior to release. The survey and

sampling technique employed was similar to the EPA procedures used for characterization, which provided a total of thirteen sampling grids per quadrant.

For example, the exterior sewer line was not sampled in 1993 but was assumed to be contaminated, based on downstream contamination in the line and at the sewage treatment plant. Soil around the pipe was not accessible, therefore, following excavation of the pipe, gamma measurements, using the Bicron FIDLER, and soil samples were obtained to characterize the extent of the contamination in the soil around the sewer pipe. Following remediation and release by NES, a 100% gamma scan of the trench walls and floor was performed, and systematic soil samples were obtained at intervals that coincided with the joints of the sewer pipe, connection and exit from the manway, and at the juncture with the main line at the street.

Other areas, such as outside the east door, required repeated 100% scans and sampling due to the discovery of buried Am-241 foils not detected prior to flooding and soil disruption by movement of excavating equipment.

Each section of the building, including roof, floor, ceiling and walls was divided into quadrants, such that each section would appear to be a separate entity. Each of the grid locations chosen were surveyed completely for both alpha and gamma emissions using a 100 cm², 59 cm² or 425 cm² alpha probes and the FIDLER or 2 inch NaI low energy gamma probes. At each designated location, the area with the highest reading during the scan was then chosen to obtain a one minute count. A wipe sample of the highest area was then taken to determine removable activity. Before shipment to the WCL&R, all swipes taken by the DOH were counted in the field using a Ludlum 2200 ratemeter and a Ludlum 43-10-1 alpha counter. This was done to expedite follow-up remediation by NES if removable contamination found approached the DOL limits.

Outdoor areas were surveyed with the Bicron FIDLER by both the DEC and DOH at different times. The DOH survey was conducted primarily in what was considered an "affected area," which included all of the fenced-in area, front of the building, and east side

to the property line. An approximate 5 x 10 meter paced grid was used with a one minute contact reading taken at each point. Systematic and bias soil samples of 0-15 cm depth were taken in unpaved areas. A separate 10 x 10 meter grid was established for an area outside the east door, where most of the soil particles were discovered and was most affected by flooding and soil movement. This area was surveyed on two different dates prior to the final survey; before grading and after grading for water runoff. Surficial gamma exposure rates ($\mu\text{R/hr.}$) at one meter above the ground surface were also obtained at the same points in the affected areas.

WASTE HANDLING

The contract with NES included dismantling and discarding all roof HVAC systems and wall partitions in the office area. Materials located in the manufacturing area were considered to be contaminated and were packaged as radioactive waste. All materials from the office area were scanned and swiped for contamination. Clean materials were disposed as clean waste by a local commercial waste hauler.

DOH was responsible for performing surveys and sampling of approximately 10% of all materials discarded as "clean" waste. Periodic grab sampling of items designated for disposal by NES were surveyed with both a FIDLER for gamma and an Eberline ESP-1 and AC-3 alpha probe. Swipe samples were obtained from representative materials and counted on-site to determine levels of removable contamination. Special attention was given to interior portions of duct work and HVAC components, since removable contamination had been detected in air conditioning ducts located in the office area. These swipes were also sent to WCL&R for confirmatory analysis. Of the approximately 200 swipes taken of discarded clean waste, the highest level of removable contamination detected was 5 dpm/100 cm^2 . This was below the 33 dpm/100 cm^2 allowed by DOL, and therefore, all "clean" waste was released by DOH.

Radioactive waste included all materials located in the former manufacturing area. This consisted of: sheetrock, fiberglass insulation, wall studding, ceiling tiles, grids,

electrical wiring, plumbing and fixtures, cement block, steel shot and dust from the Blastrac, water filters, concrete flooring chunks, soil, exhaust ducts and decontamination materials used by NES. All radioactive waste was packaged in B-25 steel boxes supplied by Envirocare. NES agreed to act as the shipper of this waste, and thus being responsible for the contents of the shipping containers. New York State DOH was the generator of record. All shipping containers (B-25 boxes) transported to Envirocare had to meet USDOT 49 CFR shipping requirements. As a confirmatory measure, DOH performed a duplicative test with NES, for removable alpha contamination. The DOT standard for removable alpha contamination is 2.2 dpm/cm² averaged over 300 cm².

To insure these boxes met the DOT requirements, DOH staff took 300 cm² swipes of each surface of the B-25 container and counted the sample on-site, prior to loading boxes on the transport vehicle. No sample taken by DOH exceeded the removable contamination limits of DOT. The highest level detected was 41 dpm/300 cm² or about 14 dpm/100 cm², which would also have met DOL limits of 33 dpm/100 cm². A total of 6,500 ft³ of radioactive waste were shipped to the Envirocare facility in Utah.

CONCLUSIONS

The primary objective of the DOH was to insure that the chosen contractor (NES) for the decontamination of the former EAD building in Tonawanda, N.Y., met all of the requirements stipulated by the Task Force and stated in the contract. Specifically, that the building and grounds could be released for unrestricted use by DOH, the DOL and the DEC.

After the DOH reviewed the final release survey submitted by NES, as well as the confirmatory survey reports of both the DOL and the DEC, the DOH staff concluded that all phases of the mitigation contract with NES were fulfilled and the property at 71 Pearce Avenue, formerly known as the EAD building, could be released to the owner for unrestricted use.

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TABLE 1. New York State Release Criteria for EAD Facility.

Limit	Removable Average dpm/100cm ²	Removable Maximum dpm/100cm ²	Fixed Average dpm/100cm ²	Fixed Maximum dpm/100cm ²	mRem/hr @ 1 cm	Concentration
Alpha Emitters	33	100	1,000	3,000		
Beta - Gamma Emitters	220	1,100			0.2	
Soil (pCi/g)						30
Water (pCi/l)						20

SELECTING REASONABLE FUTURE LAND USE SCENARIOS

William E. Allred
P.O. Box 1625
Idaho National Engineering Laboratory
(208) 526-5052

Robert W. Smith
P.O. Box 1625
Idaho National Engineering Laboratory
(208) 526-9345

ABSTRACT

This paper examines a process to help select the most reasonable future land use scenario(s) for hazardous waste and/or low-level radioactive waste disposal sites. The process involves evaluating future land use scenarios by applying selected criteria currently used by commercial mortgage companies to determine the feasibility of obtaining a loan for purchasing such land. The basis for the process is that only land use activities for which a loan can be obtained will be considered. To examine the process, a low-level radioactive waste site, the Radioactive Waste Management Complex at the Idaho National Engineering Laboratory, is used as an example. The authors suggest that the process is a very precise, comprehensive, and systematic (common sense) approach for determining reasonable future use of land. Implementing such a process will help enhance the planning, decisionmaking, safe management, and cleanup of present and future disposal facilities.

INTRODUCTION

The ultimate risk to human health by waste disposal activities result from exposure to waste. One pathway is the inadvertent intruder. Regulations^a developed for low-level radioactive waste (LLW) management and land disposal contain performance objectives that, if complied with, will protect individuals from inadvertent intrusion onto a LLW land

a. Requirements for the regulation of LLW disposal sites are contained in Title 10, Code of Federal Regulations, Part 61 (10 CFR 61), "Licensing Requirements for Land Disposal of Radioactive Waste" and Department of Energy (DOE) Order 5820.2A, "Radioactive Waste Management," Chapter III, Management Of Low-Level Radioactive Waste (see References 1 and 2).

disposal site.^{1,2} The evaluation of these performance objectives include implementing future land use scenarios developed while preparing 10 CFR 61. The future land use (inadvertent intruder) scenarios developed for 10 CFR 61 are standardized and also deterministic; that is, they are simply assumed to occur without attempting to assign a probability to their occurrence. These scenarios are very conservative and are selected to reasonably overestimate the exposure/doses that may result from a given disposal site. Time and effort involved in considering such conservative scenarios can result in increased disposal costs. Putting safety factors and compliance with regulations in perspective, this paper suggests an alternate approach. This approach uses a process to evaluate more reasonable and realistic future land use scenarios. The basis for this process is that only activities for which commercial financing can be obtained should be considered as reasonable. Such a process requires using criteria that depend on specific land use practices and location. The process applies selected criteria currently used by commercial mortgage companies to determine the feasibility of obtaining a loan for purchasing land. To examine the process, an actual LLW site, the Radioactive Waste Management Complex (RWMC) at the Idaho National Engineering Laboratory (INEL), is used as an example. The example site is viewed at least 100 years after closure. The intrusion onto the site would be inadvertent, that is, the intruder would not recognize the LLW disposal site. Also, to validate findings from the process, a case study involving land use adjacent to the INEL is provided. Although the conclusions reached in the paper are specific only for the RWMC at the INEL, the process with supporting analysis is widely applicable, defensible, and can be used for any type of disposal.

INEL DESCRIPTION AND LAND USE

The INEL is located within the eastern Snake River Plain in southeastern Idaho, and comprises approximately 890 square miles. The RWMC is located near the southwestern corner of the INEL Site (see Figure 1).

The environment at the INEL, RWMC, and adjacent area consists of arid sagebrush desert at an average elevation of 5,000 feet. The area receives an average annual

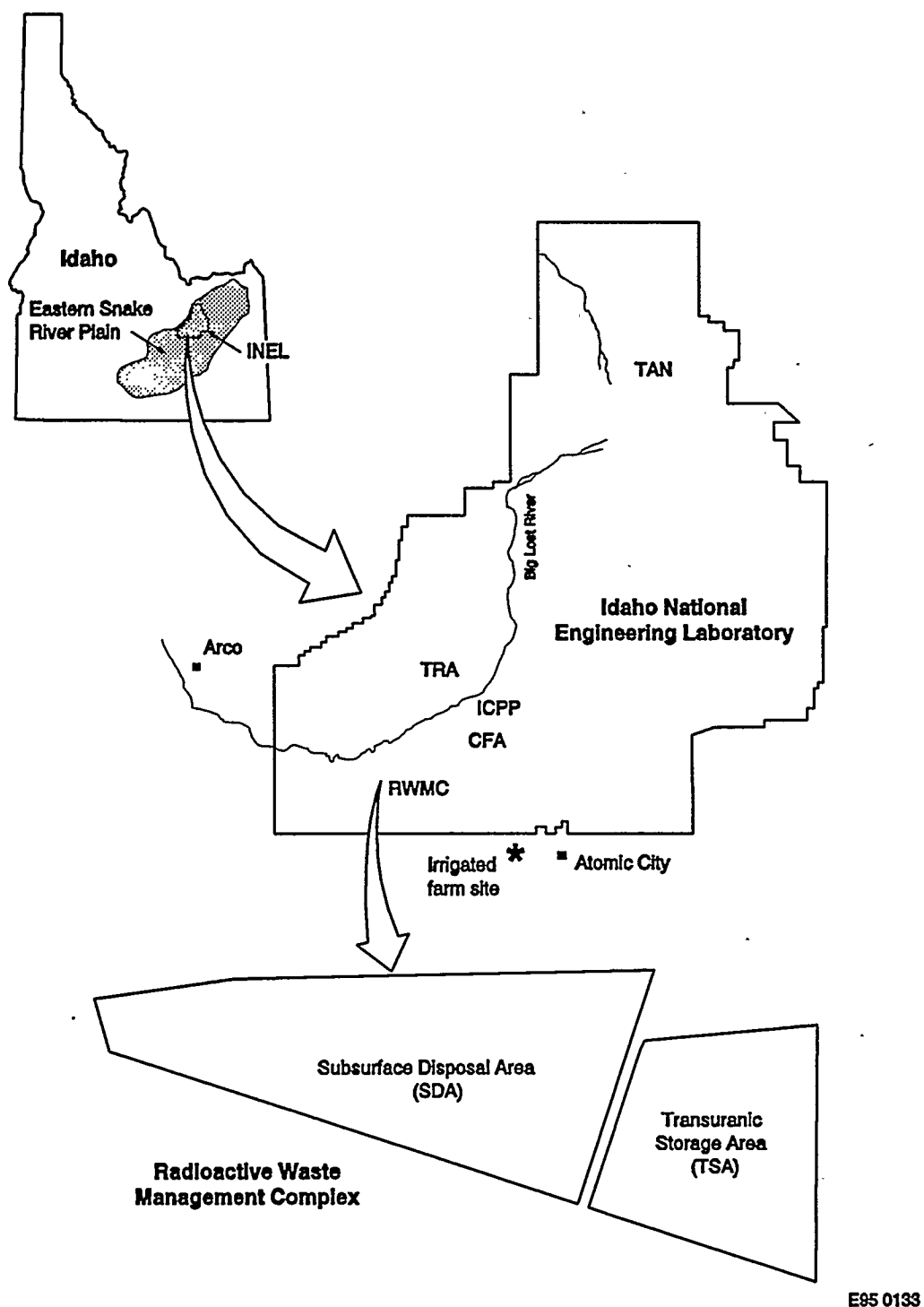


Figure 1. Overview of the INEL and the RWMC.

precipitation of 8.5 inches, and daily air temperature extremes can vary from -30°F in January to over 100°F in July. Surficial deposits of the area, except for some outcropping of basalt (lava) flows, consist of moderate to deep sandy loam soils (approximately 25 feet). In the southwestern part of the INEL, these soils have low water-holding capacity. In dry years, surface water in the area is essentially nonexistent. The INEL Site covers the north-central portion of the Snake River plain aquifer. Depth to groundwater ranges from approximately 200 feet in northern portions of the Site to 900 feet in the southern portions. The depth to the groundwater at the RWMC is approximately 575 feet. The RWMC resides in a small depression with flat to rolling topography.^{3,4}

Future use of much of the INEL land, other than for the INEL mission^b, is limited because of the climate, lava flows, and general desert soil conditions. Because of the limitations and location of the land, it is not probable that a community would be established in the future at the RWMC. It is more likely that the area could be used for agricultural purposes, mostly livestock grazing. If adjacent lands were used for irrigated farming, then the RWMC area could become part of the irrigated operation. Since surface water is almost nonexistent, this irrigation would come from wells. Some private ground next to the southern boundary of the INEL has been used in the past for irrigated farming (see Case Study below). Dry farming of small grains, although a remote possibility, is also a likely scenario.

Because of these reasons, the likely inadvertent future land use scenarios for the RWMC area are (1) livestock grazing, (2) irrigated farming of alfalfa and small grains by use of wells, (3) irrigated farming of row crops such as potatoes or sugar beets by use of wells, and (4) dry farming of small grains.

The RWMC example only considers the most likely inadvertent intrusion scenarios that are agriculturally related. Because of this relationship, farm credit organization loan criteria is used to evaluate these scenarios.

b. On the basis that the intrusion would be inadvertent, future land use scenarios for INEL activities are not considered in this paper.

LOAN CRITERIA AND APPLICATION

The basis for the process examined in this paper is that only land use activities for which a loan can be obtained will be considered reasonable. To obtain such a loan, a loan application has to pass certain criteria (standards currently used by most mortgage companies). Through interviews with several farm credit organizations in southeastern Idaho, we discovered five criteria used in evaluating loan requests:^c

1. **Site History** - This criteria requires that historical records and history of land use be examined. Site activity history will not be considered as a factor in the RWMC example (on the basis that the intrusion would be inadvertent with no knowledge of site activity history).
2. **Characteristics of Site** - This criteria requires examination of the environmental aspects of the site, including climate, soils/geology, hydrology, and topography. Also, adjacent land use would be an important factor to consider.
3. **Legally Permissible** - This criteria requires examination of the legal requirements for land use, including zoning requirements, known land use restrictions, and water rights (legal access to water in the area). Current legal requirements will be used as a factor in the RWMC example.
4. **Economically Feasible** - This criteria requires examination of such issues as salability of the land, marketability of product produced on the land, location of the property, and access to water, markets, utilities, and roads. An important factor in the example given in this paper would be the current economic break-even point for pumping groundwater (lift in feet from the

c. Information was obtained during interviews with R. G. Morrison, appraiser, Farm Credit Services, Idaho Falls, Idaho, and D. Allred, Vice President, Eastern Idaho Agriculture Credit Association, Rexburg, Idaho.

source of water to the surface) for crop irrigation purposes. Mortgage personnel have determined that the break-even point for pumping water in southeastern Idaho is 300 feet for small grains and alfalfa, and 400 feet for row crops such as potatoes and sugar beets.

5. **Maximum Productivity** - This criteria requires examining alternatives to determine the land use with the highest net return. Important factors in the RWMC example are to determine if it would be more profitable to use the land for grazing, dry farming (growing small grains), or irrigated farming (growing row crops such as potatoes).

Table 1 compares the likely future land use scenarios identified in this paper with the given agriculture loan criteria and the RWMC site characteristics. This will identify the selected scenario(s) (i.e., only land use activities for which a loan can be obtained will be considered.)

The scenarios in Table 1 were evaluated by farm credit personnel, who indicated that only one scenario, livestock grazing, would be capable of obtaining a loan.

CASE STUDY

This case study analyzed an actual attempt to use land next to the southern border of the INEL for an irrigated farming operation. The attempt, which was financed by a local bank, was not successful and the land was repossessed.

Situation

Much of the land in areas next to the INEL is Federal or State owned (public) and primarily used for controlled livestock grazing. This undeveloped land is arid, sagebrush desert with soils that have moderate to severe irrigation limitations. However, a piece of privately owned land that is in the same area as the public land and the RWMC (bordering

Table 1. Evaluation of Land Use Based on Loan Application Criteria.

Loan Criteria	RWMC Characteristics	RWMC Land Use Inadvertent (LIKELY) Scenarios			
		Livestock grazing	Irrigated Farm (grain)	Irrigated Farm (row crop)	Dry Farm (grain)
1. History of Site^a	Other than site activities, agricultural	Adequate	Prohibitive	Prohibitive	Limited
2. Characteristics of Site					
Climate	Climate is arid, desert sagebrush type with annual precipitation of 8.5 inches.	Adequate	Prohibitive	Prohibitive	Limited
Soils/Geology	The soils have moderate to severe irrigation limitations.	Adequate (controlled grazing)	Prohibitive	Prohibitive	Prohibitive
Hydrology	The surface water is limited, ground water depth is approximately 570 feet.	Limited (one stock well might pay)	Prohibitive	Prohibitive	Prohibitive
Topography	The RWMC is in a depression with the area having flat to rolling type of topography.	Adequate	Limited	Limited	Limited
Adjacent land use	Adjacent land mostly used for controlled livestock grazing.	Adequate	Limited	Limited	Limited
3. Legally Permissible					
Current legal requirements (zoning, land use restrictions, water rights)	The RWMC is currently on a Federal Reservation.	— ^a	— ^a	— ^a	— ^a
	Intruder would follow permissible legal requirements at time of intrusion. Access to water (water rights) would be important factor.	Adequate	Limited	Limited	Adequate
4. Economically Feasible					
Current salability of land	Salability of land would be in the category of marginal ground sales (i.e., livestock grazing).	Adequate	Limited	Limited	Limited
Access to water, markets, utilities, roads	Surface water is limited and access to groundwater may be prohibitive (570 feet to groundwater).	limited (may be adequate with stock well)	Prohibitive	Prohibitive	Limited
Marketability of product	This will depend on product (i.e., livestock produced on land could be profitable). Cost might be prohibitive for cultivated crops (cost of access to water).	Adequate	Adequate	Adequate	Adequate
Improvements	Cost may be prohibitive for type of ground.	adequate	Prohibitive	Prohibitive	Limited
5. Maximum Productivity					
Land use alternatives with the highest net income	Maximum productivity of land would be non-cultivated marginal ground (i.e., grazing of livestock).	Adequate	Limited	limited	Limited
	Is Scenario Capable of Obtaining Loan ^b ?	Yes	No	No	No

a. DOE site activity history will not be considered as a factor in this study (on the basis that the intrusion would be inadvertent with no knowledge of DOE site activity history.)

b. Evaluated by farm credit personnel.

Atomic City, see Figure 1) was developed and used for a period of time as an irrigated farm (one of the likely scenarios depicted in this paper).

This private land was originally used for livestock grazing, the same use as other land in the immediate area. Because the price of agriculture land was high at this time (1970–1980s), the owner put this piece of land up for sale. At the same time, several financial entities thought it a good risk to finance land that would be developed and used for growing cash crops such as small grains and potatoes. Access to irrigation water, groundwater in this case, was much more flexible during this period as far as water rights and obtaining water permits were concerned. Depth to groundwater did not seem to be discussed at the time.

A local bank financed a local farmer to purchase the land. The farmer had a good history in developing and operating such land. He developed the land by cultivating it and constructing an irrigation well with a circular sprinkler system. The farmer found that this type of land needed a tremendous amount of water per acre to grow cultivated crops. This factor, and the depth to the groundwater, contributed to very significant operational costs. Due to operational costs and the cost of development, this farm went financially broke in just a few years. The bank repossessed the land and improvements, and tried to move it on the market. The land was not salable for quite a period of time. The bank finally sold the land to a local County (Bonneville County, who was looking for a landfill area) at a depressed price. Later, Bonneville County traded this land to a different farmer/rancher. The new owner is currently using the land at Atomic City for grazing purposes and has used the well for stock water.

Analysis

The reasons that this cultivated irrigation operation was not successful relate back to the agriculture loan criteria described in this paper. Two primary reasons are: (1) The soils in this area have moderate to severe irrigation limitations. It would take a significant amount of water for row crops to be successfully grown to maturity; (2) Surface water is limited (snow melt and rain) and groundwater depth is over 500 feet. Current standards for growing crops such as potatoes (economic break-even point for well lift of water) is 400 feet. Currently, local agricultural financial institutions feel that it would not be feasible for this type of operation on this land. More likely, the maximum productivity of such land would be non-cultivated use in livestock grazing.

SUMMARY

The use of selected criteria currently used by mortgage companies to determine the feasibility of obtaining a loan for purchasing land can be an excellent (common sense) process for determining reasonable future use of land.

In the example given in this paper, only one scenario, grazing of livestock, would be reasonable for the RWMC. This type of scenario is much less restrictive than a residential scenario with basements and gardens. With a less restrictive scenario, funds spent for over-conservative scenarios at this site could be put to better use at other sites proven to be much more restrictive by such a process.

Such a process will help enhance the planning, decisionmaking, safe management, and cleanup of present and future disposal facilities. The process is defensible, easily understood and well established.

ACKNOWLEDGEMENTS

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A MOWER DETECTOR TO JUDGE SOIL SORTING

Edward T. Bramlitt (presenting author) and Nels R. Johnson
Thermo Nuclear Services, Inc.
5635 Jefferson Street NE
Albuquerque, NM 87109
(505) 345-9931/Fax (505) 761-5410

ABSTRACT

Thermo Nuclear Services (TNS) has developed a mower detector as an inexpensive and fast means for deciding potential value of soil sorting for cleanup. It is a shielded detector box on wheels pushed over the ground (as a person mows grass) at 30 ft/min with gamma-ray counts recorded every 0.25 sec. It mirrors images detection by the TNS transportable sorter system which conveys soil at 30 ft/min and toggles a gate to send soil on separate paths based on counts. The mower detector shows if contamination is variable and suitable for sorting, and by unique calibration sources, it indicates detection sensitivity. The mower detector has been used to characterize some soil at Department of Energy sites in New Jersey and South Carolina.

THE PLANNING, CONSTRUCTION, AND OPERATION OF A RADIOACTIVE WASTE
STORAGE FACILITY FOR AN AUSTRALIAN STATE RADIATION REGULATORY
AUTHORITY

J.D.Wallace, R.Kleinschmidt & P.Veevers
Radiation Health, Queensland Health Dept., AUSTRALIA
December, 1995

ABSTRACT

Radiation regulatory authorities have a responsibility for the management of radioactive waste. This, more often than not, includes the collection and safe storage of radioactive sources in disused radiation devices and devices seized by the regulatory authority following an accident, abandonment or unauthorised use. The public aversion to all things radioactive, regardless of the safety controls, together with the Not In My Back Yard (NIMBY) syndrome combine to make the establishment of a radioactive materials store a near impossible task, despite the fact that such a facility is a fundamental tool for regulatory authorities to provide for the radiation safety of the public. In Queensland the successful completion and operational use of such a storage facility has taken a total of 8 years of concerted effort by the staff of the regulatory authority, the expenditure of over \$2 million (AUS) not including regulatory staff costs and the cost of construction of an earlier separate facility. This paper is a summary of the major developments in the planning, construction and eventual operation of the facility including technical and administrative details, together with the lessons learned from the perspective of the overall project.

BACKGROUND

In 1986, the Queensland state radiation regulatory authority (Radiation Health), identified the urgent need for a purpose built radioactive materials store to replace the barely adequate facility in use at the time which was essentially a modified world war II air raid shelter. This store was in the central business district of the city of Brisbane (pop. 1.5 million) within several metres of the Brisbane river and immediately beneath a 30 metre high cliff face which had experienced several boulder shedding incidents. In addition to this, the store was dusty, had no artificial lighting and was historical in that there was an incomplete inventory record and no corporate memory in relation to the first use of the facility as a

store. As the store was not purpose built and lacked even the most fundamental of facilities, some of the devices had not been examined since they were placed in the store perhaps more than 20 years before. The weight of many of the devices and packages and the lack of any handling facilities, combined with the restrictive internal dimensions of the store resulted in radiation gauges, transport containers and packages simply being left on the floor with all floor space eventually being taken up.

It was clear from the need to walk on the gauges and packages to move through the store and the projected rapid growth in use of radioactive sources in Queensland, that the existing facility was well past its use by date and in urgent need of replacement. The limitations on physical capacity together with the serious safety related concerns regarding the location of the store made it imperative that the existing facility no longer accept sources for storage. Additionally the store should be replaced with a purpose built facility with appropriate capacity to enable relocation of the contents of the old store and to handle the projected waste storage requirements for the next 20 years.

PLANNING

The approach adopted by Radiation Health to deal with this situation was:

- (i) Advise licensees (approximately 300 with a total of over 2000 sealed radioactive sources) that the state regulatory authority was no longer able to accept waste radioactive sources pending construction of a new storage facility. Licensees were required to either store their waste in the short term or return the sealed sources to the original supplier, with specific approvals to do so being obtained from the relevant regulatory authority in the jurisdiction to which the sources were to be returned. Copies of such approvals were to be submitted to Radiation Health to obtain approval to transfer the sources concerned. This approach being consistent with the IAEA transboundary code.

- (ii) Advise the department of Health of the situation and seek funding for the planning and construction of a purpose built storage facility on government land in proximity to the Radiation Health work unit.

Site selection for all new government facilities at the time was undertaken by another state government department (the Administrative Services department). The site selected was state government land at Redbank (an outer Brisbane Industrial site).

A new storage facility was constructed on the site at a cost of approximately \$1.2 million and was completed by mid 1989. The selection of the site and construction of the facility attracted considerable protest by way of individuals occupying the construction site, some minor vandalism and one case of serious vandalism involving a potential threat to life for the construction workers. Several members of the then opposition party attended protest rallies at the Redbank site and were arrested by the Police along with many other protesters. The government of the day decided that it would not use the facility until after a state election which was set for December 1989. During the course of the election campaign the leader of the opposition party gave an undertaking to the electorate that, if elected, they would not allow the use of the Redbank facility and would commission consultants to examine a number of sites to select an alternative location for a new storage facility.

While the siting of the storage facility was not a major issue in the election campaign, the election resulted in a change of government. The immediate result was that an instruction was issued for the department to divest itself of the Redbank facility and consequently the facility was never used. There was an investigation of several alternative uses for the store however the specialised nature of the facility meant that it was unsuitable for any purpose other than that for which it was originally designed.

The development of a further new storage facility was then required. The process of planning for the store was restarted with requirements for the facility considered afresh. The requirement identified was for a robust, secure construction designed to resist all but the most determined efforts at intrusion. The facility was to provide in excess of 100 m² of

useable storage area and be such that no member of the public would receive a dose in excess of 0.5mSv per year. In reality the actual doses to members of the public would be much less than this.

The store would be constructed as three separate storage chambers, with individual security doors. One of the chambers was to be designed specifically for the storage of radium. The radium store door was to be a solid steel covered door with edge seals to minimise the loss of any radon gas leaks.

A consultancy firm was hired to assess 73 potential sites within 150 kilometres of Brisbane. The Redbank site was included in the 73 sites. Ranking of the suitability of sites identified the top 10 sites of which Redbank was one. The government selected two sites (near Esk and Beerburrum), both within state forests and about 120 km from Brisbane, for further detailed study.

CONSULTATION

A process of community consultation was undertaken in these two areas while the detailed study was completed. This consultation took the form of information pamphlets distributed in the mail, public meetings, meetings with interest groups such as local protest groups and local government organisations and setting up special public presentation and information booths. These information booths were staffed by a senior radiation physicist from the regulatory authority, a senior staff member of the Minister's office and an assistant and were established on a rolling basis, in five locations in and around the two areas under detailed site investigation.

Several hundred individuals attended the information booths. The main concern of most of these individuals was based on misinformation disseminated by the lead protest group known as CARD (Citizens Against Radioactive Dumps) and centred around the emotive term "dump". The overwhelming majority of people believed that the facility was to be a dump or disposal site and there was a perception that a great deal of the material would be liquid

waste which would leak and contaminate the surrounding area and eventually get into the water supply.

Individuals, the media, the CARD group and local government representatives were all advised of the clear government policy of not storing liquid sources at the proposed facility and that the facility was to be a storage facility only and not a disposal site.

Many people maintained that the facility was to be a "dump" site and continued to fan further concern regarding possible contamination of the water supply by liquid wastes, despite the fact that the intended purpose and proposed contents of the store were clearly identified and the government indicated its intention to sign an agreement with the local shire council specifying the nature of the store and the limits to be imposed on acceptance of sources into the store.

Such was the hysteria associated with the site selection process that several people were uncontrollably emotional when discussing issues associated with it and genuinely believed that the facility represented a major threat to them and their families finances and health. Two examples are worth relating briefly:

- (i) The first case involved a strawberry farmer. This individual was emotionally distraught and could barely talk coherently as he expressed his fear that the "dump" would mean his livelihood would be seriously threatened because radioactive material may leak into the ground and this possibility would have a negative impact on produce sales.

He was somewhat calmer when it was pointed out to him that the hydrology probes used to plan irrigation programs incorporated sealed radioactive sources and that these sources were actually placed briefly into the ground to undertake moisture level measurements. He was aware of this procedure and yet remained unconcerned despite the sealed sources intimate contact (within the probe) with the ground.

- (ii) The second case involved an elderly couple who had lived in the area for most of their lives. They were concerned that we should know about the earthquakes in the area. They believed that an earthquake would result in the store collapsing or failing in some way that would result in damage to the stored containers and lead to a leak of radioactive material and contaminate the entire area. Discussion revealed that they were in fact content to continue living in a house not designed or built to survive earthquakes which had suffered some minor damage from several earthquakes/tremors over the last half century. It was identified that the storage facility was to be a very substantial robust reinforced concrete construction, designed and built to survive an earthquake at least one level higher on the Richter scale than the maximum strength earthquake ever recorded in that region.

In both of these cases individual perceptions of the potential problems combined with misinformation about the nature of the facility and its contents by some of the protest groups lead to unfounded concerns and unnecessary worry. Despite this the information booths were able to provide an accessible avenue for the local community to accurate information concerning the storage facility.

In 1992 a decision was made by the Minister for Health to locate the storage facility at the Esk site. While the two sites both met the fundamental physical requirements of being flood free, away from populated areas and within reasonable distance of the regulatory authority, the Beerburum site was in proximity to farming and dairy areas where established products were produced with names associated with geographic locations and towns. Accordingly the potential adverse economic impact would have been greater for this area and therefore the Esk site was selected as the preferred site.

To facilitate public acceptance of the facility it was decided that the Government would sign an agreement document with the local Shire Council to establish operational restrictions for the facility. The agreement document was drafted by a combination of administrative, legal and scientific staff of the state government in consultation with the Shire Council and identified the nature of the facility, limitations on what would be accepted into

the store, and the nature and frequency of external technical audits of the facility and its operation.

CONSTRUCTION

The overall layout of the facility is shown in figure 1 and the basic design of the storage facility is shown in figure 2. The facility consists of three storage areas, two general storage areas (1 & 3) and a special radium storage area (2) providing an overall effective storage floor space of approximately 120 m² together with an external preparation area (partly covered) for future conditioning of waste when it is prepared for final relocation to the national shallow ground burial facility. While not all waste will be suitable for such shallow ground burial the substantial majority of material to be held in the store will be.

The design requirements for robustness and radiation shielding of the gamma and neutron radiation resulted in the selection of 400 mm thick reinforced concrete walls for all outer walls of the three storage areas as shown. All other walls and the ceiling are 200 mm concrete. The building was designed and constructed to withstand an earthquake one point higher on the Richter scale than the maximum recorded for the area. (Note: The region is relatively stable with minimal earthquake activity.)

It is located in an elevated flood free area of state owned pine forest not readily visible from public roads, over 1½ kilometres from the nearest residence and 10 kilometres from the town of Esk (pop ~ 3000).

The store security includes an external three metre high barbed wire topped security fence, and an external photoelectric beam sensor to detect movement in proximity to the doors. Security cameras are positioned to record (VCR) the source of any trigger of the photoelectric beam. Movement sensors attached to the doors would alarm if they were opened without disarming the security system. Internal security consists of separate internal locked steel gates to each storage chamber, twin security cameras to monitor and record any intrusion to the store with remote alarm to a State government 24 hour security service in

Brisbane. In addition to this a local security firm is retained to undertake at least one site visit and inspection per day. The building ventilation system, both normal and radium store, incorporate security steel bars to prevent unauthorised intrusion and prevent small animal access.

The store incorporates a thermally activated water based fire suppression system with floor drainage and collection into two 5000 litre tanks to enable retention for contamination checks prior to release. A minimum of combustible material has been used in construction with the result that the fire loading is minimal and the consequent risk of serious fire being near zero. Fire alarms signals are also monitored remotely at the 24 hour security monitoring facility in Brisbane. The concrete and steel construction combined with a 70 m fire break around the facility ensures that the store will not be adversely affected by bushfires. Additionally an uninterruptable power supply based on a 24 hour diesel generator is located in a separate building to the store to ensure that the store will not suffer any loss of mechanical integrity in the event that the entire diesel fuel supply ignites.

The gamma radiation field, neutron radiation field and radon concentration are continuously monitored in the various storage rooms with remote alarm signals to the 24 hour security monitoring facility in Brisbane.

The radium store is a sealed room which incorporates a large volume ($2 \text{ m}^3\text{s}^{-1}$) ventilation system which can be activated manually (incorporates a 30 minute delay on door lock) or can be activated by a radon sensor when the radon concentration in the radium store exceeds a preset value (currently 1000 Bqm^{-3}). The radon ventilation system incorporates 4 ground level intakes and 4 upper level intakes spaced around the room to draw air out of the room with airflow drawn into the room via two large ceiling mounted openings which incorporate appropriate control vanes.

Continuous radon monitoring is provided by two Alphaguard model PQ2000 radon monitors with remote reporting at a computer facility in the preparation area where the radon levels and other relevant data (temperature, relative humidity etc.) are recorded. The use of

double monitoring systems is to provide appropriate redundancy. Background (precommissioning) radon levels were found to vary between 10-60 Bq m⁻³.

In addition to the active radiation monitoring within the store a set of four passive environmental radiation monitors are attached to the perimeter fence.

Operation

One condition of the facility agreement document was that no operational use was to be made of the store prior to a satisfactory assessment of the facility, its infrastructure and the management plan by an external technical auditor. The Australian Radiation Laboratory (National government body) undertook the role of external technical auditor and completed a comprehensive inspection, testing and assessment audit in November 1994. The auditors report praised highly the facility and the management plan and gave a strong endorsement of the suitability of the facility for the task for which it was designed.

The facility commenced operations on the 7th of December 1994 with the relocation of 219 containers from the departments old store at Petrie Bight. The transport operation took approximately two hours with the containers arriving at the facility mid morning. The relocation involved two large transport vehicles, a police escort vehicle carrying a Physicist from Radiation Health and a departmental vehicle carrying two Physicists from Radiation Health together with a wide range of emergency response equipment. In compliance with a Ministerial public undertaking the vehicles did not take the shortest route (which passes over the main water supply dam for the city of Brisbane) but travelled via the Highway approaching from the south of the facility.

All packages were in compliance with the Australian Code of Practice for the Safe Transport of Radioactive Substances (1990) which is essentially the 1985 IAEA transport regulations. The majority of packages were type A packages with a number of excepted packages also transported. There were no sources requiring type B containers moved in this initial transport operation. The type A packages included a large number of 20L and 60L

drums and a small number of specially made sheet steel boxes to transport certain large dimension gauges. All transport containers were receipted into the store and placed in a storage bay by 6.30pm that evening.

While there were only a handful of containers with radium sources (all low activity sources from old markers, compasses and smoke detectors) placed in the facility in this first movement of material, there was a slow growth of radon levels, in the radium storage area, recorded during the first few days immediately after relocation. Following an investigation it was established that radon was leaking from a small hole drilled into the 20L and 60L drums to pass the stainless steel cable connecting the inventory identification plate to the device in the container. The interim solution to stop the radon leak was to place the drums inside 205L drums which had been sealed along the seams with silastic and around the lid O-ring with vacuum grease. There was a dramatic decrease in the radon levels (to precommissioning background levels) in the radium store immediately after this modification was implemented. In the near future it is proposed that the drums will be removed from the outer 205L container and examined and modified with a view to ensuring that the container itself is thoroughly sealed.

A rigorous program of monthly, quarterly and 6 monthly internal audits has now been in operation for approximately 12 months with the first annual audit underway currently. This internal audit is an essential part of our facility management plan which was itself approved by the external technical auditor prior to commissioning of the facility.

There has been some emphasis placed on awarding maintenance and other contracts locally, where ever possible, as a means of providing some direct community benefit from the facilities operations. Security services, grounds maintenance, road maintenance and some electrical contracting work have all been awarded to local businesses.

A number of issues have contributed to establishing a level of acceptance of the facility amongst the local community, the most important of these being the development of the formal written agreement between the state government and the local government

authority (Shire council). The local community have strong ties to the local government authority and are generally more willing to accept advice they get from that level of government. Likewise the local shire mayor and local government senior officers have a highly developed sense of serving the community.

The agreement document made provision for the creation of a Management Advisory Committee (MAC) to provide an independent avenue of advice to the Minister, reporting on the operational management of the facility by the regulatory authority. The MAC is comprised of two departmental (State) representatives, one of which is a senior radiation physicist from the regulatory authority and the other a senior officer from the departments central office, and two local government representatives, one of which is an elected representative (Shire Mayor) and the other is the senior executive officer of the local government body. The MAC is to meet several times a year with its inaugural meeting taking place prior to commissioning of the facility and immediately after publication of the external technical auditors report of the facility infrastructure, procedures and management plan.

The MAC has been shown to be very valuable as it is seen as a conduit to the facility management and operation and in this manner provides a local monitoring and reporting venue for the facility and its use.

Lessons Learned

The following factors have emerged as being of considerable importance in the process of establishing and maintaining community acceptance of the Esk storage facility:

- Community consultation
- Involvement of trusted community representatives in facility management
- Development of a formal agreement concerning facility operation
- Provision of some direct community benefits
- Access to information concerning facility operation

**REAL-TIME ALPHA MONITORING OF A RADIOACTIVE LIQUID WASTE STREAM
AT LOS ALAMOS NATIONAL LABORATORY**

**John D. Johnson, Charles R. Whitley, Mohini Rawool-Sullivan
Los Alamos National Laboratory
(505) 665-4054**

ABSTRACT

This poster display concerns the development, installation, and testing of a real-time radioactive liquid waste monitor at Los Alamos National Laboratory (LANL). The detector system was designed for the LANL Radioactive Liquid Waste Treatment Facility so that influent to the plant could be monitored in real time. By knowing the activity of the influent, plant operators can better monitor treatment, better segregate waste (potentially), and monitor the regulatory compliance of users of the LANL Radioactive Liquid Waste Collection System. The detector system uses long-range alpha detection technology, which is a nonintrusive method of characterization that determines alpha activity on the liquid surface by measuring the ionization of ambient air. Extensive testing has been performed to ensure long-term use with a minimal amount of maintenance. The final design was a simple cost-effective alpha monitor that could be modified for monitoring influent waste streams at various points in the LANL Radioactive Liquid Waste Collection System.

MANAGEMENT BY PLASTIC MONOLITHS OF TOXIC WASTES
FOR FINAL DISPOSAL

Hyman Lubowitz
Environmental Protection Polymers, Inc
26 Coraltree lane
Rolling Hills Estates, CA 90274
(310) 541-0089

No paper available

DANCING WITH THE REGULATIONS - PART DEUX

Robert L. Nitschke
Lockheed Martin Idaho Technologies
P. O. Box 1625
Idaho Falls, ID 83415-3960
(208) 526-1463

ABSTRACT

The disposal of low-level radioactive waste (LLW) in the United States has long been subjected to two very similar regulations depending upon the location. Disposal sites located on Department of Energy (DOE) Reservations are subject to DOE Order 5820.2A "Radioactive Waste Management," while disposal sites located elsewhere are subject to the Nuclear Regulatory Commission regulation 10 CFR 61 "Licensing Requirements for Land Disposal of Radioactive Waste." While life was not necessarily good, there was only one sheet of music to dance to. Recently a new player, named CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act), has ridden into those DOE towns, and for those whose disposal facilities lie within or adjacent to Superfund sites, she has brought along a different drum to dance to. This paper discusses the differences and similarities between the different dance partners and their associated musical scores (i.e., the performance assessment (PA) required by the DOE order and the baseline risk assessment (BRA) required by CERCLA). The paper then provides a brief discussion on the latest dancer to cut in: the Defense Nuclear Facilities Safety Board (DNFSB). This discussion should help to alleviate the confusion while dancing on the LLW disposal regulatory ballroom floor.

When visions of disposing of low-level radioactive waste (LLW) dance in the heads of generators, operators, and regulators two prominent regulations usually come to mind. For Department of Energy (DOE) sites, DOE Order 5820.2A "Radioactive Waste Management", Chapter III, Management of Low-Level Waste specifies the policy, guidelines and minimum requirements by which the DOE and all its contractors will manage its low-level radioactive waste. In particular, chapter III requires the preparation of a site specific performance assessment (PA) for disposal of LLW to demonstrate compliance with various performance objectives. The effective date of this order is September 26, 1988 and as such only applies to those wastes disposed after that time. On the commercial side, Title 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste", establishes technical requirements for the land disposal of commercial low-level waste including site selection, site

design, and facility operation and closure. The application of these regulations is fairly straightforward particularly for a single site and for future disposal. However, it should be noted that there has been marginal success to date.

Then along comes CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act), also known as Superfund. CERCLA was enacted to provide funding and enforcement authority for cleaning up the many thousands of hazardous waste sites throughout the United States. The supporting regulation is 40 CFR 300 entitled "National Oil and Hazardous Substances Pollution Contingency Plan" also known as the NCP. In a manner similar to the DOE Order, the NCP requires an assessment, called a baseline risk assessment (BRA)[Section 300.430(d)] whose purpose is to determine a need to clean up and if so, by how much.

Past activities and disposal practices have resulted in many of the DOE sites making the Environmental Protection Agency's (EPA) most wanted list: the National Priorities List (NPL). Because of the various collocated sites and activities at the different DOE sites, one can find active LLW disposal sites adjacent to or even inside a CERCLA site. The question then becomes under what statutory framework should these commingled activities be subjected. Should the DOE Order 5820.2A (PA) address the past disposal, should the CERCLA BRA address the future disposal, should CERCLA BRA address the pre-88 disposal and the DOE Order PA address all post 88 disposal, ??? This situation also raises other questions in inquiring minds about which regulation is "better" than the other, why they are not the same, which is more technically sound, etc.

The key to understanding and resolving these questions is to start at the beginning and be clear on the reasons and objectives of the two regulations and associated analyses. From this perspective it will then become easier to see not only why there are similarities but why there are differences. Also it will be easier to determine a technically appropriate position and path forward with the regulators and the public.

Simply stated, the purpose of a CERCLA BRA is primarily to determine if there is a need to cleanup a past disposal site under a leave-as-is option. Based on the results of this assessment, other information pertaining to how much to cleanup and the best way to do so might follow. The purpose of the DOE Order 5820.2A performance assessment is primarily to demonstrate compliance which is really determining the suitability of the environmental setting for LLW disposal and to specify Waste Acceptance Criteria (WAC) for future disposal. Obviously the desire is to conduct the disposal in a manner so that the site does not become a future candidate for a Superfund site. Of course, the overarching objective for both of these regulations is the protection of the health and safety of the public, workers, and the environment. This common overarching objective helps identify the similarities in the two approaches. Other objectives of the regulations help identify the differences.

Three major similarities are: the PA and the BRA both address the fate and transport of radioactive contaminants; both assessments determine subsequent exposure to workers and the public; and finally both the PA and BRA are used to demonstrate/document the degree of protectiveness or lack thereof to the public and workers. Now for each of these similarities there are a whole host of accompanying information that can also be the same.

Demographics, site description, environmental setting, even possibly model selection are areas where there are commonalities. One must be careful however, in that the degree to which any of the supporting areas are described can vary greatly. This variance is highly dependent not only on preliminary results (that is, how close you are to the acceptable risk range or performance objectives) but also on data availability, time, and agency involvement among other things. As an example, if one can demonstrate acceptable CERCLA groundwater results by only considering a 1-D homogeneous subsurface regime with conservative properties than that is as far as the analysis needs to and should go. On the other hand, for the exact same site, if by more realistically modeling the vadose zone and accounting for other mechanisms such as dispersion and decay, one can increase the projected lifetime of the disposal facility, or can lessen packaging requirements or eliminate pretreatment of various waste forms then that is the appropriate level of analyses for the PA to consider. In a different scenario, if by characterizing and modeling a site more robustly, major remediation could be avoided that is how the BRA should be approached. At the same

site, by just strengthening the packaging requirements, say grouting the waste, less intense modeling might be needed to demonstrate compliance. Now if the similarities can be that different what can one say about some of the key differences? Could the differences be similar?

First of all, the PA considers the radioactive components of the waste while a BRA considers all hazardous substances, radioactive and non-radioactive. The ramifications of this can be considerable. For example, if there were a large quantity of volatile organic compounds in the waste, it might be necessary to look at a multi phase, multidimensional computational tool, while if one is looking at only nonvolatile radioactive constituents a much simpler model could possibly suffice. Another area of difference is that the acceptance levels/criteria are unlike. In the case of CERCLA, limits for both carcinogenic and noncarcinogenic effects are specified. The limits are for cancer incidence a "point of departure" of 10^{-6} , with an acceptable risk range given as 10^{-4} to 10^{-6} . For noncancer adverse health effects a hazard index of less than 1 is the limit. For a PA, the acceptance limits are not risk but dose-based. There are several of these but as an example, an all pathways public dose limit is 25 mrem/year, while a chronic inadvertent intruder dose limit is 100 mrem/yr. Any comparisons between the two approaches are further complicated by the use of differing dose conversion factors and methodologies.

Another major difference, the impact of which can not be overstated, is the degree of involvement by various parties in the different processes. In the case of the PA, the process is fairly prescriptive, entirely internal to DOE with the field offices or their contractors preparing the document and DOE HQ, with the assistance of a Peer Review Panel, providing the approval. For a BRA, the process involves not only the DOE Field Office but the State and the Regional EPA as well. There is also substantial involvement by the public: reviewing scoping documents, work plans, records of decisions and the like. This multiple party, consensual arrangement, allows greater flexibility in the type and the amount of information that is both needed and desired to make a cleanup decision. This opportunity also offers the potential for much conflict resolution.

These additional participating parties and their agreements can also lead to different times of compliance being considered, different points of compliance being addressed, and even different exposure scenarios being evaluated than what would be done for a performance assessment at the same location. As an example, the PA process requires that an intruder scenario be evaluated and that certain dose limits be met. For a BRA, the parties might agree to treat the disposal site as a landfill and through institutional control would not consider an intruder scenario to be credible. For the case of compliance times, the DOE Order is not specific. Ten thousand years has been recommended by the Performance Assessment Task Team, but nothing is official. Several performance assessments have even carried the calculations out to peak dose which in some cases can be hundreds of thousands of years or more. CERCLA is also not specific with respect to times of compliance with the determination being made by the governing agencies. Depending on the situation, the time of compliance can range from just a present day evaluation to possibly out to 10,000 years.

There are numerous other lesser differences in the two approaches, but the above give a sense of the major ones, the wide range of these differences, as well as why there should be differences. It should be readily apparent that any comparisons between the two methodologies would be most difficult and for the most part inappropriate. To say one is better than the other is to miss the point. To determine the need to cleanup a past hazardous waste site, CERCLA is the more appropriate tool. To determine the suitability of an active and future low-level radioactive disposal facility then the DOE Order is the more appropriate method.

It is now time to revisit the original conundrum posed in paragraph three of what approach is to be used when one has both a CERCLA site and a disposal facility in close proximity. This particular situation has also drawn the attention of the Defense Nuclear Facilities Safety Board (DNFSB) and manifests itself in their recommendation 94-2. The board basically recommends the entire source term be included and the performance objectives achieved in the site performance assessment. While the intent is well meant, the application of a regulation developed for present and future disposal to past disposal activities is not appropriate. A more appropriate treatment is to evaluate the active and planned LLW

disposal site in accordance with the DOE Order. Then evaluate the past disposal activity in accordance with CERCLA. Only after the results of these two analyses and associated decisions have been made should the results be examined collectively. Let's examine this approach in a little more detail so that the wisdom of this approach is more evident. The PA will show that either the site and any planned engineered controls slot suitable for LLW disposal or it is not. If it is not, another location should be identified. If it does meet the performance objectives, then it is time to turn attention to the neighboring CERCLA area. This unit should be evaluated according to CERCLA and it will be shown to present either acceptable risks to the public and the environment or unacceptable risks. In the case of acceptable risk results, no further evaluation is needed and the LLW disposal can continue. In the case of unacceptable risks, then any one of several decisions are possible. One might be to remediate the site to acceptable levels, in which case the LLW disposal can proceed. In the case of where remediation is neither practical, or cost effective, a decision might be to limit any future use of that area. In this case, the decision to continue to dispose of LLW might be determined to be appropriate even though if one did an entire source term analysis the performance objectives would not be achieved. This stepwise approach allows for better decisions to be made.

In conclusion, while there are differing regulations that apply to very similar situations, that is okay. And when these regulations are applied appropriately, sound decisions can be made. However, failing to realize the key differences and misapplying the regulations will only lead to much difficulty and possibly unwise decisions.

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EVALUATION OF THE LONG-TERM PERFORMANCE
OF SIX ALTERNATIVE DISPOSAL METHODS FOR LLRW

Rick Kossik and Greg Sharp
Golder Associates Inc.
4104 148th Ave NE
Redmond, Washington 98052
(206) 883-0777

Trung Chau
Rogers & Associates Engineering Corp.
515 East 4500 South
Salt Lake City, Utah 84107
(801) 263-1600

ABSTRACT

The State of New York has carried out a comparison of six alternative disposal methods for low-level radioactive waste (LLRW). An important part of these evaluations involved quantitatively analyzing the long-term (10,000 yr) performance of the methods with respect to dose to humans, radionuclide concentrations in the environment, and cumulative release from the facility. Four near-surface methods (covered above-grade vault, uncovered above-grade vault, below-grade vault, augered holes) and two mine methods (vertical shaft mine and drift mine) were evaluated. Each method was analyzed for several generic site conditions applicable for the state. The evaluations were carried out using RIP (Repository Integration Program), an integrated, total system performance assessment computer code which has been applied to radioactive waste disposal facilities both in the U.S. (Yucca Mountain, WIPP) and worldwide. The evaluations indicate that mines in intact low-permeability rock and near-surface facilities with engineered covers generally have a high potential to perform well (within regulatory limits). Uncovered above-grade vaults and mines in highly fractured crystalline rock, however, have a high potential to perform poorly, exceeding regulatory limits.

INTRODUCTION

The New York State Low-Level Radioactive Waste Siting Commission (NYSC) was responsible for the selection of a preferred method or methods for disposal of New York State's low-level radioactive waste (LLRW). In July 1993, the Siting Commission published its plan for selecting a preferred method for disposal of LLRW¹ and in March 1994 finalized the supporting method evaluation procedures². These reports defined the disposal methods to

be studied, the factors to be evaluated, and the nature and sources of data required to complete the method selection program.

The method evaluation procedures identified 19 evaluation factors which would be used to compare alternative methods for disposal of LLRW in the state. Three of these factors (Protection of the Health and Safety of the Public; Radiological Impacts on Air, Water and Biota; and Long-Term Containment Ability) required quantitative analysis of the alternative disposal methods in terms of the undisturbed, long-term (10,000 yr or more) performance of the facilities with respect to radionuclide release, environmental concentrations, and dose received by humans.

Simulating the behavior of a disposal system in order to obtain quantitative estimates of performance measures such as these is referred to as *performance assessment*. This paper provides a brief summary of the detailed performance assessment analyses³ that were carried out in order to provide a quantitative comparison of six alternative disposal methods based on the three long-term performance-based evaluation factors.

ALTERNATIVE DISPOSAL METHODS

Previous to this study, conceptual designs for six alternative disposal methods were developed⁴:

- Uncovered Above-Grade Vault (UAGV);
- Covered Above-Grade Vault (CAGV);
- Below-Grade Vault (BGV);
- Augered Holes (AH);
- Drift Mine (DM); and
- Vertical Shaft Mine (VSM).

The first method represents an *uncovered near-surface method*. The next three methods are referred to here collectively as *covered near-surface methods*. The last two are referred to as *mine methods*.

A Generic Site Characteristics Report⁵ prepared for the State defined sets of generic sites for each of the disposal methods which were believed to be representative of sites available in New York. Three generic sites were defined for the near-surface methods (glacial till, sand and gravel, silt and clay), and four generic sites were defined for the mine methods (shale, salt, limestone, and igneous/metamorphic). For the drift mine, however, only the shale and igneous/metamorphic sites were considered to be applicable. The study described here separately considered the performance of each disposal method for all relevant generic site conditions.

A Source Term Report⁶ was prepared for the State which specified the waste inventory for disposal. The same inventory was assumed for each disposal method. Forty seven radionuclides (including decay chains) were explicitly considered in the analyses described below.

METHODOLOGY

Overview

The key activities in these evaluations were as follows:

- Identification of the significant features, events, and processes controlling system behavior;
- Development of an integrated conceptual model of system behavior;
- Representation of the conceptual model within a mathematical framework as a set of equations and algorithms (using an appropriate computational tool);

- Quantification of the relevant input parameters required for the simulations, consistent with the available information;
- Performance of the calculations (using the computational tool) to develop quantitative estimates of releases, concentrations, and doses (i.e., the performance measures) over a 10,000 year period;
- Qualitative analyses of the sensitivity of the results to the key input assumptions; and
- Comparison of the various methods with respect to the performance measures.

The specific performance measures by which the methods were compared were:

- 1) peak dose to the maximally exposed individual associated with a single year of exposure (mrem/yr);
- 2) peak concentration in surface water, groundwater and air (pCi/L); and
- 3) cumulative release of radioactive materials from the facility for 10,000 years after closure (kg).

The objective of the performance assessment modelling effort was to simulate the movement of radionuclides from the *waste form*, through the intervening containment layers of the *engineered barrier system* (EBS) and the *geosphere*, to the *biosphere*, where doses to humans and other adverse environmental effects could potentially occur. Note that the conceptual models *did not* consider human intrusion or natural disruptions (e.g., earthquakes, floods), since the evaluations discussed here were intended to assess undisturbed performance (i.e., disturbed performance was considered by other evaluation factors²).

Computational Tool

The computational tool used to carry out the long-term performance assessments was RIP (*Repository Integration Program*). This computer program was specifically developed by Golder Associates to simulate radioactive waste disposal facilities, and is currently being

applied to the potential High-Level Radioactive Waste (HLRW) site at Yucca Mountain, Nevada⁷ and the Waste Isolation Pilot Plant (WIPP) in New Mexico⁸. RIP has also been applied to a variety of disposal facilities worldwide (e.g., Spain, Canada, United Kingdom, Japan).

RIP is state-of-the-art, and capable of representing the uncertainty in model parameters and processes, as well as uncertainty in the occurrence and consequences of disruptive events (such as earthquakes and human intrusion). As discussed below, however, the analyses carried out for this study were deterministic.

RIP is structure to facilitate a "top-down", "modular" approach to modeling, in which the user can readily develop an integrated total system model, and then add detail and complexity as necessary. As a result of this flexibility, the same computational tool can be used to simulate radically different systems, and can be used to carry out both simple scoping calculations and detailed physically-based analyses. RIP is well documented in a Theory Manual and User's Guide⁹, and has been verified to ASME NQA-2 and ISO-9001 standards¹⁰.

Modeling Approach

RIP is capable of modelling a system with great detail. It is important to note, however, that the level of detail included in a conceptual model and the associated quantitative calculations must be consistent with the amount of available information and the ultimate purpose of the analysis. Hence, an assessment to support licensing of an actual facility would likely be much more detailed than an assessment to support method selection.

Given the generic nature of the evaluations and the ultimate objectives, a deterministic approach (as opposed to a probabilistic approach) was adopted. That is, because the evaluations were to consist of relatively high-level calculations based on preliminary conceptual designs and generic site conditions, with the ultimate objective being to provide a relative, semi-quantitative comparison of various methods, probabilistic analysis was

considered to be inappropriate at this stage. Hence, the objective of this study was to carry out deterministic analyses and include sufficient detail to allow the various methods to be differentiated. It was recognized, however, that future, more detailed assessments (e.g., to support site selection or licensing) would require probabilistic analysis.

Specification of Input Parameters

In order to carry out the performance assessments, it was necessary to make assumptions regarding the appropriate values for a large number of input parameters. In general, an effort was made to select "typical" or "reasonable" values for these parameters, as opposed to "conservative" (i.e., extreme) values. Although an effort was made to avoid conservative assumptions, in some instances such assumptions could not be entirely avoided. In particular, if limited data were available regarding a process, and/or if detailed simulation of the process was not practical, the process was represented in a conservative manner. Whenever such a conservative assumption was incorporated into the analyses, however, an effort was made to avoid inadvertently biasing one method over another.

The performance of any facility will be strongly dependent on the actual site conditions. For the purposes of the method evaluation study, a number of generic sites had been defined⁵, and each method was evaluated with respect to a number of these sites. Because the sites were generic and therefore not specified in great detail, it was necessary to make a number of assumptions regarding input parameters which are highly variable and site-specific. Again, an effort was made to choose "reasonable" or "typical" values for these types of parameters.

RESULTS

The detailed performance results produced for this study included peak doses, time histories of dose by exposure pathway and by radionuclide, as well as cumulative release and peak concentration by waste class³. The results are summarized below.

Relative Comparison of Methods

The key points of the comparative analyses can be summarized as follows:

- The UAGV disposal method, regardless of generic site conditions, performs very poorly. The poor performance of the UAGV is due to erosion of the concrete barrier, and the subsequent exposure and deposition of waste material onto soils.
- The mine methods in tight, intact rock (represented by the generic shale, salt and limestone sites) perform the best with regard to all measures. The excellent performance of these mine methods at these sites is due to the extremely low groundwater flow rates through the facility and the extremely long groundwater travel times required for groundwater to reach potential receptors.
- The mine methods in highly fractured rock (represented by the igneous/metamorphic site) perform very poorly with respect to peak dose and groundwater concentration, although very well with respect to containment. The poor performance is due to fast travel times and low dilution rates in the groundwater pathway, whereas the good performance with respect to containment is due to the low groundwater flow rate through the facility.
- All of the covered near-surface disposal methods perform relatively well. Their performance is much better than that of the UAGV method and the mine methods in highly fractured rock, but generally poorer than that of the mines in tight, intact rock. The relatively good performance of the covered near-surface methods is primarily due to the effectiveness of the geosphere barrier for the groundwater pathway. Note that a key assumption for these disposal methods is that the cover is not eroded over the time scale of interest.

Comparison of Performance to Regulatory Criteria

The intent of this study was to focus on relative comparisons, rather than on absolute estimates. Nevertheless, it is still worthwhile to compare the results to applicable regulatory criteria and background concentrations, as this provides a context for the results.

- *Total Peak Dose.* For peak dose, the appropriate regulatory criteria is a limit of 25 mrem/yr (NYCRR6 Part 382). Based on this study, it is likely that the covered near-surface methods and the mine methods in tight intact rock would meet this criteria. The uncovered above-grade vault and the mine methods in highly fractured rock, however, are likely to greatly exceed this limit. Note that background doses throughout the state (from radon, cosmic radiation, medical procedures, etc.) would be on the order of several hundred mrem/yr¹¹.
- *Concentration in Environmental Media.* There are no regulatory limits for concentration based on total (alpha, beta, and gamma) activity, and hence a direct comparison to simulation results is not possible. However, drinking water standards (40 CFR 141) include a provision that gross alpha particle activity (excluding radon and uranium) be less than 15 pCi/L. Based on this study, it is likely that the covered near-surface methods and the mine methods in tight intact rock would meet this criteria. The uncovered above-grade vault and the mine methods in highly fractured rock, however, are likely to exceed this limit. Note that background concentrations vary depending on the rock type, but could be as high as several hundred pCi/L for some sites¹². Regulations pertaining to uranium mill tailings (40 CFR 192) require the annual average air concentration of radon-222 to be less than 0.5 pCi/L above background. It is likely that all of the disposal methods could meet such a criteria.
- *Release from the EBS.* There are also no regulatory limits on cumulative release for low-level disposal facilities. However, an annual release limit of

0.001% of the total curies at 1,000 yr has been established for high-level facilities (10 CFR 60). Based on this study, it is likely that the mine methods and the covered near-surface methods could provide a level of containment which would meet such a criteria.

Applicability of Simulation Results

The results presented here should be viewed as a comparison of methods based on a relatively consistent, but somewhat conservative estimate of their expected performance. The performance of the disposal methods under extreme, highly unlikely conditions (either good or bad) is not explicitly considered. Note, however, that the potential for poor performance of a disposal method under some extreme conditions can be addressed to some extent using the method-specific siting criteria detailed in the report³. If the actual site is selected from a large number of candidates based on these method-specific siting criteria, then the performance is likely to be better than for the "typical" conditions simulated here. Moreover, the actual design of the facility could be modified to optimize performance.

It should be noted that more detailed analysis explicitly incorporating uncertainties in features, processes and events will eventually be required for licensing a final design at a selected site for a specified waste inventory. Due to the flexibility of the computational tool which was used, the simulations discussed in this paper could readily be extended to the level required. It would be expected that the results of such detailed analyses would be consistent, although not identical, to those presented here.

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A DECISION TOOL FOR SELECTING TRENCH CAP DESIGNS

G.B. Paige, J.J. Stone, T.E. Hakonson*, and L.J. Lane
USDA-ARS, 2000 E. Allen Rd., Tucson AZ. 85719, and
*Center for Ecological Risk Assessment and Management,
Colorado State Univ., Ft. Collins, CO. 80523.

ABSTRACT

A computer based prototype decision support system (PDSS) is being developed to assist the risk manager in selecting an appropriate trench cap design for waste disposal sites. The selection of the "best" design among feasible alternatives requires consideration of multiple and often conflicting objectives. The methodology used in the selection process consists of: selecting and parameterizing decision variables using data, simulation models, or expert opinion; selecting feasible trench cap design alternatives; ordering the decision variables and ranking the design alternatives. The decision model is based on multi-objective decision theory and uses a unique approach to order the decision variables and rank the design alternatives. Trench cap designs are evaluated based on federal regulations, hydrologic performance, cover stability and cost. Four trench cap designs, which were monitored for a four year period at Hill Air Force Base in Utah, are used to demonstrate the application of the PDSS and evaluate the results of the decision model. The results of the PDSS, using both data and simulations, illustrate the relative advantages of each of the cap designs and which cap is the "best" alternative for a given set of criteria and a particular importance order of those decision criteria.

The primary purpose of DOE's Environmental Restoration Program is to manage the health and ecological risks associated with intentional and accidental releases of radioactive and hazardous contaminants to the environment. Containment is viewed as a viable cleanup solution for most DOE sites that have low to intermediate levels of residual contaminants and pose few risks to humans or ecosystems. A trench cap placed over the waste is a central feature of most containment strategies and can range from a very simple soil cap to an extremely complex engineered design that mitigates both the vertical and lateral flow of water and gases. The primary functions of the cap are to isolate the buried waste from the surface environment and to control hydrologic processes, including erosion, that can cause contaminant migration from the site.^{1, 2}

The process of selecting containment cover technologies for radioactive and hazardous waste landfills requires that trench cap designs be evaluated in a repeatable, objective, and scientifically defensible manner that takes into account all the necessary technical, regulatory, and economic factors. The Environmental Protection Agency (EPA) technical guidance for final covers describes a recommended cap design, often called EPA's RCRA cap, that will meet the final cap performance standard.³ It is important to note that EPA offers the RCRA cap design as guidance and does not require its use if another design can be shown to meet the technical performance standards. Research in trench cap designs have demonstrated that there may be alternatives to the recommended design which offer certain technical and economic advantages.^{2,4,5,6} A basic need is to be able to evaluate and compare these alternative designs with the EPA RCRA design for specific waste sites while taking into account the technical, regulatory, and economic issues. A prototype decision support system (PDSS) to assist the risk manager in evaluating capping alternatives for radioactive and hazardous waste landfills is presented herein. The PDSS incorporates methods for calculating, integrating and valuing technical, regulatory, and economic criteria.

The goal of developing the PDSS is to improve the quality of technical information used by the risk manager to select landfill capping designs that are cost effective and meet regulatory performance standards. The overall objective is to develop and test a prototype decision support system to evaluate landfill cap designs. The use of a DSS to design and evaluate trench cap remediation technology will reduce the likelihood of selecting a trench cap technology that does not meet performance objectives and imposes the attendant costs of fixing mistakes. Candidate remediation technologies can be evaluated beforehand with the DSS to identify technical and regulatory problems inherent in the technologies, and to assess the projected long-term performance and practicality of the designs from a construction and economic viewpoint.

METHODS AND MATERIALS

The PDSS presented in this paper follows the approach described by Lane et al. and Paige et al.^{7,8} The methodology used in the selection process consists of: 1) selecting and

parameterizing decision variables or criteria, 2) selecting feasible trench cap design alternatives, 3) ordering the decision variables, and 4) ranking the design alternatives. The components of the PDSS include: simulation models, a decision model, and a graphical user interface. Decision variables can be parameterized using the simulation models, data, or expert opinion. The general category of decision variables for the evaluation of trench cap designs is specified by the EPA guidelines.³ These include such factors as the elements of the water balance, erosion, and subsidence. The specific decision variables will depend on the current state of the science (i.e. unsaturated flow dynamics, contaminant pathway analysis, erosion mechanics), regulations (minimize percolation and erosion), and socio-economics (cost, site location). Further details of the simulation models and the decision model are given below.

Simulation Model

The simulation models embedded in the PDSS are the EPA recommended HELP (Hydrologic Evaluation of Landfill Performance) water balance model^{9,10} and the overland flow erosion component of the CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) model.¹¹ The HELP model computes the water balance, soil water movement within the trench cap system, and the necessary input variables for use by the erosion component of the CREAMS model. The erosion component of the CREAMS model is incorporated as an alternative to the EPA recommended USLE (Universal Soil Loss Equation).¹² CREAMS estimates of water-induced erosion of the cap account more explicitly for the temporal and spatial variation of the erosion process than the USLE.

HELP was developed by the U.S. Army Corps of Engineers Waterways Experiment Station (WES) for the EPA Risk Reduction Engineering Laboratory. It is a quasi-two-dimensional model that uses weather, soil and design data and calculates the infiltration, surface runoff, percolation, evapotranspiration (ET), soil water storage, and lateral drainage in a shallow landfill system with up to twelve different layers. The model simulates water flow within three different soil layer types: vertical percolation, lateral drainage, and barrier

soil layers with or without a geomembrane. However, the HELP model is unable to simulate flow through a capillary barrier.

The CREAMS overland erosion component has been added to the HELP model to simulate trench cap erosion. The erosion component of CREAMS can be used to predict sediment yield and particle composition of the sediment on an annual or a storm event basis. The erosion component requires the input of hydrologic parameters for each runoff event simulated by the HELP model and an erosion parameter file. The principal outputs from the overland flow component are the soil loss per unit area and the concentration of each particle type for each storm.

Decision Model

The decision model, based on multi-objective decision theory, combines the dimensionless scoring functions of Wymore¹³ with the decision tools of Yakowitz et al.^{14,15} The conventional and viable alternatives are scored on the same set of decision criteria (i.e., percolation of leachate, runoff, ET, sediment loss, and cost). The scoring functions are used to scale the decision criteria, which have different units and magnitudes, to a common scale ranging from 0 to 1. The individual criterion scores are then aggregated for each alternative with a minimum amount of interaction with the decision maker. In particular, while an additive value function is assumed, the alternatives are not ranked on a single vector of weights associated with the criteria. The method considers all possible weight vectors consistent with an importance order of the decision criteria discerned by the decision model from the simulation results and scoring functions. The trench cap design with the highest aggregated score, for a given importance order of the criteria, is considered to be the "best" design among the conventional and feasible alternatives. The decision model is demonstrated using an example application from the Hill Air Force Base Cover demonstration project.

EXAMPLE: Hill Air Force Base Cover Demonstration

Four shallow landfill cover design test plots were installed at Hill Air Force Base (AFB) in Layton, Utah and their performance monitored for a four year period.² There are three basic cover designs: a control soil cover; a modified EPA RCRA cover; and two versions of a Los Alamos Design that contain erosion control measures, an improved vegetation cover to enhance evapotranspiration, and a capillary barrier to divert downward flow of water. The control cap consists of 90 cm of soil. The modified RCRA design consists of 120 cm of soil, 30 cm of sand (lateral drainage layer), 60 cm of compacted clay (hydraulic barrier). The Los Alamos designs consist of a thin gravel mulch over 150 cm of soil, 30 cm of gravel (capillary break). One of the Los Alamos caps was seeded with native perennial grasses and the other (Los Alamos 2) with both native perennial grasses and two species of shrubs to enhance ET. The surface and all of the underlying layers of the trench caps were built with a four percent slope.

The plots were instrumented to measure the performance of the covers with respect to controlling the hydrology and erosion of the trench cap. Precipitation, surface runoff, lateral flow, and percolation out of the gravel drainage layer were measured on a daily basis. Soil moisture and sediment yield were monitored approximately bi-weekly. Soil moisture content was measured using a neutron probe moisture meter. ET was estimated by solving a simple water balance equation:

$$ET = P - R - L - I - dS$$

where ET is evapotranspiration (m), P is precipitation (m), R is runoff (m), I is lateral drainage (m), and dS is change in soil moisture (m). The annual average values for the four year period are presented in Table 1. The decision criteria considered for evaluating these designs are: runoff (including lateral flow), ET, percolation (leachate production), sediment yield, and cost. Runoff, ET and percolation are important criteria for evaluating the ability of a cover design to control the hydrology of a trench cap. Sediment yield is important criteria for evaluating the long-term integrity of the cap as well as compliance with federal regulations.

Table 1. Observed Results: Average Annual Value for Each Decision Criterion.

Cap Design	Decision Criteria				
	Runoff	Percolation	Lateral Flow	ET	Sediment Yield
		-----cm-----			Kg/ha
Control cap	1.40	14.74	not applicable	27.37	118.70
RCRA cap	1.30	0.13	10.74	28.80	76.70
Los Alamos 1	0.35	6.82	4.83	24.25	4.50
Los Alamos 2	0.56	7.28	2.95	33.99	4.80

For this example the trench cap designs were evaluated using both field data and simulation models. The modified RCRA cap and the control cap were parameterized using the simulation models (HELP3 and CREAMS) and the Los Alamos caps were parameterized using the field data since the HELP model is unable to simulate capillary barriers. The calibrated input files for the two trench cap designs from Hill AFB were used in version 3 of the HELP model and the results compared to those obtained from version 2 of the model.¹⁶ Because the ET calculation changed from version 2 to version 3, the ET was slightly higher and the percolation was slightly lower for both designs for all four years. However, the overall results of HELP3 for this data set were not significantly different from version 2 in terms of the distribution of the water balance. Scoring functions were selected and set up for each of the decision criteria using the conventional design threshold and baseline values. The two generic score functions used in this example are presented in Figures 1a and 1b. The modified RCRA cap was selected as the "conventional" design because it is currently in widespread use and is considered to be the state-of-the-art by regulators and practicing engineers. For sediment yield a "more is worse" scoring function was selected (Fig. 1c) and parameterized using the results from the simulation models. The generic scoring function included a lower threshold of the sediment yield produced by the conventional design for the four year period. The average annual sediment yield for the conventional cover scored 0.5 by definition. The slope of the scoring function at the baseline value is a function of the threshold values determined by the maximum and minimum annual values of the conventional design. The score for each of the alternative designs was then determined by evaluating the average annual value from the alternative designs for each of the decision criteria (Fig. 1d).

The "more is worse" scoring function was also used for cost and percolation. However, for ET and runoff the "more is better" scoring function was selected. The modified RCRA design, as the "conventional" has a score of 0.5 for each of the decision criteria evaluated. The resulting score matrix for this example is presented in Table 2.

The next step is to rank the decision criteria in order of importance. The decision model determines a default importance order using the absolute values of the slopes of the scoring functions of each decision criteria at the baseline values which have been normalized to remove the units. The PDSS will also allow the decision maker to specify the importance or priority order associated with an environmental policy or regulations.

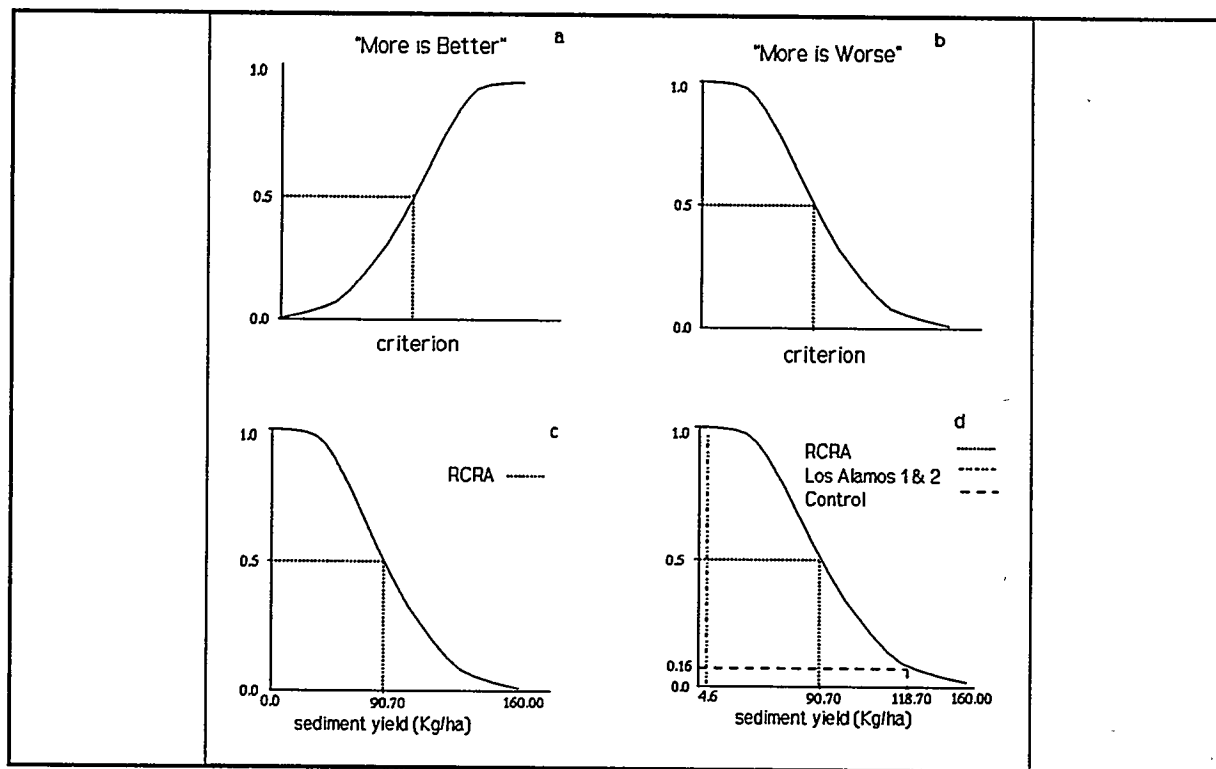


Figure 1. Scoring functions: a) generic more is better; b) generic more is worse; c) sediment yield scoring function parameterized using the RCRA cap; and d) scoring of the alternative designs for sediment yield.

Table 2. Score matrix used in decision model.

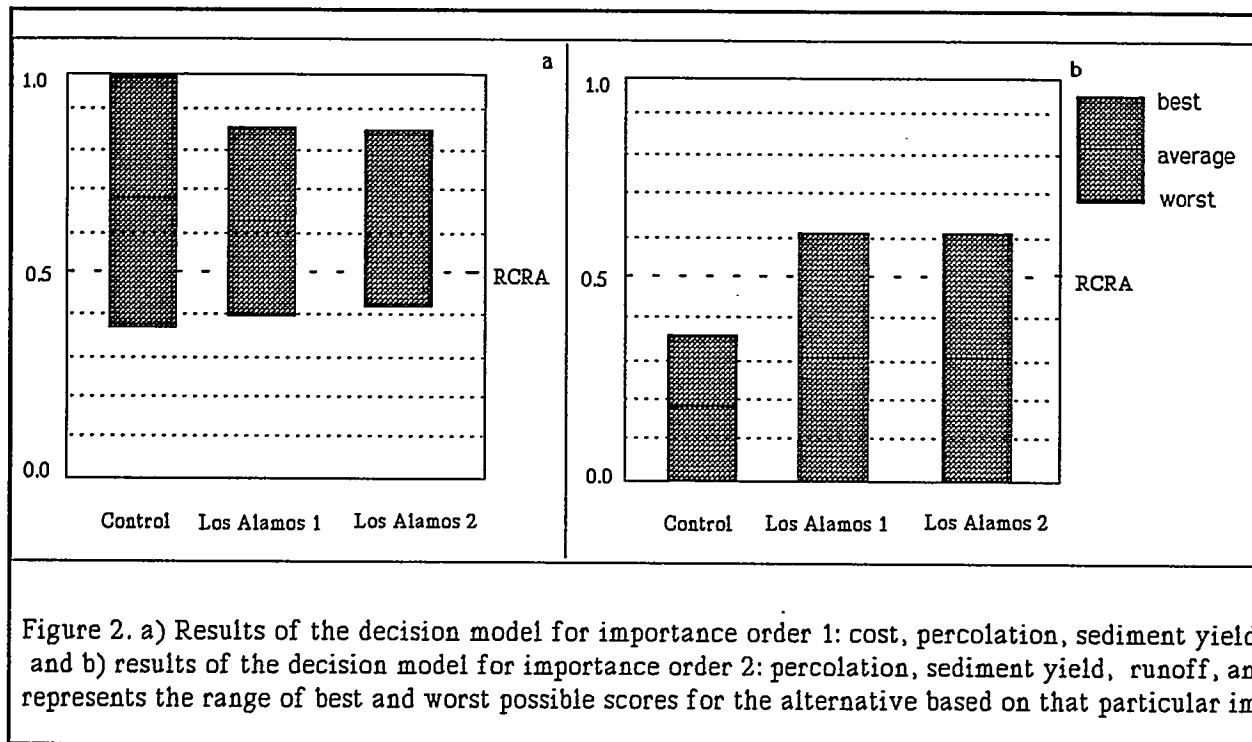
Cap Design	Decision Criteria				
	Runoff & Lateral Flow	Percolation	ET	Cost	Sediment Yield
Control cap	0.0	0.0	0.635	1.0	0.16
RCRA cap	0.5	0.5	0.5	0.5	0.5
Los Alamos 1	0.03	0.0	0.23	0.89	1.0
Los Alamos 2	0.01	0.0	0.23	0.89	1.0

The result of solving the two linear programs in the decision model to determine the best and worst composite scores for each of the alternatives is presented in Figure 2a. The importance order of the decision variables selected for this example (from most to least important) is: cost, percolation, sediment yield, runoff, and ET. The best and the worst composite scores for the modified RCRA design are both 0.5 since this design scores 0.5 for each criterion. The bar graph for each of the alternative designs represents the range of best and worst composite scores considering all possible weight vectors. A large spread in the range of possible composite scores indicates that it is highly sensitive to a particular weight vector. Due to its very low construction cost, the best possible score for the control cap is 1.0 when cost is ranked first in the importance order. However, because it does not score very well in the other decision criteria it can score relatively low depending upon the weight vector.

All three of the alternatives have better average scores than the conventional, modified RCRA cap design. The composite scores for Los Alamos designs 1 and 2 are almost the same for this importance order, and show less sensitivity to a particular weight vector than the control cap. For this importance order, ranking the designs in descending order by the average of the best and worst composite scores yields: Los Alamos 2, Los Alamos 1, the control cap, and modified RCRA. It is important to note that the cost decision criterion only represents construction cost, and not long term monitoring, maintenance, or potential remediation costs. Though the control cap costs much less to construct than the alternative designs, it has a much higher percolation rate and therefore the

potential for clean-up costs is much greater. These factors should be taken into account when evaluating a particular design with cost as one of the decision criteria.

The risk manager is able to change the importance order of the decision variables in an interactive format and then compare the composite results of the alternatives for different importance orders. For example, the risk manager may consider minimizing percolation into the waste layer or erosion of the trench cap more important than minimizing cost for a given situation, and therefore give them a higher importance level. Changing the importance order of the decision variables so that percolation is the most important, decreases the average score of the of the Los Alamos designs and the control cap and changes the sensitivity of the composite scores (Fig. 2b). This importance order changes the ranking of the alternatives, with the modified RCRA cap scoring highest; followed by the Los Alamos designs and the control cap.



DISCUSSION

Risk managers are interested in assessing the long-term performance of a landfill trench cap design for a particular site. Landfill covers are designed to last hundreds of years. The decision model in the PDSS uses the annual average value of the decision criteria for each of the alternatives. The annual average, maximum, and minimum of the conventional design were used to parameterize the scoring functions. The risk manager is able to change the importance order of the decision variables and then compare the composite results of the alternatives for different importance orders side by side in a graphical presentation.

The PDSS was able to differentiate between the alternatives when using both the data and the simulation models to parameterize the decision variables. Detailed results of the preliminary evaluation of the PDSS using the Hill AFB trench cap demonstration study are presented in Paige et al., 1996.^{8,16} For the Hill AFB trench cap designs, changing the importance order of the decision variables has a significant affect on the composite scores of the alternative designs and thus their relative ranking.⁸ The specific benefits of each of the trench cap designs were evident in the results of the decision model. The most appropriate design for a particular location also depends on the specific needs and characteristics of the site.

SUMMARY

The PDSS is being developed for the evaluation of landfill trench cap designs. In order to evaluate a complete landfill site design, the risk manager would have to consider multiple external factors including a complete risk analysis. The most appropriate or "best" alternative trench cap design also depends upon the specific needs and characteristics of the site in question, the type of waste and how it is stored, and the potential long-term risks and costs. The ultimate decision would have to be made by the risk manager taking many of these factors, as well as local and federal regulations, into consideration. The goal of the PDSS is to improve the quality of the technical information used by the risk manager to

select trench cap designs that are cost effective and meet regulatory performance standards. The HELP model is the only model currently sanctioned by the EPA for design and evaluation of landfill covers. With the addition of the CREAMS erosion component and the decision model, the PDSS becomes a powerful tool for agencies concerned with the design and evaluation of landfill trench caps. The risk manager will be able to evaluate potential landfill trench cap technologies with the PDSS in order to identify technical and regulatory problems inherent in the designs and evaluate long-term projected performance.

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EVOLUTION IN PERFORMANCE ASSESSMENT MODELING AS A RESULT OF REGULATORY REVIEW

J.H. Rowat, G.M. Dolinar, M.E. Stephens and D.S. Rattan
Waste Management and Decommissioning
AECL Chalk River Laboratories
Chalk River, Ontario, Canada KOJ 1JO
(613)-584-3311

ABSTRACT

AECL is planning to build the IRUS (Intrusion Resistant Underground Structure) facility for near-surface disposal of LLRW. The PSAR (preliminary safety assessment report) was subject to an initial regulatory review during mid-1992. The regulatory authority provided comments on many aspects of the safety assessment documentation including a number of questions on specific PA (Performance Assessment) modelling assumptions. As a result of these comments as well as a separate detailed review of the IRUS disposal concept, changes were made to the conceptual and mathematical models. The original disposal concept included a non-sorbing vault backfill, with a strong reliance on the wasteform as a barrier. This concept was altered to decrease reliance on the wasteform by replacing the original backfill with a sand/clinoptilolite mix, which is a better sorber of metal cations. This change lead to changes in the PA models which in turn altered the safety case for the facility. This, and other changes that impacted performance assessment modelling are the subject of this paper.

INTRODUCTION

AECL is proposing to construct the IRUS disposal facility at its Chalk River Laboratories site. The IRUS repository is a near-surface concrete vault (dimensions: 20×30 m horizontal, 8 m vertical) that will be built in an unsaturated sand formation on the Chalk River Laboratories (CRL) property¹. The vault has 0.6 m thick concrete walls and a 1.0 m thick concrete roof that will be constructed from a blend of concrete that was designed to resist chloride and sulfate ingress. The structure is designed for a service life of 500 years or more. The base of the vault will be one meter above the level of the highest recorded water table, and the structure is to have a 2 m thick multilayer earthen cover, which, along with the concrete roof, is designed to divert infiltration, to be erosion-resistant and to prevent biointrusion.

One of the features of the IRUS vault is a permeable bottom to prevent the accumulation of water inside the vault (i.e., to prevent "bathtubbing"). The vault will be filled with equal volumes of waste packages and backfill. The backfill consists of a 90:10 mixture of sand:clinoptilolite, the clinoptilolite (a natural zeolite) being a strong sorber of radionuclide cations. About 2000 m³ of waste packages will be placed in the vault, with 90 vol% compacted miscellaneous trash and 10 vol% bituminized wastes. The bottom 60 cm of the vault is a buffer layer which includes a 30 cm layer of sand/clinoptilolite and a 30 cm layer of sand/clay buffer layer, which are good sorbers of metal cations.

Disposal System and Performance Assessment Models

The PA model for the IRUS groundwater pathway, treats the vault as a random array of waste packages separated and surrounded by backfill. The path for radionuclide migration is outwards from the waste packages into the backfill, down through the buffer and overburden, and into an aquifer, with subsequent transfer to a downgradient well and surface water bodies. Mass transfer of nuclides from the repository down to the top of the aquifer is assumed to be vertical and one-dimensional; flow in the aquifer is assumed to be one-dimensional and horizontal.

The source term for the vault is a semi-analytical model, and includes the following processes: waste form leaching, sorption and mass transfer in the backfill, and failure of the vault roof and waste package containers. The governing equation for mass transfer is assumed to be the advection-dispersion equation. Container performance determines the onset of nuclide migration from the waste packages. The vault roof is an intrusion barrier and prevents the infiltration of precipitation. The roof performance function determines the time and rate at which infiltrating water begins to penetrate sections of the vault. This in turn changes the local dominant transport mechanism from diffusion to advection, thereby increasing the overall mass transfer rate in the process. Although the IRUS design includes a substantial thickness of earthen cover, no credit is explicitly taken for the earthen cover in the mass-transfer modelling.

A key component of the source term arises from the mobile nuclides that get washed out of the vault and unsaturated layers at the onset of infiltration. This component, termed the wash-out flux, is often quite sensitive to the shape of the roof performance function. Sudden roof failures have a strong influence on the downstream flux and concentration profiles of the more mobile radionuclide anions (e.g., C-14, I-129). In contrast to the mobile nuclides, time scales for the migration of strongly sorbed nuclides are usually much greater than the time scale for roof failure. Hence, the downstream flux and concentration profiles of strongly sorbed nuclides (e.g., Pu and U isotopes) are not very sensitive to the shape of the roof failure function.

REGULATORY EVALUATION AND COMMENTS

The initial safety assessment report formally termed the IRUS Preliminary Safety Assessment Report (PSAR) was submitted to the Canadian nuclear energy regulator, the Atomic Energy Control Board (AECB), in January of 1992, and the regulator's comments were received by October of 1992. The primary result of the regulatory review was that approval to construct the repository was not granted.

After carefully considering the comments the PA team felt that the regulator's concerns were broad enough in scope to warrant a formal Features/Events/Processes (FEP) analysis of the project² so that issues in addition to those raised by regulatory review could also be identified and addressed. The FEP analysis is described in a companion paper at this meeting³. In the present paper, three areas which have received considerable effort to improve the safety case in response to regulatory concerns will be discussed. The first two areas, which are closely related, are the simplification of the IRUS inventory and the resulting ripple effect on how the wasteform and backfill are modelled. The third area is related to the thoroughness of documentation and focuses primarily on the creation of a series of documents collectively referred to as the PSAR Supporting Documents. The process of addressing the regulator's concerns with regard to PA assumptions and information deficiencies raised a host of PA issues that had to be addressed – some of these are discussed below.

Backfill and Waste Form

The original IRUS disposal concept included a sand backfill in the vault, with a strong reliance on wasteforms to retard the release of contaminants. Because of this reliance on waste forms, and because it was mathematically convenient, the sand backfill was assumed to be non-sorbing. A critical re-examination of these assumptions indicated that changes were warranted. Data on waste form performance led the PA team to conclude that although there were reasons to expect reasonable waste form performance (particularly from the bituminized wastes), the data to support the case were limited. In addition, it was felt that it would be prudent to decrease the reliance on the wasteform by increasing the number of barriers in the system—in this case by the addition of a sorbing backfill. It was decided to model waste form performance using either an instantaneous release model (for compacted wastes), or a model based on a user-specified cumulative fraction released (for bituminous wastes).

The reduction of emphasis on waste form performance means that less credit is now taken for one of the main engineered barriers in the system. To compensate for this, the sand backfill will be replaced by a 90:10 wt% mixture of sand:clinoptilolite. Clinoptilolite, a natural zeolite, is a good sorber of metal cations and it has a relatively high cation exchange capacity. Furthermore, there was a reasonable set of internal data and external literature to support the choice of this material. This change lead to changes in the mathematical model for the vault, which prior to then had been premised on a nonsorbing backfill; the present vault model is documented in a report by Rowat et al.⁴.

Waste Streams

The evolution of the safety case has included a reduction in the proposed scope and variety of waste streams to be emplaced in the IRUS facility. The number of waste streams has been reduced from 16 to three. The three waste steams are: baled dry active trash wastes, bituminized incinerator ash, and bituminized reverse osmosis concentrate from a liquid waste stream. On a volume basis, the baled wastes dominate the repository,

representing 90 % of the inventory. Radiologically however, as is often the case, comparisons are meaningful only on a nuclide by nuclide basis. The baled waste and bituminized liquid wastes are produced on an ongoing basis, while the bituminized ash is a fixed volume generated during the operating life of an onsite incinerator.

One of the primary reasons for selecting these three waste streams was the level of characterization data that exists for them. An ash analysis program, which began about a decade ago, has determined through direct chemical analysis of the ash, the radiological and metals inventory. The ash was created by incinerating bales, so a significant amount of knowledge was simultaneously generated about the bales. Gamma scanning of bales and ash yields a good correlation between the streams, with volume reduction factors taken into consideration. Continued gamma scanning of bales indicates that the inventory from bale to bale has not changed dramatically, providing confidence in the continued representativeness of the data. For the more volatile fraction of contaminants, which would be somewhat depleted in the ash, knowledge of waste origins, as well as stack sampling was used to determine inventories. The analysis of the liquid wastes was inherently simpler than the analysis of the solid waste, primarily because of the increased ease with which homogeneous samples could be collected—all the liquid waste feed to the evaporator/bituminizer is analyzed.

Because the inventory of the IRUS facility has been preselected and limited to three waste streams this has allowed the inventory to be very well characterized for performance assessment purposes. This statement pertains not only to the knowledge of radiological and non-radiological contaminants, but also to other chemical constituents of the wastes and the various interactions that may occur.

Supporting Documents

The PSAR Supporting Documents, which number 15, were written to address several important issues. Firstly, and perhaps most importantly, these documents record many of the underlying assumptions, analysis, data sources and conclusions which are employed in the

PSAR. This purpose may seem obvious, but in several instances in the previous safety case, no such documentation of information was available. The second function of the supporting documents is to allow the PSAR to be a more readable document because many of the cumbersome details and didactic explanations can be referred to the supporting documents rather than presented in the PSAR.

The iterative nature of performance assessment is such that successive PA iterations should provide ever better estimates of facility performance, and a better focus for experimental and data collection programs. With each new assessment, scientific and technical support staff are called on to provide updated estimates of parameters and parameter variability, if there are technical grounds for doing so. A restructuring of the project to have experimental and data assembly needs defined by PA team largely resolved problems associated with compounding conservatism. Direct communication between the PA group and experimental/technical support staff has also led to more effective experimental programs. This process was most evident in the process of defining the scope of the individual supporting documents and reaching agreement with the various contributors as to the content and approach required to establish their part of the safety case.

The following list very briefly summarizes the supporting documents and their content:

- Inventory Characterization Report - detailed analysis of the three waste streams;
- FEP Analysis Report - Document outlining the FEP process and disposition of the issues;
- SYVAC-NSURE Documentation - Report outlining the basic structure of the NSURE mass-transfer code and its implementation under the SYVAC executive.

- **Backfill and Buffer Report** - Summary of the various experiments and tests performed on the sorbing materials clinoptilolite and dochart clay.
- **Vault Model Report, Aquifer Modelling Report and Geosphere Sensitivity Report**- three reports discussing the models employed in NSURE and the validity of the assumptions employed in the models.
- **Partition Coefficients Compilation** - A report interpreting, selecting and adjusting (for expected conditions) sorption coefficients for the various contaminants in the assessment.
- **Water Table Study** - An analysis of the water table fluctuations of the aquifer beneath IRUS.
- **Concrete Program** - A summary of the experiments and tests performed in the evaluation of various concrete mix designs for IRUS.
- **Worker Dose Assessment** - An analysis of the predicted doses to workers emplacing wastes into the IRUS facility.
- **Duke Swamp Scenario** - The analysis of a "special" scenario where contaminants migrating from IRUS adsorb onto the peat deposits of a nearby wetland. Doses are estimated from the use of the contaminated peat as a soil amendment.
- **Heating Rate Limit** - a theoretical examination of the temperature response of the IRUS facility to heat generation (radioactive decay, organic decomposition, exothermic corrosion of metals).
- **Scoping Calculations** - An appendix to the PSAR which provides simple, transparent hand calculations along with comparisons to NSURE code results.

- International Near-Surface LLRW Disposal - An appendix of the PSAR which provides information on near-surface disposal practices in other countries.

From a project management perspective, one of the advantages of the supporting documents approach was to ensure that individual contributors understood the scope of work required for each of the documents listed above. This also provided a measure of insurance that issues were not being allowed to "fall through the cracks", to be uncovered only at the culmination of the project.

CONCLUSIONS

In summary, regulatory review of the IRUS project had two major benefits:

- (1) Supporting documents were created to address regulatory issues. Specific technical issues that had been overlooked or insufficiently probed were identified and addressed. This, for example, precipitated the decision to place less reliance on waste forms and to introduce an additional barrier in the form of a strongly sorbing backfill.
- (2) Regulatory review instigated an internal restructuring of the project to enable better communication between data providers and the end users of these data (the PA team). The licensing of a LLRW disposal facility is very much a multidisciplinary process, involving civil and design engineers, hydrogeologists, radiochemists, chemical engineers, mathematical modellers, etc. Making the PA team the primary contact for experimentalists and information providers ensured that the project needs were communicated clearly and that efficient use was made of resources. It also ensured that the PA group was made aware, firsthand, of important technical issues that might otherwise escape their attention.

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**SAFETY ASSESSMENT GUIDANCE IN THE INTERNATIONAL
ATOMIC ENERGY AGENCY RADWASS PROGRAM**

Ivan F. Vovk and Roger R. Seitz
P.O. Box 100
International Atomic Energy Agency
(43) 1- 2060-26101

ABSTRACT

The IAEA RADWASS programme is aimed at establishing a coherent and comprehensive set of principles and standards for the safe management of waste and formulating the guidelines necessary for their application. A large portion of this programme has been devoted to safety assessments for various waste management activities. Five Safety Guides are planned to be developed to provide general guidance to enable operators and regulators to develop necessary framework for safety assessment process in accordance with international recommendations. They cover predisposal, near surface disposal, geological disposal, uranium/thorium mining and milling waste, and decommissioning and environmental restoration. The Guide on safety assessment for near surface disposal is at the most advanced stage of preparation. This draft Safety Guide contains guidance on description of the disposal system, development of a conceptual model, identification and description of relevant scenarios and pathways, consequence analysis, presentation of results and confidence building. The set of RADWASS publications is currently undergoing in-depth review to ensure a harmonized approach throughout the Safety Series.

INTRODUCTION

Safe management of radioactive waste is of high national and international visibility. Safety of near surface and geological disposal is a subject of growing interest of the present generation and will evidently retain its importance for many generations to come.

As a contribution to the process of demonstrating that radioactive waste can be managed safely, the IAEA has initiated the Radioactive Waste Safety Standards (RADWASS) programme in which it intends to document the internationally agreed approaches to safe radioactive waste management, including disposal, and provide Member States with a comprehensive series of documents to assist in derivation of and to complement national

criteria, standards and practices. These documents are published as part of the Agency's Safety Series covering nuclear safety, radiation protection, transport of radioactive materials and radioactive waste management.

The importance of the programme has been reaffirmed by the Agency's General Conference, which at its thirty-eighth regular session held in September 1994, invited the Board of Governors and the Director General "to maintain the emphasis given to radioactive waste management, especially with regard to RADWASS, to commence with planning activities for a convention of the safety of waste management and begin the process of collecting relevant background information (including appropriate RADWASS documents) that would be useful in drafting the convention".

The principles and responsibilities in radioactive waste management contained in two recently published top level RADWASS documents^{1,2} were considered by a group of experts at their meeting in July 1995 as a generally suitable basis for the convention. The convention is likely to contain an article on assessment and verification of safety.

In the past, the RADWASS programme was overseen by the International Radioactive Waste Management Advisory Committee (INWAC), extended later to give broader representation of the national regulatory bodies (extended INWAC). Recently, in accordance with the modification of the review and preparation process for Agency standards to promote a more coherent and consistent policy and better reflect the viewpoint of Member States, new advisory bodies have been proposed. A new body, the Advisory Commission on Safety Standards (ACSS), consisting of Member States' senior government officials, will be responsible for guiding the Agency's overall safety standards programme. Extended INWAC will be replaced by WASSAC (Waste Safety Standards Advisory Committee) which will be the review body for all waste-related standards.

In guiding the RADWASS programme INWAC took a position that safety of any waste management system must be convincingly shown prior to its operation. This can be done by means of safety assessments which provide the principal tool to investigate, quantify

and explain both potential radiological impacts and safety of a selected waste management system. Therefore, a noteworthy portion of the planned RADWASS documentation is devoted to this topic. For that reason, and also taking into account the importance of the safety assessments for the practical implementation of the waste management safety convention, further support of this position by Member States and, therefore, by WASSAC is also expected. Nonetheless, a review of the RADWASS programme that was to have been carried out by INWAC will now be carried out by WASSAC so the programme, as described here, may be modified.

The objective of this paper is to provide information on the status of the RADWASS documents for assessing the safety of waste management facilities with the emphasis on the safety assessment guidance for near surface disposal.

STATUS OF RADWASS DOCUMENTS ON SAFETY ASSESSMENT

In hierarchical order, the Agency's Safety Series comprises: the Fundamentals, stating basic objectives, concepts and principles; the Standards, stating basic requirements to be fulfilled in the case of particular activities or applications; the Guides, containing recommendations related to the fulfillment of the basic requirements stated in the Standards; and the Practices, giving examples and detailed descriptions of methods which can be applied in implementation of both the Standards and the Guides.

On recommendations of the INWAC in 1993, the RADWASS programme was structured following the above general framework as a complete body of 55 documents for six subject areas (1- Planning, 2- Predisposal, 3- Near surface disposal, 4- Geological disposal, 4- Uranium/thorium mining and milling waste, 6- Decommissioning and environmental restoration)³.

The most important aspects of radioactive waste management are outlined in the 9 principles formulated in the Fundamentals document¹. These principles comprise the main safety objectives:

- protection of human health;
 - protection of the environment;
 - protection beyond national borders;
 - protection of future generations; and
- demand that
- no undue burdens are imposed on future generations;
 - radioactive waste is managed in an appropriate legal framework;
 - generation of radioactive waste is controlled;
 - account is taken of interdependencies among radioactive waste generation and management steps; and
 - safety of the facilities is assured.

In order to fulfill the requirements governed by the above mentioned principles it is necessary, in the first place, to assess the safety of the radioactive waste management facility. Comprehensive safety and environmental impact assessments are considered in the published Standard² and the draft Standards for other subject areas to be key elements in ensuring safety and environmental protection. They are required to be performed and updated, as necessary, in support of application to the regulatory body for approval to construct, to operate and to decommission a facility or to close a repository and if significant changes in approved conditions appear.

The above principles are very general. The requirements will have to be formulated in a concrete and, as necessary, quantitative numerical form so that compliance can be demonstrated, for example, through predictive modelling. For predisposal facilities the requirements will have to be closely linked to current safety requirements for any other nuclear facility. Furthermore, additional requirements will need to be developed to take into account the unique challenges of demonstrating long term safety of near surface and geological disposal.

The scientific and technical basis for the development of such requirements in the RADWASS documents is provided in the relevant publications of international organizations

such as the IAEA, OECD/NEA and ICRP. In relation to the radiological protection aspects of the principles, recommendations of the International Basic Safety Standards for radiation protection⁴ are relevant.

Safety assessment methodologies for radioactive waste management facilities have been developed and demonstrated over many years in a number of countries. An important methodological basis for safety assessment is establishing and examining links between safety assessment results and regulatory requirements, between mathematical models used in the performance assessments, and between model development and operating facility or laboratory, or natural analogue observations. On this basis, within the RADWASS programme, 5 Guides, one Guide for each subject area (with the exception of Planning), will provide general guidance to enable operators and regulators to develop the necessary framework for the safety assessment process and to elaborate specific guidelines for various activities comprising safety assessment of waste management facilities in accordance with international recommendations and national regulatory requirements.

At present two Guides are at an advanced stage of preparation. The draft Guide on safety assessment for near surface disposal is being finalized by the IAEA Secretariat and the draft Guide on safety assessment for the decommissioning of nuclear facilities has been prepared and reviewed by consultants' and technical committee meetings, respectively.

Safety assessment Guides for three other subject areas are still in the stage of preparation and approval of the terms of references.

SAFETY ASSESSMENT GUIDANCE FOR DISPOSAL

In addition to the two Guides, the planned RADWASS documents on safety assessment in the disposal subject areas include a number of Practices, covering specific subjects, for example, selection of scenarios for safety assessment of near surface and geological disposal facilities.

Difficulties with projecting site and facility behaviour for long times distinguish post-closure assessments from more typical operational safety assessments. The IAEA report⁵ examines the question of what type of safety assessment is needed to cover time periods far into the future and also what sort of safety criteria (or safety indicators) are appropriate at such times. The report concludes that the assessed long term consequences of disposal systems in terms of risk and dose can only be considered as indicators of safety. The long term safety case can be made most effectively by the combined use of several safety indicators, such as risk, dose, environmental concentration, biospheric flux, flux through barriers and time recognizing, however, that risk and dose remain the most fundamental of the indicators of safety.

As to the exact numerical limits set for doses or risks, no formalized single consensus for the post-closure phase of repositories has been obtained. Some experts argue that precise values of such limits are not of great relevance because of relatively low resolution of the analyses and the conservative approach to safety normally employed. The licensing issue of most concern at present is not what the formal criteria should be, but rather how one can demonstrate compliance with a given set of criteria. The difficulty in demonstrating compliance is greatly influenced by the time duration for which compliance is required and which is also difficult to specify. Thus, specification of generically applicable numerical safety criteria for disposal still remains an open issue that requires further consideration.

Near Surface Disposal

The draft Guide on safety assessment for near surface disposal includes consideration of the operational and post-closure phases but emphasizes post-closure issues. Guidance includes general considerations for safety assessment relevant to the near surface disposal option and the presentation of guidelines recommended for major activities comprising a safety assessment. In addition, the activities necessary for confidence building and for developing the basis for assurance that regulatory standards have been met by the waste disposal system are considered.

Although safety assessment plays a role in all stages of a near surface disposal facility, its principal role is in license application and approval process. Therefore, its use is of greater importance in the stages following early concept development and site selection. Such assessments can then be developed to assist in system optimization and facility design by carrying out comparative assessments for various combinations of alternative waste packages, disposal modules and site management and closure measures.

The Safety assessment process described in the draft Guide involves the following activities:

- description of the disposal system, including site, waste form and engineered structures;
- determination of conceptual models of the behaviour of the system and its subcomponents;
- identification and description of relevant scenarios;
- identification of the pathways potentially leading to the transfer of radionuclides from the repository to humans and the environment;
- implementation of appropriate models;
- evaluation of the system performance; and
- verification of compliance of the assessment results with the design goals through critical review.

Following are several examples of the guidance and advice given in the draft Guide covering the safety assessment activities listed above.

The model should be consistent with the assessment objective; easy to use (considering the complexity of the system); and one, for which the data can be obtained. The model should be appropriate for the application, the algorithms should be accurate, the assumptions should be reasonable, and the input data representative.

The source term used in the model should be representative of potential releases of radionuclides from various waste forms under the identified range of environmental

conditions and should consider degradation of engineered barriers, for example, such as cover systems and concrete structures. Early models are likely to be simple but as understanding of the system develops it may become necessary to employ more detailed models to ensure that the system is adequately represented. But the models should be simple enough to be compatible and commensurate with available data, or the result could be greater uncertainty rather than an improved accuracy. The assessor must use judgement here to ensure a proper balance between using simple models and conservative data and more detailed models that may need some data not readily available.

Reasonable conservatism should be built into the safety assessment modelling from the beginning. A simple modelling approach is likely to be more efficient, cost effective, and defensible. Assumptions should be formulated based on available data and knowledge of the system or similar systems, to avoid underestimating release and transport of radionuclides or, if required, the exposure of the inadvertent intruder. Any decrease in the original conservatism used in the analysis should be based on a more detailed understanding of the waste disposal system and will require a more rigorous defence. This should be achieved by additional modelling efforts or refined data. Since defence of the results can be the most difficult aspect of an assessment, any approach to make that defence easier will be a long term benefit. An approach which balances simplicity, conservatism and realism, is likely to be the best starting point for assessments.

It is recognized that some uncertainties, particularly those associated with human actions dictated by future socio-economic conditions or major changes in climatic conditions, may in principle affect the exposure of humans in the future yet are not readily amendable to quantified predictions. In such circumstances to impose artificially generated values which disguise this problem could lead to a spurious impression of accuracy and produce misleading results. Safety assessment is based on a conceptual model whose prime purpose is to provide a framework in which to allow analysis to proceed. Where suitable mathematical models can be derived and the data exist then predictions can be quantitative. When this is not the case only qualitative deductions can be made; perhaps rating risk as high, medium or low according to circumstances. This does not invalidate the assessment process but renders it

more dependent on the assessor's judgement, supported where possible by calculation. Within this framework, however, the basis for the judgement should be carefully documented for examination as part of the safety assessment. The assessor should be careful that the reliability of information available is reflected in the level of calculational detail provided in the assessment, which should therefore change according to the length of time into the future being considered.

Some further recommendations are provided in the conclusions of this paper.

Geological Disposal

A draft terms of reference for the Guide on safety assessment for geological disposal has been prepared for review by WASSAC. It includes the following major points to be addressed.

- (a) Definition of safety assessment and interpretation of the assessed long term radiological consequences of disposal systems.
- (b) Review of geological disposal as an option suitable to deal with long lived, high level and heat generating waste.
- (c) Safety philosophy and specific safety features of geological disposal, including:
 - a system of multiple containment barriers
 - passively safe state
 - time frames
 - safety indicators
- (d) Safety requirements, regulatory and performance criteria for geological disposal.
- (e) Iterative approach and major uses of safety assessments:
 - to derive or specify waste acceptance requirements
 - for selection of a site
 - for facility design
 - for license approval at various repository stages.
- (f) Data requirements and acquisition of information on the disposal system:
 - regional studies

- observations at and around the site
- underground laboratories
- (g) Development of appropriate models.
- (h) Identification of exposure scenarios and pathways.
- (i) Integrated assessment of potential radiological consequences:
 - model calculations
 - sensitivity analysis
 - uncertainty analysis
- (j) Presentation of results:
 - verification of compliance of the assessment with criteria
 - level of presentation
- (k) Confidence building:
 - verification, calibration and validation of models
 - natural analogues
 - peer reviews
 - quality assurance

CONCLUSIONS

1. The safety issue for radioactive waste has a high international visibility.
2. There is a sound scientific and technical basis for providing guidance and advice on safety assessment for on-going and planned radioactive waste management practices, in particular, for near surface and geological disposal.
3. A large part of the IAEA RADWASS documentation is being devoted to this topic with emphasis given to describing ways of ensuring that principles and requirements for radiological protection and safety for workers, members of the public and the environment are met.
4. Safety assessments play a role in different stages of the process of establishing waste repositories. Preliminary assessments can be used in site selection. Safety assessments provide inputs to repository design and allow the definition of waste

- acceptance requirements on a repository specific basis. Finally, licensing of a repository should be based on the outcome of a safety assessment.
5. Quantitative results from assessments of a disposal system do not, however, provide hard criteria which obviate the need for human judgement. They are indicators of what might happen under certain conditions that may prevail in the future.
 6. Because of the complexity of a disposal system composed of both natural and engineered parts, repository models tend to be complex. Careful presentation of simplified results, particularly to the public, explaining why the assumptions used in the modelling process do not lead to an underestimate of the consequences of disposal, is therefore important.
 7. To substantiate the outcome of the safety assessment the following are required:
 - a thorough discussion of the conceptual model and the physical basis for the model;
 - the basis for selecting or developing scenarios and pathways;
 - documentation of assumptions and justifications of simplifications used; and
 - a summary of the model and code inputs and the data on which the inputs are based.
 8. Documentation of the results of the safety assessment should include information on importance of changes in key parameter values with respect to the conclusions and the outcomes of any sensitivity and uncertainty analyses.
 9. For the soundness of all decisions based on the results of a safety assessment it is essential that the results deserve a high level of confidence. Scientists, regulators, decision-makers and the public should all have confidence in the information, insights and results provided by safety assessments. Activities contributing to confidence building include: verification, calibration and validation of models, investigation of relevant natural analogues, quality assurance and peer review.

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PERFORMANCE-ASSESSMENT PROGRESS FOR THE ROZAN
LOW-LEVEL WASTE DISPOSAL FACILITY

Lech Smietanski, Jan Mitrega, Zbigniew Frankowski,
Andrzej Gawin, Jerzy Pachla,

Polish Geological Institute,
00-975 Warsaw, 4 Rakowiecka
Poland, tel.: + 48 (22) 49 53 51 ext. 558
fax: + 48 (22) 49 53 42

ABSTRACT

The paper presents a condensed progress report on the performance assessment of Poland's low-level waste disposal facility which is operating since 1961. The Rozan repository is of near-surface type with facilities which are the concrete fortifications built about 1910.

Site characterization activities supplied information on regional geology, geohydrology, climatic and hydrologic conditions and terrain surface evolution due to geodynamic processes.

Field surveys enabled to decode lithological, hydrogeological and geochemical site specific conditions. From the laboratory tests the data on groundwater chemistry and soil geochemical and hydraulic characteristics were obtained.

The site geohydrologic main vulnerable element is the upmost directly endangered unconfined aquifer which is perched in relation to the region-wide hydraulic system. Heterogeneity of this system reflects in a wide range of hydraulic conductivity and thickness variations. It strongly affects velocity and flow directions. The chemistry of groundwater is unstable due to large sensitivity to external impacts.

Modeling of the migration of the critical long-lived radionuclides Tc-99, U-238 and Pu-239 showed that the nearly 20 m thick unsaturated zone plays crucial role as an effective protective barrier. These radionuclides constitute minor part of the total inventory. Modeling of the development of the H-3 plume pointed out the role the macrodispersion plays in the unsaturated zone beneath the repository.

OBJECTIVE

The safety assessment of the Rozan low-level waste disposal facility including its structural and geotechnical long term stability as well as radiological impacts.

THE REPOSITORY

The repository is of a near-surface type with facilities which are the concrete fortifications built about 1910. It is believed to be one of the first massive usage of Portland cement. Tests and analysis of the concrete strength reveal that despite of over 80 years which elapsed, this facility's material has not been changed (20÷25 MPa in 1910 vs. 23.2 MPa in 1992). Geophysical surveys (non-destructive technique of ultrasonic soundings, microseismic and geo-thermic profiling, thermovision and radar SIR-3 examination) also confirm a good integrity of the structures. In operation since 1961.

SITE CHARACTERIZATION ACTIVITIES

Archive records were examined to decode regional and multi-annual conditions:

- climate (temperature, precipitation) variations since 1900,
- hydrology (seasonal distributions) and water balance (based on energy conservation) since 1966,
- geology (stratygraphy, tectonics, seismicity, lithological units, evolution)
- hydrogeology (groundwater occurrences, systems, recharge-discharge profiles),
- cartography (surface evolution due to geodynamic processes) since 1512.

Field studies to decode site specific conditions:

- geological mapping (surficial deposits),
- geoelectric soundings and profiling (geometry, continuity and lithologic contacts),
- observation well drilling and logging (8 wells on 3 ha repository area and 16 within 0.5 km radius and 12 more distant, respectively) to justify and improve geophysical image and monitor the unconfined aquifer (sampling, groundwater-table configuration and variations),
- testing hydraulic properties and actual flow velocities (solid weight slug tests, i.e. not disturbing version, interpreted with Hvorslev's time-lag, in-hole direction and velocity measurements by I-131 and thermal source methods),
- vadose-zone moisture content and its seasonal changes (isotope and non-isotope methods)

- groundwater environmental isotopic signatures (recharge conditions),
- meteorological observations (to link regional and site conditions).

Laboratory tests to obtain:

- groundwater chemistry,
- soil characteristics (permeability, porosity, sorption, geochemistry)

SITE CHARACTERISTIC MAIN FEATURES

Geology

The Quaternary overburden is around 170 m thick and comprises of 13 alternating till, sand and silty series. The geological structure of the Quaternary system was generally completed 135 Ka ago. Further geomorphologic modifications relate to the evolution of the Narew river valley due to erosion.

Geomorphology

The repository is located on a terrain culmination elevated $122 \div 125$ m a.s.l., which is also local surface water divide. The present distance to the Narew river is around 800 m.

Geological hazards

Potential over the long time period:

- land surface distortion in a case of diversified vertical movement of rock masses (neotectonics), magnitude of 0.25 m/8 Ka to 1.0 m/30 Ka,
- erosion due to river meandering or headward migration of gullies into the waste disposal site, 10 to 30 Ka,
- glaciation, 5 to 50 Ka.

Eliminated:

- overland flooding,
- risk due to catastrophic river floodings of recurrence to a few thousand years,
- groundwater intrusion due to excessive rainfall or induced by river water stage (single rainfall event should be one order higher than the recorded max. annual sum),
- seismic.

Based on the geological hazard assessment it can be concluded that no reasonable prediction will be obtainable for the time frame beyond 5 to 10 thousand years.

Hydrogeology

An important role in the regional hydrogeology is played by deeper continuous moraine clay complex, which is 30÷40 m thick, and constitutes a base for the shallow groundwater system and effective isolation of the deeper groundwater system.

The whole upmost directly endangered aquifer is perched in relation to the river and simultaneously perched in reference to the region-wide hydraulic system of moraine highland.

Heterogeneity of the system is reflected in a wide range of permeability coefficient values. Vadose-zone permeabilities, except for tills, range from less than 0.4 m/d to more than 80 m/d in fully saturated state. Saturated-zone permeabilities for endangered aquifer fall within the range of 5 to 20 m/d outside of and 0.2 to 5 m/d in the region of repository, respectively.

Groundwater actual flow velocity values range from 0.02 to 0.20 m/d. The thickness of aquifer is very variable, generally from a half to some meters. Water table configuration and outflow to the discharge zone are strongly affected by local morphology of the underlying moraine clay layer. Thus, released pollutants partly will migrate from the region beneath the repository towards the south and not to the by-passing Narew river.

Climate

Present climate conditions of the site are expressed by mean precipitation of 688 mm/a corrected to the ground level and max. daily rainfall of 50 mm. Potential evapotranspiration is 707 mm/a. The moisture deficiency occurs from April to September and as calculated for the period 1966-1990 is 12.5 to 98 mm/a depending on soil cover. The groundwater year-to-year recharge may vary from a few to around 200 mm/a. Decreasing trend in annual amount of precipitation is observed since the beginning of century.

Geochemistry

Groundwater samples from the repository area and its vicinity reveal that chemical composition of water of this unconfined system is unstable due to large sensitivity to external impacts. Despite of that, a distinct zoning of migration controlling parameters (pH, Eh) prevails in the area. Sorption properties of vadose-zone and aquifer materials are rather low (in a view of possible Kd ranges found in the literature), as typically for glacio-fluvial and outwash sediments.

Radiological Monitoring

Radiological monitoring is an activity carried out by the special body and authorized services operating under the supervision of the National Atomic Agency. The 300 m. - wide an intermediate zone has been established preventively on the request of the Ministry of Environment Protection. The land use, however, is not a subject to any limitations. In a view of measurements it can be concluded that a level of the radioactivity of particular environmental elements, i.e. water, grass, soil and ray, is controlled by the concentration of the natural isotope K-40. At present Cs-134 and CS-137 radioactivity originating from the Chernobyl catastrophe is at trace level and often below detection point, although some records from 1986÷87 reveal a radioactive effect of this disaster.

Recently, the groundwater monitoring revealed H-3 leakage from one facility. Geochemical determinations make the evidence that it is the only radionuclide being released from the facility.

The detected and monitored H-3 plume has not crossed the Rozan repository boundary yet.

Inventory of the Radionuclides

According to the Institute of Atomic Energy (IAE) data, total activity of the radionuclides disposed off in the Rozan repository was estimated at 445 Ci. This activity was dated on the 1st January 1992 and was an outcome of hand calculations after examining all shipment records since 1961.

A computerized data base was prepared in 1992-1993 and all shipment records were put into the computer files. The shipment records underwent the verification procedure as well. After processing the computer based data the total activity dated on the 31st December 1994 was estimated at 800 to 1100 Ci.

THE RADIONUCLIDE TRANSPORT MODELING

Screening calculations revealed that the critical radionuclides for the groundwater pathway are: H-3, Tc-99, U-238 and Pu-239.

Hypothetical release of Tc-99, U-238 and Pu-239 was modeled with an assumption that after 500 years all engineered barriers fail and there is no sorption in the unsaturated zone. With this conservative approach simulation of these three long-lived radionuclides transport in groundwater showed the development of the contaminated plume within the 500 years time span after the release begun.

Next round of the radionuclide transport modeling was carried out assigning the unsaturated zone literature K_d values, except for the uranium. The partial disintegration of the repository cover was also assumed.

Water flow and the radionuclide transport through the repository, unsaturated and saturated zone was modeled by the VS2D, DUST and ANPLA codes. The outcome of the modeling showed that the long-lived radionuclide flux leaking from the repository does not create the contaminated plume within 6000 years time span after the release. This is the effect of the unsaturated zone sorption capacity. The DUST code could not exceed 6000 years of simulated time because of its internal constraints.

H-3 MIGRATION

A number of problems were encountered in an attempts to model the development of the detected H-3 plume.

It was assumed that the H-3 released from the repository migrates down the vertical flow path through the unsaturated zone. Also the H-3 flux cross-sectional area was assumed constant along its path to the water table and equal to the area of the release surface. Because of the low permeability of the mainly silty aquifer privileged flow paths within its body had to be assumed to minimize discrepancy between observed and calculated H-3 concentrations. These privileged flow zones were assigned high permeability values. This approach turned out to be partly unrealistic because of the lack of clear evidence of the existence of such high permeability zones.

Next the attention was focused on the lithological structure of the unsaturated zone. The borehole lithological profiles show the presence of silty, fine, medium and coarse sand alternations in form of layers and lenses.

Several simulations (VS2D code) of water flow in the unsaturated zone below the repository revealed clearly the presence of significant horizontal component of water flow

velocity. Horizontal velocity component causes the macrodispersion of the H-3 flux leaking from the repository. Macrodispersion the more enlarges the width of the H-3 flux the deeper it penetrates the unsaturated zone down into the aquifer.

Finally the cross-sectional area of the H-3 flux is likely to be much larger at the groundwater table level than at the release level. The influence of the macrodispersion creating so called short-cuts in the unsaturated zone on the development of the H-3 plume in the underlying aquifer is now investigated. Modeling the H-3 migration incorporates the question of proper model calibration as well as helps to understand the recharge and flow patterns.

ACKNOWLEDGMENTS

This work gets technical and financial support from the International Atomic Energy Agency and National Atomic Energy Agency.

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PERFORMANCE ASSESSMENT FOR LOW-LEVEL WASTE DISPOSAL IN THE UK

A.B. Ashworth
Her Majesty's Inspectorate of Pollution (HMIP)
UK Department of the Environment
2 Marsham Street, London SW1P 3EB

ABSTRACT

British Nuclear Fuels plc (BNFL) operate a site for the disposal of Low Level Radioactive Waste at Drigg in West Cumbria, in North-West England. HMIP are responsible for the regulation of the site with regard to environmental discharges of radioactive materials, both operational and post-closure. This paper is concerned with post-closure matters only. Two post-closure performance assessments have been carried out for this site: one by the National Radiological Protection Board (NRPB) in 1987; and a subsequent one carried out on behalf of HMIP, completed in 1991. Currently, BNFL are preparing a Safety Case for continued operation of the Drigg site, and it is expected that the core of this Case will comprise BNFL's own analysis of post-closure performance. HMIP has developed procedures for the assessment of this Case, based upon experience of the previous Drigg assessments, and also upon the experience of similar work carried out in the assessment of Intermediate Level Waste (ILW) disposal at both deep and shallow potential sites. This paper describes the more important features of these procedures.

INTRODUCTION - THE DRIGG SITE FOR LLW DISPOSAL

The Drigg site is located in West Cumbria, a county in North-West England. It has been used since 1959 for the disposal of solid LLW, much of which arises at the nearby Sellafield Reprocessing Complex. The operator of the site, British Nuclear Fuels plc (BNFL), also operates the Sellafield Reprocessing Plants. In addition, the site receives waste from a variety of customers throughout the UK.

The original disposal concept, in operation up until the late eighties, was loose tipping into shallow trenches, followed by filling and capping. This was supplanted by an engineered system of concrete lined vaults for the emplacement of compacted and drummed wastes disposed of in grouted half-height ISO containers. Some large items of waste will be grouted in place in the vault.

The host medium is clay in a heterogeneous and discontinuous layer, interspersed with sandstone strata. The region in which the repository lies is glacial, and the next glaciation is expected, based on historical climate data, at some time between 5000 and 50,000 years hence. At this time, it is expected that the repository and its contents will be dispersed widely. This timescale constrains the period over which any performance assessment can be expected to generate reliable results.

REGULATION OF THE DRIGG DISPOSAL SITE

The site is a Nuclear Licensed Site under the terms of the Nuclear Installations Act 1975 (ref 1). A site license for operational matters is granted by the Nuclear Installations Inspectorate (HMNI). The site also requires an authorization for discharges to the environment (both operational and post-closure) under the terms of the Radioactive Substances Act 1993 (RSA 93) (ref 2). For post-closure aspects, this legislation is supplemented by published regulatory guidance (3). HMIP is the responsible body for such authorizations.*

Authorization for vault disposal was granted by HMIP in 1991. Conditions within the authorization were set, based in part on the results of an independent post-closure performance assessment carried out on behalf of HMIP. The timescale for re-authorization of disposals at the Drigg site is not laid down by statute. Nevertheless, there is a commitment to revisit the authorization approximately every four years. Consequently, the regulatory procedure is currently under way.

PROCEDURE FOR REGULATORY ASSESSMENT - GENERAL MATTERS

Two extreme approaches to an assessment of a Safety Case can be formulated. At one extreme, the regulator can carry out a full independent analysis, having developed the

* In April of 1996, HMIP will be incorporated into the new Environment Agency of England and Wales, alongside certain other bodies. This change is not expected to affect either the regulatory regime, or the detailed procedures as described in this paper.

appropriate models and data interpretations completely independently of the operator. At the other extreme, the regulator can simply arrange for an independent peer review of the operator's Safety Case, with emphasis on the strength of support underpinning each of the operator's arguments.

The former approach is precluded by resource considerations. Furthermore, the regulator cannot dictate the course of data collection or other site investigation programmes. The data requirements for the formulation of a Safety Case and for an independent assessment, although overlapping, will not be identical.

On the other hand, a straightforward 'classical' style peer review of the Safety Case is not considered to be sufficiently rigorous if HMIP is to discharge its regulatory responsibilities. Whereas a peer review may identify potential weak areas in the Case, it can not explore the significance of such potential weaknesses in a numerical sense. Consequently, the HMIP procedure is designed to run a course between these two extreme approaches.

The approach adopted by HMIP in relation to the submitted Safety Case is described by Read and Sumerling (ref 4). Other papers in the same document (ref 4) by Thompson and by Stearn set the regulatory background to the approach. This approach allows, if necessary, for an assessment of the Safety Case by means of an independent, partial and selective post-closure performance assessment. That is, HMIP will not develop a parallel or surrogate Safety Case; rather, it will select those areas which are considered to be weak or relatively unsupported and explore these areas in depth. This exploration can proceed all the way through to numerical calculations, based upon models developed independently of the operator, if this is found to be necessary. In particular, this thorough approach will be used if the regulator believes that alternative models, or alternative interpretations of the data, have not been fully explored by the operator in the Safety Case as presented.

THE REGULATORY PROCEDURE

1. The regulator (HMIP) will initiate discussions with the operator (BNFL). A plan will be formulated to cover: the document structure (of the Safety Case); timing of delivery; procedures for information exchange.
2. HMIP will produce its own timetable for assessment of the case. This is expected to cover approximately one and a half to two years, from delivery of the first tranche of documents up to final reporting. The product of this assessment will take the form of conditions for inclusion in the new authorization, and the timing for issue of such a re-authorization will be identified on the plan.
3. HMIP will initiate a contract, managed by the Radioactive Waste Disposal Centre (RWDAC) of HMIP, for assessment of the Safety Case. The contract will include two principal elements:
 - a. Provision for a peer review of the Case. Experience has shown that approximately 12 to 15 independent experts will be required. This expertise will be used, initially, to examine the Case and produce a detailed critique. Issues raised by the expert panel may then be in turn raised with the operator for explanation or clarification. Of particular interest to the panel will be the question of traceability. That is, how are the arguments presented in the Safety Case supported? How have the individual decisions been taken, justified and recorded?

The panel will also raise issues worthy of independent numerical assessment.

- b. Using the HMIP suite of assessment codes, a numerical analysis of the Case will be carried out, selecting those areas where significant uncertainty exists, in the opinion of the expert group. This analysis will take the form on an independent selective partial PSA.

4. Results from both of the above elements will be used, firstly, to inform discussions with the Drigg operator; and secondly to determine the conditions under which operations at the Drigg site can continue - that is, the conditions written into any issued re-authorization.

THE INDEPENDENT PSA

HMIP has developed the capability to carry out independent Probabilistic Systems Assessments. This capability is described by Thompson and Sagar (ref 5). The paper provides a background to the development of this capability, based upon experience in the UK and the US.

A suite of Monte Carlo simulation codes called VANDAL (ref 6) has been developed and tested in a series of trials and applications, notable DRY RUN 3 (ref 7), a preliminary assessment of proposals for a UK deep repository, and a previous assessment of the Drigg site. Climate driven boundary conditions for VANDAL are supplied by a second suite of Monte Carlo codes, TIME (ref 8).

The elements of such an assessment are (ref 5):

1. Collation of factual data to be used in the assessment, by reference to the data provided by the operator.
2. Development of conceptual models (incorporating the associated uncertainty).
3. Elicitation of probability distribution functions of the parameter values which provide the input to the models.
4. Development and calibration of the computational models.
5. Carrying out total system simulations.

6. Identification and re-analysis of high risk conditions.
7. In parallel with steps 1 - 6, development of a database listing all assumptions and decisions; that is, all potential sources of bias.
8. Presentation of results (risk, or other outputs), with all the associated uncertainty and biases.
9. Studies on the sensitivity of the consequence distributions (the results) to model and parameter uncertainty.
10. The output from step 9 will form the basis of further discussions with the operator and/or the establishment of conditions to be attached to the re-authorization.

AUTHORIZATION CONDITIONS

If and when a re-authorization is granted to the operator, certain conditions will be attached. These are in many forms, but usually include: annual and total limits for the disposal of certain types of activity (alpha, beta etc) and for certain radionuclides; areas where research or data gathering should be concentrated; areas where uncertainty and bias in the operator's PSA should be addressed by re-analysis etc.; a requirement to develop and submit forward plans to reduce identified uncertainties.

CLIMATE CHANGE

The system model employed by HMIP (ref 5) incorporates a unique climate model for simulation of future climate sequences. In the case of the Drigg site, the appropriate version of the TIME code is TIME 2. It is likely that this version, used in the previous HMIP assessment, will be updated for use in the current phase of authorization.

On the basis of quaternary records, TIME 2 simulates sequences containing five climate states - Present Day (Temperate), Savanna, Boreal, Tundra, and Glacial. These sequences are used to establish the climate driven boundary conditions for the VANDAL suite of codes. The code also has provision for human intrusion and a feature for river meander.

CONCLUSIONS

The UK regulatory framework precludes the regulator from dictating prescriptive measures for the preparation of a Safety Case by an operator; rather, the regulator limits its initial input to providing guidance (ref 3). Consequently, HMIP must prepare itself to deal with a Case, the contents and shape of which cannot be known in advance of the commencement of the regulatory procedure. Although outline planning, as described in this paper, is an essential preparation, detailed planning must await submissions by the operator. Additionally, the course of an assessment cannot be determined at the outset due to the inherently iterative nature of the process.

It is entirely possible, for instance, that HMIP's independent contracted expertise takes the same view as the operator in the matter of, say, conceptual model development and selection. However, HMIP must be prepared for the situation where such agreement is wanting.

The regulator faces demands from its parent governmental organization for accurate projections of cost and timescale. However, such projections themselves contain uncertainties as a consequence of the non-prescriptive nature of the regulations. Such cost and time projections therefore need to be presented with caveats and honest allowances for uncertainty.

ACKNOWLEDGEMENTS

The author wishes to thank HMIP for permission to publish this paper. The procedures described here are under development and may be used as a contribution to the

development of policy. However, currently, the contents of this paper do not constitute UK Government Policy.

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Donald E. Wood

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PUBLIC ACCEPTANCE FOR CENTRALIZED STORAGE AND
REPOSITORIES OF LOW-LEVEL WASTE SESSION (PANEL)

Hans R. Lutz, facilitator

PANEL DISCUSSION

Participants from various parts of the world will provide a summary of their particular country's approach to low-level waste management and the cost of public acceptance for low-level waste management facilities. Participants will discuss the number, geographic location, and type of low-level waste repositories and centralized storage facilities located in their countries. Each will discuss the amount, distribution, and duration of funds to gain public acceptance of these facilities. Participants will provide an estimated \$/meter³ for centralized storage facilities and repositories. The panel will include a brief discussion about the ethical aspects of public acceptance costs, approaches for negotiating acceptance, and lessons learned in each country. The audience is invited to participate in the discussion.

Panel Members:

Hans R. Lutz
Switzerland
9 0 11 41 56 200 38 54

Donald E. Saire
Austria
43 1 2060 22674

Ivan F. Vovk
Austria
43 1 2060 26101

John Wallace
Australia
07 252-5446

Ronald Gingerich
United States
(203) 244-2007

SOIL TREATMENT SESSION (PANEL)

Shiv Vijayan, facilitator

PANEL DISCUSSION

Panel discussion covering waste volume reduction, soil decontamination by chemical methods, cleanup target, technology selection and economics, and disposal considerations and costs.

Panel Members:

Shiv Vijayan
Atomic Energy of Canada, Limited
(613) 584-3311

Jagdish (Jeet) L. Malhotra
Morgantown Energy Technology Center
(304) 285-4053

Duncan Moffett
Acres International, Limited
(905) 374-5200

Caroline (Cas) Mason
Los Alamos National Laboratory
(505) 665-2422

Heather J. Walsh
Lawrence Livermore National Laboratory
(510) 424-4193

Charles L. Hellier
Thermo Nucleon
(615) 481-0683

C. F. (Pierre) Wong
Atomic Energy of Canada, Limited
(613) 584-3311

Gerald F. Maul, Jr.
EG&G Mound Applied Technologies
(513) 865-4285

NATIONAL ACADEMY OF SCIENCES WARD VALLEY REPORT SESSION (PANEL)

John (Jack) B. Robertson, facilitator

PANEL DISCUSSION

This panel will provide a technical discussion of (1) the charge given the National Academy of Sciences by Secretary of the Interior Bruce Babbitt to examine seven issues related to the proposed Ward Valley site and (2) how the assembled committee reached its conclusions. No attempt will be made to assess the social or political aspects of the charge, conclusions, or followup actions.

Panel Members:

Howard Wilshire
U.S. Geological Survey
(415) 329-4934

Martin D. Mifflin
Mifflin and Associates, Inc.
(703) 434-9733

Bridget R. Scanlon
Texas Bureau of Economic Ecology
(512) 471-7721

Eric G. Lappala
Harding Lawson Associates
(609) 936-0700

COST ESTIMATES AND ECONOMIC EVALUATIONS FOR
CONCEPTUAL LLRW DISPOSAL FACILITY DESIGNS

R. D. Baird and N. Chau
Rogers & Associates Engineering Corporation
P.O. Box 330
Salt Lake City, UT 84110-0330
(801) 263-1600

C. D. Breeds
SubTerra, Inc.
5106 272nd Avenue, N.E.
Redmond, WA 98053

ABSTRACT

Total life-cycle costs were estimated in support of the New York LLRW Siting Commission's project to select a disposal method from four near-surface LLRW disposal methods (namely, uncovered above-grade vaults, covered above-grade vaults, below-grade vaults, and augered holes) and two mined methods (namely, vertical shaft mines and drift mines). Conceptual designs for the disposal methods were prepared and used as the basis for the cost estimates. Typical economic performance of each disposal method was assessed. Life-cycle costs expressed in 1994 dollars ranged from \$1,100 million (for below-grade vaults and both mined disposal methods) to \$2,000 million (for augered holes). Present values ranged from \$620 million (for below-grade vaults) to \$1,100 million (for augered holes).

INTRODUCTION

Among other responsibilities, the New York State Low-Level Radioactive Waste Siting Commission (the Commission) was required to select the method to be used for disposing low-level radioactive waste (LLRW) generated in the State of New York. The Commission considered six disposal methods in this selection, namely:

- Above-grade concrete vaults with no earthen cover system.
- Covered above-grade concrete vaults.
- Below-grade concrete vaults.
- Augered holes.
- Vertical shaft mines.

- Drift mines.

The required disposal capacity was estimated to be about 5.5 million cubic feet, and the annual disposal rate was assumed to be constant over the 60-year operating life of the disposal facility.

The Commission's selection process required that life-cycle costs and economic evaluations be prepared. To support this selection process, the Commission authorized preparation of a three-volume Disposal Method Conceptual Design Report.¹ In preparing this report, life-cycle costs were estimated and economics were evaluated for each disposal method. This paper summarizes the findings of that work.

COST ESTIMATES

The cost estimates for each disposal method were calculated in 1994 dollars as though each cost were incurred in 1994. No effects of inflation were projected in the cost estimates, and 1994 prices for materials and services were assumed. Costs were estimated separately for the preoperations, operation, closure and post-closure, and institutional control periods of the facility. The preoperations period was assumed generally to last 7 years, the operations period to last 60 years, the closure and post-closure period generally to last 7 years, and the institutional control period to last 100 years.

The major cost components considered in these cost estimates included:

- Site and method selection.
- Site characterization.
- Facility licensing.
- Financial assurance.
- Payroll.
- Construction.
- Engineering and design.

- Equipment.
- Construction management.
- Fuel, utilities, and materials.
- Maintenance.
- Environmental monitoring.
- Regulatory activities.
- Financial assurances.
- Legal fees.
- Facility closure.
- Contingencies.

The magnitudes of over 300 individual cost components were estimated in preparing these cost estimates.

Costs were estimated using three types of estimates, depending on the cost components involved:

- Quantity estimates.
- Scaling estimates.
- Experience estimates.

Quantity estimates were prepared for cost components that could be characterized by a quantity or amount of material, labor, or other item for which a cost per unit was known or could be estimated. The quantity estimates were determined as the product of the quantity or amount and the unit cost. For example, the cost of concrete construction was estimated as the volume of concrete times the cost per unit volume to place the concrete.

Scaling estimates were prepared for cost components whose magnitude would be difficult to estimate as a quantity estimate, and where the cost could be related to some other cost component whose magnitude could also be estimated. In this type of estimate, the cost

is a percentage of the known cost. For example, the cost of construction management was estimated as 4.5 percent of the cost to construct a facility.

Experience estimates were used when there appeared to be no other basis for estimating costs. In these estimates, experience with other projects of similar character was used as a basis for the estimate. For example, legal fees were estimated as an annual amount, based on experience with similar development activities.

The estimated life-cycle costs are summarized in Table 1. As shown, estimated total life-cycle costs ranged from about \$1,100 million to about \$2,000 million expressed in 1994 dollars. For all disposal methods, the operational costs comprise the vast majority of the estimated life-cycle costs. For near-surface disposal methods, disposal unit construction and payroll costs comprised from 65 to 80 percent of the estimated operating costs. In contrast, these components totaled between 40 and 50 percent of the operating costs for disposal in mines.

ECONOMIC EVALUATION

The economic performance of each of the six LLRW disposal methods was also evaluated. The economics evaluations took into account:

- Magnitudes of estimated cash flows.
- Timing of estimated cash flows.
- Assumed inflation rate of 3 percent per year.
- Assumed discount rate of 6 percent per year for costs through the end of the post-closure period.
- Assumed secure interest rate of 5 percent per year for funds to support activities during closure, post-closure, and institutional control periods.
- Assumed absence of tax effects because of public ownership.

The resulting present values for the estimated total life-cycle costs of the six disposal methods are summarized in Table 2. The table shows present values of estimated life-cycle costs to range from about \$620 million for disposal in below-grade concrete vaults to about \$1,100 million for disposal in augered holes. The present values for life-cycle costs for disposal in above-grade concrete vaults and mines are intermediate between these extremes.

The economic evaluation also involved estimating unit disposal costs. The initial base-case unit disposal costs, expressed in 1994 dollars, are:

<u>Disposal Method</u>	<u>Unit Disposal Cost (\$/ft³)</u>
Uncovered above-grade concrete vaults	270
Covered above-grade concrete vaults	210
Below-grade concrete vaults	190
Augered holes	310
Vertical shaft mines	290-320
Drift mines	270-300

Table 1. Summary of estimated life-cycle costs for six LLRW disposal methods.

Estimated Costs (\$Million)									
Period	Uncovered		Covered						
	Above-Grade		Above-Grade		Below-Grade		Vertical		
	Concrete	Vaults	Concrete	Vaults	Concrete	Vaults	Augered Holes	Shaft Mines ^c	Drift Mines ^c
Preoperations	190		190		190		240	270-300	250-280
Operations ^a	1000		940		860		1,600	740-830	740-820
Closure and Post-Closure	100		240		30		150	30	20
Institutional Control	40		40		30		60	40	40
Total ^b	1,400		1,400		1,100		2,000	1,100-1,200	1,100-1,200

a. Includes \$52 million for financial assurances.

b. Totals may not equal the sum of components because of roundoff.

c. Depending on characteristics of host rock formation.

Table 2. Summary of present value of life-cycle costs for six LLRW disposal methods.

	Present Values of Estimated Costs (\$Million)
Uncovered Above-Grade Concrete Vaults	\$30
Covered Above-Grade Concrete Vaults	720
Covered Below-Grade Concrete Vaults	620
Augered Holes	1100
Vertical Shaft Mines ^a	830-900
Drift Mines ^a	810-880

a. Depending on characteristics of host rock formation.

SUMMARY AND CONCLUSIONS

The constant-dollar life-cycle costs for six conceptual LLRW disposal facilities using different disposal methods were estimated to range from about \$1.1 billion to about \$2.0 billion. The present values of estimated life-cycle costs were estimated to range from about \$620 million to about \$1.1 billion. Unit disposal costs were estimated to range from about \$190 to \$320 per cubic foot.

ACKNOWLEDGMENTS

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A COMPARISON OF COSTS ASSOCIATED WITH UTILITY
MANAGEMENT OPTIONS FOR DRY ACTIVE WASTE

Carol Hornibrook
EPRI, Manager, Low Level Waste Management
3412 Hillview Avenue
Palo Alto, CA 94303
(415) 855-2022

ABSTRACT

The economics of low level waste management is receiving more attention today than ever before. This is due to four factors: 1) the increases in the cost of processing of these wastes; 2) increases in the cost of disposal; 3) the addition of storage costs for those without access to disposal; and 4) the increasing competitive nature of the electric generation industry. These pressures are forcing the industry to update it's evaluation of the mix of processing that will afford it the best long term economics and minimize it's risks for unforeseen costs. Whether disposal is available or not, all utilities face the same challenge of minimizing the costs associated with the management of these wastes.

There are a number of variables that will impact how a utility manages their wastes but the problem is the uncertainty of what will actually happen, i.e., will disposal be available, when and at what cost.

Using the EPRI-developed WASTECOST: DAW code, this paper explores a variety of LLW management options available to utilities. Along with providing the costs and benefits, other technical considerations which play an important part in the management of these wastes are also addressed.

INTRODUCTION

There are 103 operating nuclear power plants in the United States. Dry Active Waste (DAW) represents about 70% of the low level radioactive waste generated at a nuclear power plant.

Though DAW is the largest volume of low level radioactive waste generated by nuclear power plants, it usually has the lowest activity. DAW has the greatest potential for source reduction prior to it's generation and is the one waste stream that has multiple offsite processing options available. However, there are many factors which affect how a utility

will manage it's DAW. These factors are often conflicting making it difficult to determine the most effective and economic management approach.

What are the best management options for utilities dealing with: 1) long-term storage; 2) future disposal with several possible cost structures; 3) undefined waste form (what physical form the waste would have to be in to be accepted at the disposal facility) and 4) a variety of processing options to reduce volume? The final cost is very dependent on the mix of variables that apply to a utility's situation and the role they play in the evaluation.

To better understand the components that influence the elements of management that are important to utility management the following sub-issues are identified:

- Disposal site fee structure greatly influences the desirability of:
 - Source reduction - minimizing the volume of waste generated in the first place;
 - Volume reduction efficiencies and costs - processing the waste that is generated to reduce its final volume for disposal; - Available space for on-site storage:
 - Storage duration, and
 - Cost of storage

STORAGE COSTS

Volume And Shielding

There are two factors which have the greatest impact on storage costs. These are the volume of waste to be stored and the amount of shielding required. The volume of waste to be stored depends predominantly on the following: 1) duration of storage i.e., the longer you store waste the more waste to be stored, 2) the amount of waste generated, which can be further reduced by how the waste is processed. Utilities have the most influence over the amount of waste stored, by limiting the amount of waste generated.

Waste Form

None of the 13 proposed disposal sites have finalized their waste form requirements. With these unknowns, utilities storing their wastes will want to store a waste form that: 1) is safe (will not leak or decompose) and 2) will meet the likely waste form requirements, or 3) will meet waste form requirements with the least amount of reprocessing.

Disposal Fee Structure

The fees charged by a disposal facility will greatly influence how much the waste is reduced in volume prior to storage and for final disposal. The following are general descriptions of the five fee structures being considered by state compacts: volume-based, activity-based, annual use fee, cost allocation fee, and lump sum.(1) The actual fees charged at new disposal sites will likely be combinations of two or more of these.

ECONOMICS OF LLW PROCESSING OPTIONS

When attempting to determine the best LLW management strategy it is important to recognize that disposal costs represent only a portion of the total LLW program costs. In addition, the type of volume reduction employed often determines the percentage of the total program costs attributable to disposal.

The following is a list of the major cost elements which contribute to LLW program costs:

- Labor and material for collection, handling, storage and shipping
- labor and equipment for VR processing
- annualized material and equipment costs
- on-site processing fees
- off site processing fees
- transport to processor, storage facility and disposal site
- disposal fee(s).

"Wastecost"

The EPRI computer code, WASTECOST, was used to evaluate the cost savings and volume reduction benefits of a variety of LLW processing and management scenarios in light of the potential storage and disposal options. The WASTECOST analysis starts with a base case. For the purposes of this analysis the base case will be a volume-based fee schedule. The economic data in Table 1 has been derived from twenty four commercial nuclear power stations.

Table 1: Key Assumptions Used for Base Case - (DAW)

Type of nuclear plant	One BWR or Two PWRs
Waste type	Dry Active Waste (DAW)
Annual DAW waste generation	40,000 cu.ft.*
Volume Reduction Achieved	81%
Annual Disposal Volume	7,500 cu.ft
On-site storage capacity	50,000 cu.ft.
On-site storage costs	\$100/cu.ft.
Disposal costs	\$ 0/cu.ft.

Processing	Vol. Processed	Process Efficiency	Cost/cu.ft.
<u>On-site</u> unprocessed DAW	0	0%	\$118.65
Green is Clean	8,000 cu.ft.	95%	\$29.43
Compaction	30,000 cu.ft.	75%	\$46.63
<u>Off Site</u> Co-Mingle DAW	0	77%	.78
Incineration	0	99%	\$37.80
Off-site Supercompaction	0	88%	\$31.89
Metal Melt	2,000 cu.ft.	100%**	\$52.16
Green is Clean (GIC)	0	97%	\$22.63
	40,000 cu.ft.		

* 40,000 cu. ft. of DAW selected for this example even though it is above the average annual generation of DAW at nuclear power plants.

** Metal Melt is considered 100% efficient because after processing, no waste is sent for disposal. The metal is recycled for use as containers for radioactive wastes at Department of Energy facilities.

Impact Of Disposal Fees On Waste Minimization

The first parameter to understand is what influence does disposal cost have on determining how much waste minimization is cost effective? Disposal fees of \$75; \$300 and \$600/cu. ft. were selected. The basis for the fees selected is as follows; at Barnwell the disposal fee is \$73.00/cu.ft.; adding South Carolina's 1993 site access fee brings the total cost per cubic foot to about \$300/cu.ft. And the \$600/cu.ft. analysis is for comparison purposes only. It illustrates the effect of a dramatic increase in LLW disposal fees.

Waste Minimization Processes

Waste minimization is a term used to represent both source reduction and volume reduction. Source reduction in this paper, means not generating the waste in the first place. This can be achieved by at least two techniques. First, using substitute reusable/rewashable materials for the disposable material currently being used. In this way, the item can be used a few hundred times prior to its being worn-out. The second technique is to find a way to eliminate the need for using the material in the first place.

Volume Reduction refers to the processes that can be applied to the waste after it is generated to further reduce it's volume for disposal. This includes techniques such as incineration which has a 99% efficiency and off-site supercompaction which is 88% efficient.

Seven waste minimization scenarios were developed for this analysis. Each scenario is either dependent on not generating waste (source reduction) and/or shifting the processing of certain wastes to alternative processes. The changes in processing proposed in this paper are all based on options available to the industry, with the off-site processors regulated by either the NRC or the state in which the processing vendor is located. In those circumstances where the state regulates the vendor, the state has applied for and obtained authorization from the NRC to carry out the regulatory function. These scenarios are:

Scenario 1: Increase Green-is-Clean processing to 50% of total DAW volume.

- Scenario 2: Implement 50% DAW source reduction.
- Scenario 3: Shift On-site Compaction to Off-site Incineration.
- Scenario 4: Shift On-site Compaction to Off-site Supercompaction
- Scenario 5: Combined effect of Scenarios 1 and 2
- Scenario 6: Combined Effect of Scenarios 1, 2, and 3
- Scenario 7: Combined effect of Scenarios 1, 2, and 4

From a total program cost perspective, it is clear that the lowest cost program for all disposal cost options, is Scenario 7 which is a combination of Scenario 2, 50% DAW source reduction being applied first, then increase in the Green is Clean processing to 50% of total DAW volumes left and finally shifts current on-site compaction of waste to a more efficient off-site incineration process (Scenario 3). Scenario 7 has the second lowest O&M costs of the seven options presented or the base case.

The next item of note is the dramatic effect processing efficiency has on disposal costs. Scenarios 6 and 7 are comparable because they both employ source reduction initially and therefore their efficiencies are based on the processing of 20,000 cu.ft. of waste. Going from 94.6% VR efficiency to 99.6% efficiency saves a utility \$72,270 in disposal fees. This occurs because a 5% improvement in efficiency results in a factor of 10 less waste volume .

The three most cost effective O&M scenarios, i.e., when O&M is looked at as processing costs only are 2, 5, 6 and 7. Three of these scenarios (2, 6 and 7) are also highly efficient. The cost effectiveness and efficiencies are due primarily to the large impact source reduction (Scenario 2) has on processing costs. But the total savings are attributable to three factors: 1) the low cost of implementing a source reduction program; 2) the avoidance of processing wastes not generated; and 3) the disposal saving from having less waste to dispose. In the WASTECOST analysis of this set of assumptions, storage costs, which are capital costs, are zero and disposal is an O&M cost. Therefore, the total program costs represent the total annual O&M costs. Recognizing this, for facilities where disposal is available, the most effective ways to reduce O&M costs are to implement an aggressive source reduction program and use highly efficient off-site volume reduction processes.

Along those same lines we see that the same program efficiency can be attained at very different total costs. For example the efficiency of the base case and Scenario 2 are both 81.3, but the final volumes of waste differ significantly (7,500 vs. 3,750 respectively). The impact of cutting the waste volume in half (Scenario 2) represents a \$500,000 savings. This points to the importance of selecting the most cost effective method for achieving waste minimization rather than evaluating success on VR efficiency achieved.

If we compare the total costs for each of the three disposal cost options, it is clear that for disposal costs of \$300 and \$600/cu.ft. the highest efficiency process results in the cheapest total program costs.

Table 2: Top Four Options Ranking Program Costs from Lowest to Highest for Disposal Costs of \$73, \$300 and \$600/cu.ft.

\$73			\$300			\$600		
Scen.	TC	%Effic.	Scen.	TC	%Effic.	TC	Scen.	%Effic.
6	\$0.60M	94.6	7	\$0.7M	99.6	7	\$0.7M	99.6
7	\$0.68M	99.6	6	\$0.8M	94.6	6	\$1.1M	94.6
5	\$0.70M	88.8	5	\$1.2M	88.8	3	\$1.6M	99.3
2	\$0.82M	81.3	3		99.3	5	\$1.8M	88.8

Scen. = Scenario; TC = Total Cost; %Effic. = Percent Efficiency.

Processing Options

The most cost-effective waste minimization option is source reduction because of the low volumes that result and the low/no additional cost of implementation. However, as actual waste processing efficiencies increase there is a dramatic reduction in the volume to be disposed, which results in a significant savings on disposal costs. This is most significantly represented in Scenario 3 where 30,000 cu.ft. was originally compacted on site and reduced

to a disposal volume of 7,500 cu.ft. is instead incinerated down to 300 cu.ft. This dramatic reduction in disposal volumes translates into a disposal savings from the base case of $\$2,250,000 - \$90,000 = \$2,160,000$. When disposal is $\$600/\text{cu.ft.}$ the disposal savings are even more dramatic $\$4,500,000 - \$180,000 = \$4,320,000$. These examples make a strong case for carefully evaluating the higher costs of more efficient processes (O&M Scenario 3; incineration - O&M Base Case) $\$1,443,874 - \$988,545 = \$455,329$ (These relative differences are the same regardless of disposal costs in this analysis.)

ON-SITE STORAGE

For this analysis, storage is a capital cost. A review of the data reveals that an aggressive waste minimization program has an immediate benefit in most cases. For example, the O&M costs decreases in five of the seven cases. This decrease ranges from a O&M savings of $\$51,971$ in Scenario 4 to $\$494,272$ in Scenario 2. Total annual savings range from $\$206\text{K}$ in Scenario 1 up to $\$1,105\text{K}$ in Scenario 6. In addition, it results in a dramatic increase in the duration of time. The storage facility can accommodate generated waste.

As we saw in the disposal scenario the highest efficiency program may not be the most desirable. Because storage costs are included in this analysis, and they constitute capital costs we can look closely at the implications of individual scenarios on O&M costs versus total program costs. The greatest O&M savings over the base program is achieved by implementing Scenario 2. This is consistent with the disposal scenario discussed earlier.

When total program cost reduction is considered, it is worth comparing Scenario 6 with Scenario 7. Scenario 6 clearly has the lowest total program cost of $\$634\text{K}$. A comparison of these scenarios shows there is a point where additional processing results in additional costs rather than savings. This is true despite the storage capacity gains achieved.

From Table 3 we see that both final volume and O&M processing costs have the greatest impact on determining what percentage of the total is attributable to storage costs.

Table 3: Storage Costs as a Percent of Total Program Costs

Scenario Cost	Waste Volume	Storage Cost	\$O&M	Total Cost	Storage as a % of Total
7	90	\$ 9,000	\$ 677,720	\$ 686,720	1%
3	300	\$30,000	\$1,443,874	\$1,473,874	2%
6	1080	\$108,000	\$ 525,530	\$ 633,530	17%
5	2250	\$225,000	\$ 541,121	\$ 766,121	29%
4	3600	\$360,000	\$ 936,574	\$1,296,574	28%
2	3750	\$375,000	\$ 494,273	\$ 869,273	43%
	4500	\$450,000	\$1,082,243	\$1,532,243	29%
Base	7500	\$750,000	\$ 988,545	\$1,738,545	43%

Storage With Eventual Disposal

The costs for storage at \$100/cu.ft. and eventual disposal at \$300/cu.ft. were analyzed. [The results of this scenario are a sum of the O&M costs in any of the scenarios; the storage costs in the \$100/cu.ft.; and the disposal charge of \$300/cu.ft.] In this situation selecting the highest efficiency process (Scenario 7) has the fourth highest O&M costs (\$677,720); the lowest storage (\$9,000) and disposal (\$27,000) costs; and the lowest total program cost of \$713,720.

If one were to approach their waste minimization effort based on total program cost and the duration of storage required one might stop their analysis at Scenario 6. In that instance Scenario 6, does have a high efficiency, 94.6 (based on processing 20,000 cu.ft. of waste), and has the second lowest total cost of \$957,530, which is \$483,591 less than Scenario 5, and \$243,810 more than Scenario 7. Its O&M costs are only \$15,591 more than Scenario 5 but \$152,190 less than Scenario 7. When storage is a given, this further supports the proposition that storage duration is not the issue which drives the total cost of waste management. In fact it is the final cost that drives waste management decisions. Whether it is storage or disposal that costs \$100/cu.ft. a less aggressive waste minimization can be

justified i.e., Scenario 6 over Scenario 7. But when total cost is \$300/cu.ft or greater the most aggressive waste minimization, Scenario 7 has the lowest total costs.

Most aggressive waste minimization, as presented here does not mean waste minimization at any cost. As explained earlier you can achieve the same program efficiency 81.3%, Base Case and Scenario 2, and pay nearly \$2M more. Aggressive waste minimization as discussed in this paper is based on using the right mix of technologies to cost effectively achieve smaller and smaller volumes.

Disposal Becomes Available And You Were Planning On Long-Term Plant Storage

As pointed out in the analysis, Scenario 6 provides the most cost effective approach with a total program cost of \$633,530. This relies on an aggressive waste minimization program at 94.6% efficiency (versus the highest efficiency of 99.6%). Its O&M costs are \$31,257 over the lowest O&M option, Scenario 2. But if a utility were planning for long-term plant storage and disposal (on a volume based fee) unexpectedly became available, what would be the price of having planned on the wrong outcome? A utility planning for storage and disposal, as pointed out above would have selected Scenario 7. So the question is, what is the difference in costs between these scenarios? If you were planning on storage only you were anticipating a \$663,530 cost. With disposal at \$300/cu.ft. your cost is increased \$324,000 for every years worth of waste generated as opposed to Scenario 7 where the total cost is \$713,720. Depending on the duration of storage each year a generator chooses to enlist Scenario 6 their potential costs increase by \$324,000 emphasizing how important it is to constantly reevaluate basic planning assumptions.

DISPOSAL FEE STRUCTURE

To this point the only fee structure addressed has been volume based. This approach is the basis for all WASTECOST calculations. It is not an unreasonable approach because all disposal sites to date have operated under this type of fee structure for long-term level waste.

Effect of Waste Form On Waste Minimization Efforts

Because metal melt and GIC do not result in a waste form for LLW disposal this discussion is limited to supercompaction and incineration. The two most significant scenarios reviewed in this paper were Scenario 6 and 7. Scenario 6 is the lower cost choice for a facility with storage and no disposal options. In this case supercompaction is used on 9,000 cu. ft. of waste. This may be an acceptable waste form posing minimal risk to the generator. There is no US experience to date with how supercompacted waste maintains its integrity in time periods greater than five years. Should waste decomposition occur, reprocessing of the waste would be required. Reprocessing supercompacted waste is difficult.

Scenario 7 processes the 9,000 cu. ft. of waste using incineration. This accounts for the increased cost of this scenario. However, the result is ash which is a stable waste form. This reduces the risk of reprocessing, as a utility can store containerized ash and stabilize it if and when disposal is available and form requirements are known. This has the benefit of avoiding unnecessary reprocessing if the disposal site accepts packaged ash since indications are that ash is more acceptable than unprocessed DAW.

SUMMARY AND CONCLUSIONS

This analysis demonstrates the benefits of an aggressive waste minimization program that matches the efficiencies of available processes with the wastes and waste volumes to be processed. Waste minimization at any cost is not the solution. Waste minimization applied effectively can be achieved at a reasonable cost.

- 1) What influence does disposal cost have on determining how much waste minimization is cost effective?

The basis of the cost is not the issue, i.e., whether the cost is disposal, or storage or storage and disposal. However, when the total cost per cubic foot is at or above \$100 an aggressive waste minimization program is the most cost effective.

2) Does length of storage influence waste minimization decisions?

Length of storage does not have the impact originally assumed. However, once the cost per cubic foot is at above \$100 an aggressive waste minimization program is the most cost effective approach.

3) What volume reduction options are most desirable; what volume reduction will be achieved by each option; what will it cost?

The two most desirable waste minimization scenarios analyzed were: Scenario 6 - Which included a 50% reduction in the DAW; 1,000 cu. ft. to Metal Melt; increase GIC from 8,000 cu.ft to 10,000 cu.ft. and shift the remaining 9,000 from on-site compaction to a higher efficiency off-site supercompaction; and, Scenario 7 -Which included a 50% reduction in the DAW; 1,000 cu. ft. to Metal Melt; increase GIC from 8,000 cu.ft to 10,000 cu.ft. and shift the remaining 9,000 from on-site compaction to one of the highest efficiency off-site incineration.

The largest contributing factor to the cost effectiveness of these options is the use of 50% DAW source reduction. Based on experience to date at a number of utilities this can successfully be achieved within two years. The processing efficiency, or volume reduction achieved by Scenario 6 is 94.6% (or, after source reduction, further reducing 20,000 cu.ft. to 1080 cu. ft.). The processing efficiency, achieved by Scenario 7 is 99.6% (or, after source reduction, further reducing 20,000 cu.ft. to 90 cu. ft.).

Where Storage is \$100 and Disposal is \$300, the total annual program costs for Scenario 7 is \$713,720 and Scenario 6 is \$957,530. Where Storage costs are \$100 and

Disposal is \$0 (because it is not available), the total annual program costs for Scenario 6 is \$633,530 and Scenario 7 is \$686,720.

4) When is on-site processing beneficial and what processes for what wastes?

On-site processes are often less efficient and usually more costly than equivalent off-site processing options. The two most favorable scenarios in this analysis included 50% source reduction, GIC processing, which utilities usually prefer to have processed off site, and two off-site processes (metal melt with either supercompaction or incineration).

5) What are the quantifiable benefits of source reduction, i.e., not generating the waste?

The greatest benefit of source reduction is its impact on O&M costs. Scenario 2 illustrates the dramatic effect it has on waste volumes and O&M cost, virtually cutting them in half.

6) Which factors have the greatest impact on the cost of LLW management from a commercial nuclear utility perspective?

The basis of the cost is not the issue. When the cost per cubic foot is at above \$100 an aggressive waste minimization program is the most cost effective. However, choosing a waste minimization technology involves a combination of program total efficiency and cost. And within that cost it is a question of how important O&M costs are versus total program costs.

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EVALUATING AND PLANNING THE RADIOACTIVE WASTE OPTIONS FOR DISMANTLING THE TOKAMAK FUSION TEST REACTOR

Keith Rule*, Jim Scott, Scott Larson, Robert Parsells,
Robert Cislo, Madukar Chiruvolu, and Dennis Gallagher
Princeton Plasma Physics Laboratory,
P.O. Box 451,
Princeton, New Jersey, 08543 USA
(908) 243-2000

ABSTRACT

The Tokamak Fusion Test Reactor (TFTR) is a one-of-a kind tritium fusion research reactor, and is planned to be decommissioned within the next several years. This is the largest fusion reactor in the world and as a result of deuterium-tritium reactions is tritium contaminated and activated from 14 Mev neutrons. This presents many unusual challenges when dismantling, packaging and disposing its components and ancillary systems. Special containers are being designed to accommodate the vacuum vessel, neutral beams, and tritium delivery and processing systems. A team of experienced professionals performed a detailed field study to evaluate the requirements and appropriate methods for packaging the radioactive materials. This team focused on several current and innovative methods for waste minimization that provides the opportunist cost effective manner to package and dispose of the waste. This study also produces a functional time-phased schedule which conjoins the waste volume, weight, costs and container requirements with the detailed project activity schedule for the entire project scope. This study and project will be the first demonstration of the decommissioning of a tritium fusion test reactor. The radioactive waste disposal aspects of this project are instrumental in demonstrating the viability of a fusion power reactor with regard to its environmental impact and ultimate success.

INTRODUCTION

The scope of a radiological decommissioning is extremely dependent on the quantity of radionuclides that are present. TFTR generates 14 Mev neutrons, which interact with structural and functional materials resulting in the production of these radionuclides. In order to adequately plan for the dismantling and removal of TFTR and associated support equipment, a baseline estimate of volume, weight and composition of radioactive material has to be determined. In order to obtain this estimate, one must first identify container capabilities, radiological concentrations, and transportation and disposal parameters as

limiting factors. Field surveys and engineering evaluations can then be performed with these limiting factors and result in final tabulations of volume, weight and cost. In addition, these parameters can be applied to a project management line item schedule to produce a time-phased removal plan. This plan identifies the tasks which generate radioactive waste along with the associated volume, weight, and time of removal.

COMPONENT RADIOACTIVITY

Component radionuclide concentrations were obtained using a computer model¹. The model provides detailed nuclide distributions for each major TFTR component and associates activity to each component alloy or composite. The model used a projected Deuterium-Tritium (D-T) neutron production of $3.0 \text{ E}+20$ neutrons. This model decay corrected the values to reflect a two-year time period from reactor shutdown to the commencement of dismantling. The component(s) total radioactivity from activation was subsequently calculated using known component weights. The components that also contain tritium contamination were assigned values based on system maintenance experience and retention projections. These results were assigned to each major component by concentration and total activity and were used for estimating the radioactivity content of the packages used for the transportation and burial of the TFTR systems and components.

The total TFTR curie content from neutron activation was calculated to be 1.1 Tbq (29 Ci)². The maximum tritium radioactivity³ was projected to be 370 Tbq (10,000 Ci) (after decontamination efforts) which is assumed to be primarily in the vacuum vessel. Gamma spectroscopy measurements were also performed to compare actual isotopic data to the predicted model. The gamma spectroscopy data supported the activation model. However, the models values were found to be more conservative with approximately 20% higher values than detected. The curie content evaluation is necessary to ensure materials will not exceed the Type A category for transportation⁴ and Westinghouse Hanford Company (WHC) burial requirements⁵ for tritium and activation products.

CRITERIA

The transportation and disposal limitations for waste packaging are based on nuclide concentration and total radioactivity. Considering the computer model and field measurements, the predominant TFTR radionuclides are tritium, cobalt-60, manganese-54, iron-55, and cobalt-57. Of these, tritium and cobalt-60 are the most limiting when applied to the Department of Transportation⁴ total curie content criteria for transportation and WHC burial facility activity concentration limits⁵. In light of our analysis, these restrictions do not result in any packaging difficulties with the exception of the vacuum vessel. The limits for packaging tritiated waste are 100 Ci/m³ (disposal limit) and 1000 Ci (transportation limit) total for a Type A package. The vacuum vessel must contain less than 10,000 Curies in order for the ten segment scenario not to exceed the Type A package limit. The present total for "TFTR Holdup" according to the Materials Control & Accountability program is 13,000 Curies. The planned oxygen glow discharge cleaning should reduce this radioactivity well below the 10,000 Curies total that will remain in the vacuum vessel. In addition, tritium radioactivity amounts will be subtracted from this MC&A account as other TFTR materials are removed, which will further reduce the total for each tenth vessel segment. The tritium processing systems will require further evaluation to ensure that package limits are not exceeded.

FIELD SURVEY

The Shutdown and Removal project schedule consists of 1400 tasks. The schedule was reviewed in detail to select tasks which could generate radioactive waste. Each selected task was then evaluated for volume and weight by experienced field engineers. The field team performed an extensive review of component and system drawings, along with field walkdowns, to ensure accuracy of the calculations. The team then applied these volume and weight calculations to the container parameters which yielded the appropriate number(s) of containers required for each task. A cost analysis was then performed for packaging, transportation, and disposal.

Many tasks were identified as inaccurate or missing entirely from the project schedule. The appropriate cognizant engineers were contacted and corrections were made to modify or add the task to the project schedule. Several diagnostic systems, the Flourinert system, and the tritium purification system were the primary items that had to be included.

The predominant waste configuration is comprised of various metal alloys in the form of piping, support framing, wiring, valves, pumps and structural supports. The majority of this waste will require segmentation and size reduction for packaging in standard 2.6 m³ (90 ft³) steel boxes. Larger components, such as, the vacuum vessel, neutral beams, magnetic confinement coils, and tritium system components will require specially designed and engineered packagings which are described in the following section.

Waste volumes for each task were applied to standard 90 cubic foot containers to determine the number of containers required. The volume calculations were also adjusted to account for the differences in field packaging versus calculated packaging of these materials. A packaging efficiency factor of 70% was assigned to account for this difference. The packaging calculations also revealed that the majority of containers will exceed the WHC 10% void space criteria because the majority of TFTR waste is high density material (predominantly metal). This results in weight limitations and prevents filling containers to capacity. The weight capacity of a standard container is 7,000 lbs. and becomes the limiting factor for packaging TFTR materials. Further cost-benefit analysis will be required beyond these baseline calculations to increase packaging efficiency of the metal waste streams.

A secondary waste volume generation was also added to each task to reflect a uniform waste generation from S&R dismantling activities. This waste volume was added to the packaging efficiency subtotal to result in a total waste volume per task.

SPECIAL CONTAINERS

The tasks identified which require special containers^{6,7,8} include: vacuum vessel segments (10), neutral beams (4), poloidal field (PF) coils, toroidal field (TF) coils (40),

tritium systems and tritium purification systems. The previous calculations for radioactivity concentrations and total activity were used for calculating package constraints. All of these require Type A containers except the PF and TF coils. The activity concentration requirements for Low Specific Activity (LSA), which are exceeded due to an items' tritium content, dictate the need for Type A containers. The PF and TF coils do not contain tritium and consequently meet the LSA requirements.

Additional engineering analysis and WHC contact will be necessary to determine the most appropriate and acceptable method for bracing and support of the packaged material. The additional costs for bracing are minimal and inconsequential when compared to other itemized costs. All of the containers may also require wood bracing to prevent shifting of the contents during transportation. The vacuum vessel segments will also require concrete grout to prevent movement due to the configuration inside the container. This task has been added to the S&R project activities list. A total of 32 special containers will be required for packaging TFTR materials for disposal (excluding TF and PF coils). Detailed specifications will be developed for each container and submitted as a single package for proposal and bid acceptance.

Current WHC guidelines for waste acceptance do not permit the disposal of the TF and PF coils in their current form, that is, without placing them inside of disposal containers. If the individual TF coils and PF coils can be considered as strong tight containers (not requiring an additional container for transportation and disposal), a significant cost savings is realized. A specific SDAR request will be submitted to WHC for approval.

A detailed cost breakdown was also performed which considered package cost, void space/bracing requirements, transportation and final disposal costs according to fiscal year. In particular, the transportation weight and cost is itemized and identifies the weight breakdown, which in turn, determined the total transportation cost.

SCHEDULE

Individual waste volume for each identified task line item was entered into Excel spreadsheets and transferred to a Primavera file for the Shutdown and Removal schedule. This allowed for the development of a Primavera "Project Planner Resource Loading Report," which provides a report for radwaste volume and container usage for each task by fiscal year. This report can profile and provide the radwaste volume generation and container usage, by month, for the entire S&R project schedule. This also allows for necessary modification based on any new estimates or improvements to the individual task for any of the selected parameters. This program provides the flexibility for complete tracking of waste generation by line item task. If a particular WBS item(s) is modified, the associated radioactive waste quantity will be changed accordingly. This method provides an accurate time phased radioactive waste generation and container usage tracking system.

IMPROVEMENTS

Several improvements to the Baseline have been identified to further reduce waste quantities and costs. Improved size reduction, alternate burial options/methods, larger weight capacity containers, and coil shipments without containerization are being evaluated.

We should be able to improve the secondary waste and packaging efficiency percentages through compaction, proper size reductions and using secondary waste as a void space filler. In addition, the void space technical basis requires further investigation and discussion with WHC. The TFTR materials that will be packaged as radioactive waste exhibit greater structural strength than the approved void space fillers. We are pursuing the possibility of exemption from void space filling requirements based on the overall strength of the materials and packaging.

Recycling of copper, stainless steel, carbon steel, and titanium is also being pursued through Environmental Assessment, RECYCLE 2000 and free release⁹. 250 tons of copper is 99.99% pure with a scrap value of \$500K and possible burden (disposal cost) of \$2000K.

The predominant radionuclide is Co-60 at a maximum concentration of 140 pCi/g . 400 tons of stainless steel has a scrap value of \$150K and estimated disposal cost of \$3200K. The predominant radionuclide is also Co-60 at a maximum of 240 pCi/g. 17.5 tons of titanium is 99.99% pure with a scrap value of \$800K and estimated disposal cost of \$150K. The predominant radionuclide is Fe-55 at a maximum of 0.12 pCi/g.

SUMMARY

The TFTR activation level calculations (per package) demonstrate that all TFTR waste will be below DOT limitation for total activity of Co-60. The 1000 Curies per package DOT limit for total activity will not be exceeded through design. The vacuum vessel segmenting scenario is focused on remaining below this criteria. The TFTR activation and tritium concentration calculations for disposal indicate the following: 1) all TFTR activated waste will be below WHC criteria of 77 Ci/cubic meter; 2) the majority of TFTR radwaste will qualify as tritiated waste; and 3) none of the waste will exceed the WHC criteria of 100 Ci/m³.

Spreadsheets developed from the field surveys for weight, volume, and container specifications can be modified as improvements or refinements occur. These changes can then be transferred to the Primavvera schedule for update.

The estimated volume of waste expected to be generated from this project is 83,000 cubic feet. This is projected as being 69,900 cubic feet of primary waste and 6,800 cubic feet of secondary waste. The remaining volume consists of void space filler in the containers. The estimated burial costs at WHC is \$8.3 million dollars not including transportation from PPPL to WHC.

CONCLUSION

A total of 440 containers will be needed with 32 of these being specially designed containers.

The periodic dose rate and radioisotope measurements indicate that component activation is lower than the models projected values. The activation profile also validates the long-lived dose rate contribution of Mn-54 and Co-60.

The operation and subsequent decommissioning of a tritium fueled fusion reactor can be accomplished with minimal environmental impact. The successful maintenance, reduced radiation profiles, and radioactive waste disposal planning aspects of this project demonstrate the viability of a fusion power reactor with regard to its environmental impact.

ACKNOWLEDGMENT

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NOMENCLATURE

Ci - Curie
Bq - Becquerel
m³ - Cubic Meters

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ANALYSIS OF OPERATING COSTS OF A
LOW-LEVEL MIXED WASTE INCINERATION FACILITY

Steve L. Loghry
Royce Salmon
William H. Hermes
Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37831
615/574-2898
e-mail: loghrysl@ornl.gov

ABSTRACT

By definition, mixed wastes contain both chemically hazardous and radioactive components. These components make the treatment and disposal of mixed wastes expensive and highly complex issues because the different regulations which pertain to the two classes of contaminants frequently conflict. One method to dispose of low-level mixed wastes (LLMWs) is by incineration, which volatilizes and destroys the organic (and other) hazardous contaminants and also greatly reduces the waste volume. The U.S. Department of Energy currently incinerates liquid LLMW in its Toxic Substances Control Act (TSCA) Incinerator, located at the K-25 Site in Oak Ridge, Tennessee. This incinerator has been fully permitted since 1991 and to date has treated approximately 7×10^6 kg of liquid LLMW. This paper presents an analysis of the budgeted operating costs by category (e.g., maintenance, plant operations, sampling and analysis, and utilities) for fiscal year 1994 based on actual operating experience (i.e., a "bottoms-up" budget). These costs provide benchmarking guidelines which could be used in comparing incinerator operating costs with those of other technologies designed to dispose of liquid LLMW. A discussion of the current upgrade status and future activities are included in this paper. Capital costs are not addressed.

BACKGROUND

The U.S. Department of Energy (DOE) operates a rotary kiln incinerator with an afterburner at the K-25 Site in Oak Ridge, Tennessee. The K-25 Site Toxic Substance Control Act (TSCA) Incinerator is unique in that it is both permitted as a Resource Conservation and Recovery Act (RCRA) treatment facility and authorized by the U.S. Environmental Protection Agency (EPA) to treat TSCA wastes. Approximately 7×10^6 kg of liquid wastes, mainly wastes contaminated with uranium and polychlorinated biphenyls (PCBs), have been treated since TSCA operations began in 1991. These wastes are defined

as mixed wastes because they contain both radioactive and hazardous constituents. The K-25 Site TSCA Incinerator is the only incinerator currently licensed to treat mixed wastes. The incinerator thermal capacity is about 8.8 MW (3.0×10^7 Btu/h).

Liquid wastes are transported to the K-25 Site in tank trucks from seven sites located in Tennessee, Kentucky, and Ohio. These sites are the former gaseous diffusion plant (GDP) at K-25, the GDPs at Portsmouth and Paducah, the Oak Ridge National Laboratory (ORNL), the Y-12 Plant, the Reactive Metals, Inc. (RMI) Extrusion Plant, and the Fernald Environmental Management Project. The wastes are blended in a 3.41×10^5 -L (90.1×10^3 gal) tank farm (15 tanks) to optimize combustion efficiency and feed rate within permitted limits.

Treatment of liquid wastes including waste oils, solvents, and water solutions began in 1991 when 1×10^6 kg of waste were incinerated. Since 1991, the throughput of the incinerator has increased every year to 1.8×10^6 kg (4×10^6 lb) incinerated in 1994. At this rate of incineration, the current backlog of liquid PCB waste being stored at the K-25 Site should be eliminated by 1996. DOE plans to shift the operation to solid waste treatment starting as early as 1996. Currently, only waste from the seven sites previously mentioned are being treated at the TSCA Incinerator; however, DOE is considering the use of the incinerator to treat RCRA and TSCA waste streams from other DOE sites.¹

OPERATING COSTS OF THE TSCA MIXED-WASTE INCINERATOR

The total annual operating cost of the TSCA Incinerator is about \$25 million. This cost can be broken down into eight functional areas: plant operations, sampling and analysis, monitoring, maintenance, program management and support, administrative, environmental compliance, and technical support. These costs have previously been studied in some detail. The first, a review of the TSCA Incinerator FY-1994 budget, included an analysis of costs in each of the eight functional areas.² The second was an analysis of the impacts of DOE Orders on the costs and quality of operations in each area.¹ References to the impacts of DOE Orders should not be taken as a criticism. On the contrary, these Orders add

considerable assurance to the quality of operations and to the uniformity with which this same degree of high quality is applied to all technologies.

For the current study, it was desired to relate the operating costs in each of the eight functional areas to the technical parameters of plant operations. Backup data for the FY-1994 budget were obtained from the TSCA Incinerator project staff and used as input to this effort.

THE TSCA INCINERATOR FY-1994 BUDGET

Table 1 shows the summary table of the FY-1994 Bottoms-Up Budget for the Oak Ridge TSCA Incinerator as the budget was proposed before making the final revisions agreed to during the budget reconciliation process. A "bottoms-up" budget is produced by starting at zero dollars and adding up the estimated costs required to achieve the goals set for the coming fiscal year, based on past experience. The summary table shows the various cost elements of the estimated spending plan for FY-1994, based on a feed rate of about 1.9×10^6 kg/year (4.25×10^6 lb/year) of LLMW liquids. The FY-1994 Bottoms-Up Budget includes backup data showing detailed calculations of the various cost elements at feed rates of 1.6 and 2.3×10^6 kg/year (3.5 and 5.0×10^6 lb/year). The budget summary (Table 1) was based on the average of these feed rates.

Table 1. TSCA incinerator estimated annual operating costs per FY-1994 budget plan*

Functional area	Cost, \$/year ^b
Plant operations	8,881,000
Sampling and analysis	5,506,000
Monitoring	1,141,000
Maintenance	4,289,000
Program management and support	909,000
Administrative	1,267,000
Environmental compliance	701,000
Technical support	2,566,000
Total	25,260,000

^aPersonal communication from S. M. Crosley, Y-12 Plant, to R. Salmon, ORNL, July 1994.

^bCosts are based on a feed rate of 1.9×10^6 kg/year (4.25×10^6 lb/year).

Table 2 was produced by using the backup data of the FY-1994 budget to calculate the operating costs at feed rates of 1.6 and 2.3×10^6 kg/year (3.5 and 5.0×10^6 lb/year) and then using the average of these to obtain the costs at 1.9×10^6 kg/year (4.25×10^6 lb/year). This column agrees fairly well with the summarized costs of the preliminary FY-1994 budget, which is shown in Table 1. The differences occurred because of the minor budget revisions already mentioned, but these differences are small enough to be unimportant. The preliminary budget summaries shown in Tables 1 and 2 both agree fairly well with the final budget summary reported by Trischman et al.,¹ which shows a total of \$25,014,000. Again, differences are present because of revisions that occurred during the budget-reconciliation process; these differences are not significant in the context of this paper. Also, because the budget estimates are accounting figures and not engineering estimates, the costs presented in the following tables are shown to the final dollar.

Table 2: TSCA Incinerator estimated annual operating costs^a

	Costs, \$/year
	@1.9
$\times 10^6$ kg/year Functional area lb/year) ^b	(4.25×10^6)
Plant operations	8,856,342
Sampling and analysis	5,469,584
Monitoring	1,141,101
Maintenance	4,287,263
Program management and support	908,613
Administrative	1,266,647
Environmental compliance	701,373
Technical support	2,566,304
Total	25,197,227

^aPersonal communication from S. M. Crosley, Y-12 Plant, to R. Salmon, ORNL, July 1994.

^bAverage of 1.6 and 2.3×10^6 kg/year (3.5 and 5.0×10^6 lb/year).

TSCA INCINERATOR PLANT OPERATIONS COSTS

Plant operations costs account for about 35% of the annual operating budget. The costs listed in Tables 1 and 2 as "plant operations" consist of four items: (1) labor and supervision, (2) materials and supplies, (3) laundry service, and (4) utilities. Table 3 summarizes and details these items. The details are based on the backup data in the budget document.

Table 3. TSCA Incinerator: details of plant operations costs^a

		Costs, \$/year
		<u>@1.9 × 10⁶</u>
kg/year	Cost element	
lb/year)		(4.25 × 10 ⁶
Labor and supervision		
	Operators (25)	1,567,508
	Supervisors (6)	485,646
	Staff (19)	1,302,081
	Total labor and supervision	<u>3,355,235</u>
	Fringe benefits (approximately 31%)	1,033,412
	Total labor, supervision, and fringe	<u>4,388,647</u>
Materials and supplies		
	General materials and supplies	155,637
	Additional supplies for outages	64,850
	Other materials ^b	268,132
	Total materials and supplies	<u>488,619</u>
	Laundry service	106,190
	Utility service	
	Nitrogen	952,139
	Fuel gas	939,332
	Steam	838,559
	Air	675,172
	Electricity	264,009
	Sanitary water	120,194
	Sewage disposal	34,853
	Sanitary waste	48,628
	Total	<u>3,872,886</u>
	Grand Total	<u>8,856,342</u>

^aPersonal communication from S. M. Crosley, Y-12 Plant, to R. Salmon, ORNL, July 1994.

^bOther materials are materials consumed by the process; quantities consumed are directly proportional to throughput.

Costs of Labor and Supervision

The Oak Ridge TSCA Incinerator operates on a continuous around-the-clock basis and requires five operators on each shift (five shift positions). This leads to a requirement for 25 total operators to cover all shifts. This is arrived at as follows: An operator works 40 h/week, but, because of holidays, vacations, sick leave, required training, etc., an operator's effective average time is about 34 h/week on a year-round basis. Since a week is 168 h, the total number of operators needed is $5 \times (168/34)$, or about 25 operators. Usually, for a plant operating continuously,

$$\text{Total operators} = \frac{\text{number of shift positions} \times 168}{\text{effective hours per week per operator}} .$$

The number of shift positions required to operate a given plant depends on the size and complexity of the plant and on an analysis of the duties associated with each shift position. Any special duties resulting from regulatory or DOE requirements should be included in this analysis. Details on operator duties can be found in Trischman et al.¹ or Salmon et al.³

Under supervision and staff, Table 3 shows 6 shift supervisors (one for each rotating shift plus two relief shift supervisors) and 19 staff members. The number of staff members was subsequently reduced by one during the budget reconciliation process, giving a final requirement of 18. Key staff positions include Incinerator Operations Manager, Shift Operations Supervisor, Facility Process Engineer, Operations Trainer, Health Physics/Industrial Hygiene Coordinator, Instrumentation Engineer, Technical Operations/Blend Master, and Environmental Engineering Assistant.¹

Costs of labor and supervision account for about 17% (\$4,388,647) of the annual operating budget, with an estimated 24% of these labor costs attributable to DOE Orders.¹

Materials, Supplies, and Laundry Service

Costs of materials, supplies, and laundry service are shown in Table 3 at a feed throughput of 1.9×10^6 kg/year (4.25×10^6 lb/year). General materials and supplies

include disposable protective clothing, respirators, cartridges, flashlights, other lights, batteries, forms, labels, storage boxes, small tools, etc. Additional supplies of this type specifically required during scheduled outages are also shown. Materials listed as "other materials" are process consumables such as caustic solutions, fuel oil, and drums used to store products.

Table 3 shows the costs of laundry service required to maintain plant-supplied work clothing in proper condition; these costs are independent of plant throughput and are directly related to the number of operators.

Materials, supplies, and laundry service account for about 2% (\$594,809) of the annual operating budget. About 9% of these costs can be attributed to DOE Orders.¹

Utility Costs

Table 3 also shows the details of the annual utilities costs of the TSCA Incinerator, based on the FY-1994 Bottoms-Up Budget. The consumption of the various utilities was estimated based on past usage and FY-1994 operating plans. Electric power and natural gas are metered and are costed at rates set by the K-25 Power and Utilities Department. Nitrogen is used as a blanketing gas over the feed tanks. Natural gas is used in the primary and secondary auxiliary burners to initiate and maintain incineration conditions. Steam is used for heat, for cleaning out process lines, for atomizing the liquid waste feed, and for general purposes around the plant. Electric power is used for waste liquid and aqueous pumps and other electrically driven equipment; for the off-gas treating system, including the induced draft fan and the ionizing wet scrubber; and for lighting, instruments, and various miscellaneous uses. The annual cost for each utility is obtained by multiplying the estimated rate of consumption in units per year by the unit cost of that utility in dollars per unit. See ref. 3 for a breakdown of unit costs.

Utility costs account for about 15% (\$3,872,886) of the annual operating budget. Utility costs are deemed to be a function only of plant throughput (in the range considered—i.e., 1.6 to 2.3×10^6 kg/year).

TSCA INCINERATOR COSTS OF SAMPLING AND ANALYSIS

Sampling and analysis are necessary to ensure that operations are in compliance with the conditions specified in the operating permits. Failure to have the necessary compliance analyses could result in shutdown of the incinerator. Sampling and analysis costs account for about 22% of the annual operating budget, of which an estimated 8% is attributable to DOE Orders.¹

The regulatory permits that must be satisfied are RCRA, TSCA, National Pollutant Discharge Elimination Systems (NPDES), National Emissions Standards for Hazardous Air Pollutants (NESHAP), and the State of Tennessee air permit.

Sampling and analysis services for the K-25 Site TSCA Incinerator are provided by the K-25 Analytical Chemistry Department. Analyses are performed at the K-25 laboratory. Routine samples (those taken at regularly scheduled intervals) include wastewater, blend tank (feed), ash, sludge, NESHAP (stack emissions to atmosphere), feed waste verification (analyses of each shipment of waste received), feed tank (individual feed tanks), and NPDES (liquid discharge). In addition, there are nonroutine samples (not on a regular schedule) including ambient air, combustion gas velocity, K-1425 storage area for incoming waste, and other miscellaneous samples needed to provide guidance for plant operating decisions.

In the preparation of FY-1994 budget estimates for the TSCA Incinerator, experience in 1993 and anticipated changes in 1994 were used as guides for the number of samples of each type and the number of person-hours required for the sampling and analysis of each type of sample. These data are summarized in Table 4 which shows the breakdown of costs of sampling, analysis, and testing into its component parts. Data for Table 4 are from the supporting documentation of the FY-1994 TSCA Incinerator Bottoms-Up Budget.

Table 4. TSCA Incinerator FY-1994 Bottoms-Up Budget:
breakdown of costs of sampling and analysis^a

kg/year	Cost element	Costs, \$/year
		@ 1.9×10^6
lb/year)		(4.25×10^6)
	Dedicated persons	954,624
	K-1425 (Waste Oil Storage Facility)	44,082
	Wastewater	1,459,439
	Blend tank	860,811
	Ash	220,214
	Aqueous waste management sludge	220,214
	NESHAP (air emissions) ^b	590,348
	Verification (feed analyses)	368,630
	Feed tank	84,524
	NPDES ^c	44,284
	Ambient air	166,842
	Combustion gas velocity	131,586
	Materials	74,053
	Miscellaneous ^d	249,933
	Total	5,469,584

^aBasis: five dedicated persons provided by the Analytical Services Organization, 1760 full-time equivalent hours per person year; cost based on \$72.32/h plus overhead.

^bSampling and analyses required for compliance with NESHAP.

^cTests required for NPDES liquid discharge permit.

^dIncludes special sampling and analyses needed for guidance of plant operations. These are projected on the basis of past data.

Wastewater sampling and analyses required by the NPDES permit account for about 25 to 30% of the total sampling and analyses budget. The significant cost is primarily a result of conservative environmental management practice to sample/analyze each tank prior to release to the K-25 Site Central Neutralization Facility (CNF). This practice differs from a standard industrial practice of using statistical analyses to influence the frequency of sampling/analysis (S/A). The PCB limit of 1 ppb is the acceptance criteria for the CNF, and at this level, absolute S/A must be applied within the constraints of fixed hold-up and surge storage capacity at the TSCA Incinerator.

Waste feed accounts for another major portion of the sampling and analysis budget. Waste feed blends are prepared from several different feed tanks to optimize the feed

composition to achieve maximum feed rate. Samples must be taken and analyzed before and after each blending operation.

MONITORING

Table 5 shows the cost breakdown of monitoring services for the TSCA Incinerator. All LLMW treatment facilities have the potential for unintended radiological or chemical contamination of plant equipment and the surrounding environment. At the TSCA Incinerator, the services of several groups are necessary to perform the required monitoring to ensure compliance with regulations designed to protect plant employees and the public. These specialized groups perform their duties for the K-25 Site complex, and their costs are charged to projects or programs based on actual hours worked or on a user percentage distribution. For this reason, no labor or material charges are shown in Table 5. Monitoring costs account for 4 to 5% (\$1,141,101) of the annual operating budget and are independent of feed rate in the range of 1.6 to 2.3×10^6 kg/year (3.5 to 5.0×10^6 lb/year).

Table 5. TSCA Incinerator FY-1994 Bottoms Up Budget:
breakdown of monitoring costs^a

Costs, \$/year		
kg/year	Cost element	@ 1.9×10^6
lb/year)		(4.25×10^6
Services		
Health Physics		
	Routine coverage	372,263
	Maintenance outage	46,533
	Rad Con implementation	124,088
	Rad worker distribution	213,698
Industrial Hygiene		
	Routine coverage	143,190
	Confined-space work	23,588
	Maintenance outage	71,595
	Respirator wearers distribution (6.22% of K-25 Site total)	4,245
Nuclear Materials Control & Accountability		
	Documentation/traceability support	12,656
	Uranium accounting system	24,635
Quality Control		104,610
Total		<u>1,141,101</u>

^aCosts shown include overhead.

Three DOE Orders that affect monitoring costs are DOE 5633.3 (Control and Accountability of Nuclear Materials), DOE 5820.2A (Radioactive Waste Management), and DOE 5840.11 (Radiation Protection for Occupational Workers). Overall, it was estimated by Trischman that about 13% of the total costs of monitoring were attributable to DOE Orders.¹

MAINTENANCE

Table 6 shows the breakdown of maintenance costs for the TSCA Incinerator. The assigned maintenance staff includes one general supervisor, two maintenance supervisors (one instrument and one mechanical supervisor), two planner/estimators, and one clerk. Overtime for these salaried staff members is budgeted at 5%, except for maintenance supervisor overtime, which is budgeted at 15%. Because there is no relief maintenance supervisor, the extra overtime is allotted to take care of unusual maintenance problems that need attention after the day shift ends.

Table 6. TSCA Incinerator FY-1994 Bottoms Up Budget:
breakdown of maintenance costs*

	Costs, \$/year
kg/year	@1.9 × 10 ⁶
lb/year)	(4.25 × 10 ⁶
Labor	
Maintenance staff labor (6)	386,817
TSCA-assigned hourly labor (23)	1,537,383
Total labor	1,924,200
Fringe benefits (approximately 31 %)	592,655
Total labor and fringe	2,516,855
Materials	
Electrical	272,790
Mechanical	425,970
Other (respirators, insulation, etc.)	192,000
Total material	890,760
Services	
Maintenance (building and grounds, preventive, corrective, etc.)	827,949
Engineering	17,700
Quality Control	33,999
Total services	879,648
Grand total	4,287,263

*Personal communication from S. M. Crosley, Y-12 Plant, to R. Salmon, ORNL, July 1994.

The 23 TSCA Incinerator-assigned hourly workers include 8 maintenance mechanics, 9 instrument mechanics, 3 electricians, 2 painters, and 1 laborer. The budget includes an estimate of 15% overtime for maintenance and instrument mechanics and the laborer, 20% overtime for the electricians, and no overtime for the painters.

Maintenance costs account for about 17% (\$4,287,263) of the annual operating budget. It was estimated by Trischman that about 11% of the total cost of maintenance is related to DOE Orders, mainly in the area of worker qualifications, training, and supervision.¹

PROGRAM MANAGEMENT AND SUPPORT

The Program Management and Support Department develops and implements management systems for the control of various division programs including compliance, self-assessment, procedures, training, administrative work management, document control, occurrence reporting, etc. The FY-1994 annual budgeted cost is about 4% (\$908,613) of the total operating budget; and breaks down into about 76% labor, 12% materials, and 12% services. About 48% of this cost was directly attributable to the requirements of DOE Orders.¹

ADMINISTRATIVE

The administrative function provides for overall management, leadership, coordination, and control of the TSCA Incinerator project. It is responsible for interactions with DOE site representatives and site prime-contractor management. It provides program direction and management leadership for operations, maintenance, and facility improvements. Other matters, such as strategic planning, budgeting and financial management, funding, quality assurance, and safety, also are handled under the administrative function.

The administrative function accounts for just over 5% (\$1,266,647) of the total operating budget. The portion of administrative cost attributable to DOE Orders is about 21%.¹

ENVIRONMENTAL COMPLIANCE

A number of state and federal regulations must be complied with in order for the TSCA Incinerator to operate, and proof of compliance must be supplied in each case. Costs associated with environmental compliance are shown in Table 7. The Environmental Compliance Department (ECD) consists of three personnel, including one manager. They are assigned to oversee such functions as permit application development and modification, regulatory training for TSCA Incinerator workers, regulatory reports and documents, and

many other compliance-related issues. Overtime provisions are budgeted at 10%, excluding the manager. Material costs for ECD consist of permit fees, compliance references, and travel for regulatory training.

Table 7. TSCA Incinerator FY-1994 Bottoms Up Budget:
breakdown of environmental compliance costs^a

kg/year Cost element lb/year)	Costs, \$/year
	@1.9 × 10 ⁶ (4.25 × 10 ⁶)
Labor	
Total labor (3)	248,471
Fringe benefits (approximately 31%)	76,529
Total labor and fringe	325,000
Materials	
Permit fees	50,850
Compliance materials	12,750
Travel for training	11,250
Total materials	74,850
Services (EMD)	
Waste generator (4% distribution)	5,957
PCB (19% distribution)	50,534
Low-level waste (4% distribution)	3,332
Air program support	70,203
NPDES support	2,006
PCB	35,102
RCRA	80,232
Miscellaneous	12,035
NEPA	12,035
Air stack test development	30,087
Total services	301,523
Grand total	701,373

^aCosts are from the backup data for the FY-1994 budget.

The Environmental Management Division (EMD) supports ECD through issuance of required reports (e.g., PCB annual report, NESHAP annual report, etc.). The EMD also assists with development and assessment of environmental programs, contact with regulatory agencies, interpretation of regulations, and several other functions related to environmental compliance. Most of these services are based on actual hours worked. Some services are distributed on a site-wide percentage basis.

Costs charged to environmental compliance account for about 3% (\$701,373) of the annual operating budget. No environmental compliance costs are attributable to DOE Orders.¹

TECHNICAL SUPPORT

This function provides the technical and engineering support needed in connection with long-term process and equipment improvements and upgrades, special testing and trial burns, maintenance, capital equipment procurement, feasibility studies, and technical evaluations. Technical support costs account for about 10% (\$2,566,304) of the annual operating budget. About 11% of the technical support budget is directly attributable to DOE Orders.¹

UPGRADE STATUS OF THE K-25 TSCA INCINERATOR

The original design for the TSCA Incinerator was to process both liquid and solid feeds (including pumped sludge through a lance), and the facility is permitted to exercise those feed circuits. Excluding trial burns and performance testing, only liquid feeds have been incinerated to date. However, DOE is currently performing a readiness assessment to initiate incineration of solid feeds. The necessary design considerations and cost estimates are still in the preliminary stages, but current plans are to initially incinerate a mixture of hazardous combustible solids, such as personal protective equipment (PPE) and soil to demonstrate the effectiveness of the solid-feed systems.

A conceptual design for completing an upgrade of the Air Pollution Control System (APCS) was completed in 1995.⁴ This project was completed to ensure that the incinerator facility was prepared for installation of the upgrade to the APCS and that the installation could be completed in a timely, cost effective manner to continue operation into the 21st century should technology-based stack emissions criteria be regulated to significantly lower levels.

SUMMARY

This analysis of the K-25 Site TSCA Incinerator FY 1994 operating costs budget provides benchmarking guidelines that could be used to compare incinerator operating costs with the costs of other liquid LLMW disposal technologies in a DOE environment. Although, according to Trischman et al.,¹ the total contribution of DOE Orders to the budgeted operating costs for FY 1994 accounted for about 13% of the total budget, these costs are mainly directed at safety and quality issues.

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PHOTOCHEMICAL OXIDATION: A SOLUTION FOR THE MIXED WASTE DILEMMA

Jeffrey W. Prellberg, Lisa M. Thornton and David A. Cheuvront
Vulcan Peroxidation Systems, Inc.
5151 E. Broadway, Suite 600
Tucson, Arizona 85711
(520) 790-8383

ABSTRACT

Numerous technologies are available to remove organic contamination from water or wastewater. A variety of techniques also exist that are used to neutralize radioactive waste. However, few technologies can satisfactorily address the treatment of mixed organic/radioactive waste without creating unacceptable secondary waste products or resulting in extremely high treatment costs. An innovative solution to the mixed waste problem is on-site photochemical oxidation. Liquid-phase photochemical oxidation has a long-standing history of successful application to the destruction of organic compounds. By using photochemical oxidation, the organic contaminants are destroyed on-site leaving the water, with radionuclides, that can be reused or disposed of as appropriate. This technology offers advantages that include zero air emissions, no solid or liquid waste formation, and relatively low treatment cost. Discussion of the photochemical process will be described, and several case histories from recent design testing, including cost analyses for the resulting full-scale installations, will be presented as examples.

INTRODUCTION

Photochemical oxidation of organic contaminants in water has been studied since the early 1900s. However, commercial photochemical oxidation systems became available only as recently as the early 1980s. The technology has been advancing rapidly since that time due to aggressive research by several independent companies. To date, well over one hundred fifty treatment process designs have incorporated photochemical oxidation equipment. Full-scale applications range from groundwater remediation at Superfund sites to treatment of wastewater for reuse, and include organic contaminant destruction in landfill leachates, tank bottoms, drinking water, steam condensate chemical process streams and ultra pure water. A wide variety of organic contaminants have been destroyed including volatile organic compounds (VOCs), semi-VOCs, aromatics, alcohols, ketones, aldehydes, phenols,

ethers, phthalates, glycols, pesticides, ordnance compounds, dioxins, PCBs, PAHs, COD, BOD, TOC and most other forms of organic carbon. Photochemical oxidation has most often been used for contaminant concentrations below 500 mg/l, and is capable of destruction to below the lowest detection limit.

A unique, and relatively recent application of photochemical oxidation is to the destruction of organic contaminants in wastewater containing both radioactive and hazardous organic constituents. These so-called mixed wastes are problematic because the traditional organic treatment methods, such as activated carbon adsorption, produce radioactive solid waste. If treatment is to be done on-site, which is desirable in most cases, the solid waste must be incinerated on-site or hauled away to a permitted Mixed Waste Treatment and Storage Facility. In either case, the costs of solid waste disposal far outweigh those for water treatment alone.

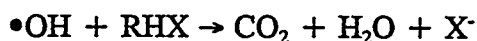
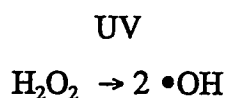
The Ultraviolet light/hydrogen peroxide (UV/H₂O₂) process is currently the most widely developed and utilized photochemical treatment process. For mixed wastes, the key benefits of UV/H₂O₂ treatment over other treatment options, aside from the economic benefits, include total on-site destruction of the organic contaminants to non-detectable levels, zero air emissions, and no generation of a secondary waste stream or sludge. Following UV/H₂O₂ the treated water is then suitable for reuse or treatment for radionuclides depending on the specific application.

The UV/H₂O₂ photochemical process is described below, and several case histories are presented as mixed waste treatment examples using the perox-pure™ UV/Oxidation Process developed by Vulcan Peroxidation Systems Inc.

PROCESS DESCRIPTION

UV/Oxidation processes combine the use of ultraviolet light (UV) and chemical oxidants such as ozone (O₃) and hydrogen peroxide (H₂O₂) to destroy dissolved organic contaminants in water. In the case of the perox-pure™ UV/Oxidation Process, high intensity

broad-band UV radiation is combined with H_2O_2 to oxidize organic contaminants to carbon dioxide and water. Through direct photolysis, the UV light reacts with the H_2O_2 to generate hydroxyl radicals ($\bullet\text{OH}$), which are highly reactive, and as shown in Table 1, are second only to fluorine in oxidation potential. The hydroxyl radicals then attack the organic molecules resulting in the destruction of the parent organic compound. The reaction is aided by the direct photolysis of the organic molecule by the UV light which can break or activate certain atomic bonds making the molecule more susceptible to oxidation. With sufficient oxidation and exposure to UV energy, the reaction by-products are carbon dioxide, water, and the appropriate inorganic salt. A simplified reaction mechanism can be shown as follows:



Depending on the chemical structure of the organic molecules, the hydroxyl radical reaction pathway can be one of addition reactions, subtraction reactions or a combination of both, leading to the mineralized end products.

Table 1 Relative Oxidation Potentials

Oxidant	Relative Oxidation Potential
Fluorine	2.32
Hydroxyl Radical	2.06
Ozone	1.52
Hydrogen Peroxide	1.31
Permanganate	1.24
Chlorine Dioxide	1.07
Chlorine	1.00

The UV/Oxidation process can be affected by a number of factors including equipment design, contaminant type and concentration, water quality parameters, and oxidant

type and dosage. Potential adverse effects from water quality parameters such as suspended solids, iron, alkalinity, and background COD levels, can be effectively managed with proper pretreatment and/or utilization of proprietary catalytic additives. In some cases, hybrid treatment technologies employing multiple unit operations can provide the most cost effective solution. However, proper equipment design is of paramount importance in achieving optimum UV/Oxidation treatment performance for any application. In most cases, bench-scale or pilot-testing is required to evaluate necessary design requirements and system sizing. Properly designed full-scale UV/Oxidation equipment should at a minimum maintain the following engineering design features; (1) meet all applicable manufacturing codes and OSHA safety requirements, (2) a properly designed UV reactor which maximizes the utilization of available UV light energy and provides sufficient turbulent mixing, even at low flow rates, (3) an effective and low maintenance automatic quartz tube and reactor chamber wall cleaner, (4) an oxidant dosing system which allows for multiple point dosing and continuous adjustment of the oxidant dosage, (5) UV lamp/power turn-down capability while maintaining constant UV density, (6) PC- or PLC-based automation features, and (7) a configuration for minimum space requirements while maintaining serviceability and ease of upgrade for future expansion. Without these necessary design features full-scale equipment can become operationally cumbersome and cost prohibitive [1, 2, 3].

CASE HISTORIES

Four case histories are presented below which describe the activities leading to full-scale perox-pure™ installations for the destruction of organic contaminants in mixed organic/radioactive waters.

EG&G Rocky Flats, Inc.

Groundwater under the OU1, 881 Hillside area of the Rocky Flats Plant near Golden, Colorado was found to be contaminated with a variety of VOCs. Because of activities at this DOE nuclear facility, the groundwater also contained radionuclides at levels which would

make activated carbon adsorption a costly treatment method. Therefore, photochemical oxidation was selected as the treatment technology of choice.

In February 1988, PSI was contracted by EG&G to perform design testing at the perox-pure™ Testing Laboratory in Tucson, Arizona. Groundwater from the 881 Hillside area was diluted 1:2 with uncontaminated water by EG&G to provide a sample for testing that contained non-hazardous levels of radionuclides. The groundwater contained approximately 1300 µg/l of VOCs, and relatively high levels of inorganic constituents. The objectives of the study were: (1) to confirm that the perox-pure™ Process could destroy each of the VOCs to below the treatment objective of 5 µg/l each, and (2) to provide full-scale treatment recommendations.

The results achieved during the perox-pure™ design study are shown in Table 2. The untreated VOC concentrations are listed along with the effluent levels. Destruction of each VOC to below the 5 µg/l treatment objective, the primary goal of the study, was demonstrated.

Table 2 VOC Destruction in Rocky Flats Groundwater with perox-pure™

Contaminant	Untreated (µg/l)	Treated (µg/l)
1,1-Dichloroethene	255	< 1
Methylene Chloride	9	< 1
1,1-Dichloroethane	6	< 1
1,1,1-Trichloroethane	470	< 1
Carbon Tetrachloride	35	< 1
Trichloroethene	400	< 1
Tetrachloroethene	153	< 1
Toluene	6	< 1

As a result of the design testing described above, EG&G purchased a 240 kilowatt (kW) perox-pure™ system which was manufactured in accordance with EG&G specifications for the nuclear industry. The treatment system was delivered in June 1990. The treatment

cost projected from the 1988 design study for a full-scale flow rate of 30 gpm is \$9.60/1000 gallons including electrical energy, hydrogen peroxide, and repair/maintenance parts.

Puget Sound Naval Shipyard

The Puget Sound Naval Shipyard (PSNS) near Bremerton, Washington receives radioactive wastewater from submarines. Wastewater typically contains 200 mg/l of various alcohols and ketones. PSNS wished to remove the organic contamination from the wastewater so that the water could be reused.

PSNS contracted VPSI to perform a **perox-pure™** design study in September 1991. Since an actual sample of the wastewater could not be provided, a synthetic water sample was supplied by PSNS. The synthetic sample was spiked with approximately 200 mg/l total of methanol, ethanol, isopropanol, acetone and methyl ethyl ketone. The objectives of the study were: (1) to demonstrate total organic carbon (TOC) destruction to less than 2 mg/l, and (2) to provide full-scale treatment recommendations.

During the **perox-pure™** design study, TOC destruction was demonstrated from 120 mg/l to less than 1 mg/l, thus achieving the first objective of the study. Specific organic analyses were not performed as they were not of interest to PSNS. The fact that the TOC was reduced to less than 1 mg/l indicates that the organic carbon was converted to carbon dioxide and that no organic by-products were produced. As a result of the study, a full-scale power requirement of 50 kW was projected for a flow rate of 5 gpm.

In February 1992, PSNS issued a procurement specification for a 60 kW **perox-pure™** system. In accordance with the specifications, the **perox-pure™** system was built to Military Standards 22, 129, 248, 271 and 278 as well as NAVSEA 0900-LP-003-8000 metals surface standards. The **perox-pure™** system included the H₂O₂ storage and feed module, ancillary support equipment, six different equipment acceptance tests prior to shipment from the PSI Manufacturing Facility, and a final equipment drawing package. The treatment cost

projected from the 1991 design testing is \$0.0013 per gallon including electrical energy, hydrogen peroxide and repair/maintenance parts.

PSNS purchased the perox-pure™ system in March 1993 and installation and start-up followed soon after.

Hanford Energy Works

Mixed waste is produced from the 242-A Evaporator/Purex Plant at the Hanford Facility near Richland, Washington. Along with alpha and beta radionuclides, the wastewater contains up to 138,000 µg/l of organic contaminants including butanol, acetone, dibutyl phosphate, dodecane, pentadecane, tetradecane, tributyl phosphate, tridecane and other aliphatic hydrocarbons. Hanford wished to reduce the organic contamination so that the water could possibly be reused at the facility.

JGC Corporation, the contractor to Hanford for selecting the treatment system, evaluated several treatment options including activated carbon adsorption, photochemical oxidation using low-intensity UV light and ozone, and photochemical oxidation using high-intensity UV light and H₂O₂. The perox-pure™ Process was selected for evaluation of the high-intensity UV/H₂O₂ option. VPSI was contracted by JGC Corporation in March 1992 to conduct a perox-pure™ design study. Since a sample of the wastewater was not available, JGC Corporation developed a synthetic solution which resembled the organic and inorganic make-up of the actual waste. The objectives of the study were: (1) to demonstrate TOC destruction to less than 10 mg/l along with specific effluent objectives for several of the organic contaminants, and (2) to provide full-scale treatment recommendations.

The synthetic sample provided by JGC Corporation contained approximately 30 mg/l of tributyl phosphate, 10 mg/l of butanol, 2 mg/l of other organics, and a TOC of 30 mg/l. Very high concentrations of ammonia, nitrate, sulfate, chloride and other inorganic ions were also present. Destruction efficiencies achieved during the design study for TOC and the three primary organic compounds are shown in Table 3 along with the required effluent

objectives. As shown, destruction efficiencies well beyond the required levels were achieved, fulfilling the first objective of the study.

Table 3 Organic Contaminant Destruction in Hanford Wastewater with perox-pure™

Contaminant	Untreated (µg/l)	Treated (µg/l)	% Destruction	Effluent Objective (µg/l)
TOC	29,000	2,000	93	10,000
Tributylphosphate	30,000	<5	99.98+	1,000
Butanol	8,800	<50	99.4+	5,000
Acetone	1,900	<10	99.5+	50

Full-scale design recommendations were made to JGC based upon the results of the laboratory study. The perox-pure™ Process was selected over the other treatment option and a specification for a perox-pure™ UV/H₂O₂ system was issued in December 1992 with modifications in July 1993. To fulfill the specifications, PSI proposed two 360 kW perox-pure™ units built to NQA-1 nuclear standards. The perox-pure™ equipment was constructed in late 1993 and delivered in February 1994. As installation of the system was just initiated in September of 1995, full-scale operating data is not yet available. However, the projected treatment cost from the 1992 design study for the full-scale flow rate of 173 gpm is \$0.005 per gallon including electrical energy, hydrogen peroxide and repair/maintenance parts. The perox-pure™ system included the H₂O₂ storage and feed module, ancillary, support equipment, effluent H₂O₂ destruction module, construction of each item to NQA-1, and pre-shipping acceptance testing.

The projected cost for removal of the organic contamination by granular activated carbon (GAC) adsorption was \$0.086 per gallon including GAC, disposal and repair/maintenance parts. The carbon usage costs were projected by Kaiser Engineering. The carbon disposal cost was estimated by Hanford using a rate of \$2,500 per drum (\$336/ft³). As shown, the projected treatment cost for GAC adsorption is approximately 17 times that for perox-pure™ treatment.

National Institutes of Health Facility

The National Institutes of Health Facility (NIH) in Bethesda, Maryland generates low level radioactive biomedical waste from their animal testing laboratories. The wastewater was generated in batches of approximately 500 gallons per day and was characterized by a TOC concentration of 3,000 to 4,000 mg/l which includes various volatile and semi-volatile compounds. In addition, the wastewater was colored and turbid. The treatment objective for the perox-pure™ system was the destruction of Total Toxic Organics (TTO) to below 2.13 mg/l.

NIH contracted VPSI to perform an on-site testing study during November and December of 1994. The testing was conducted in batch recycle mode using a perox-pure™ 30 kW system. The entire study was performed for a period of two weeks, treating several different batches of wastewater. The objectives of the study were (1) to demonstrate the ability to effectively meet the TTO treatment objective, and 2) to provide full-scale treatment recommendations.

The results of the perox-pure™ design study are shown in Table 4. The results show that significant destruction of the target TTO compounds was achieved with as little as 34 minutes of recycle oxidation time, even though the concentration of phthalate esters were approximately 9 times greater than specified.

Table 4 TTO Destruction in NIH Wastewater

Contaminant	Untreated	34 min Treated ($\mu\text{g/l}$)
Chloroform	560	11
Chloromethane	220	36
Methylene Chloride	50	25
Di-n-butylphthalate	68,800	2,000
Bis (2-ethylhexyl) phthalate	64,000	16,000
TOC (mg/l)	3,600	2,008

As a result of the on-site design study described above, a **perox-pure™** 180 kW system was recommended to treat the 500 gallon per day waste stream on a continuous basis. In the meantime the 30 kW unit remained on-site and continued to treat stored waste at the facility. The projected operating costs based on the study were \$0.48/1000 gal of wastewater including electricity, chemical costs, and repair/maintenance costs.

CONCLUSIONS

Photochemical oxidation has been established as one of the foremost treatment methods for organic contamination in water. A multitude of commercial applications exist throughout the United States, Canada and Europe. The **perox-pure™** photochemical oxidation process has been successfully and cost effectively applied to the on-site treatment of groundwaters, process wastewater, tank bottoms, landfill leachates, and potable waters. As described in this report, mixed organic/radioactive wastewaters have been added to the list of success stories in the last few years. Not only is the **perox-pure™** process much more cost effective than activated carbon adsorption, there are no air emissions, solid waste or hazardous by-products produced by the **perox-pure™** Process.

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**DC GRAPHITE ARC FURNACE, A SIMPLE SYSTEM TO REDUCE
MIXED WASTE VOLUME**

**J. Kenneth Wittle and R. A. Hamilton
Electro-Pyrolysis, Inc.
(610) 687-9070**

**J. Trescot and P. Wilver
Kennedy Van Saun**

ABSTRACT

The volume of low-level radioactive waste can be reduced by the high temperature in a DC Graphite Arc Furnace. This volume reduction can take place with the additional benefit of having the solid residue being stabilized by the vitrified product produced in the process. A DC Graphite Arc Furnace is a simple system in which electricity is used to generate heat to vitrify the material and thermally decompose any organic matter in the waste stream. Examples of this type of waste are protective clothing, resins, and grit blast materials produced in the nuclear industry. The various Department of Energy (DOE) complexes produce similar low-level waste streams. Electro-Pyrolysis, Inc. and Svedala/Kennedy Van Saun are engineering and building small 50-kg batch and up to 3,000 kg/hr continuous feed DC furnaces for the remediation, pollution prevention, and decontamination and decommissioning segments of the treatment community. This process has been demonstrated under DOE sponsorship at several facilities and has been shown to produce stable waste forms from surrogate waste materials.

A NEW TECHNOLOGY FOR CONCENTRATING AND SOLIDIFYING LIQUID LLRW

Nanette Newell
TMC, Inc.
2611 SW Third Avenue, Suite 200
Portland, Oregon 97201
503-241-7802

Matthew W. Osborn, Charles C. Carey, and Richard G. Allen
Center for Research on Occupational and Environmental Toxicology
Oregon Health Sciences University
3181 SW Sam Jackson Park Road
Portland, Oregon 97201
503-494-2508

ABSTRACT

One of the unsolved problem areas of low level radioactive waste management is the radiolabeled material generated by life sciences research and clinical diagnostics. In hundreds of academic, biotechnology, and pharmaceutical institutions, there exists large amounts of both aqueous and organic solutions containing radioactively labeled nucleic acids, proteins, peptides, and their monomeric components. We have invented a generic slurry capable of binding all these compounds, thus making it possible to concentrate and solidify the radioactive molecules into a very small and lightweight material. The slurry can be contained in both large and small disposal plastic devices designed for the size of any particular operation. The savings in disposal costs and convenience of this procedure is a very attractive alternative to the present methods of long and short term storage. Additionally, the slurry can remove radiolabeled biological compounds from organic solvents, thus solving the major problem of "mixed" waste. We are now proceeding with the field application stage for the testing of these devices and anticipate widespread use of the process. We also are exploring the use of the slurry on other types of liquid low level radioactive waste.

THE PROBLEM

The disposal of radioactive and toxic waste is an increasingly expensive problem. Although most low level radioactive waste (LLRW) presents only minimal health risks, communities have been hesitant to permit LLRW disposal sites, thus necessitating on-site waste storage or solidification and shipment to one of two LLRW disposal sites in the country. These sites occasionally exclude wastes from places outside their locale. For

instance, Barnwell, S.C. excluded wastes from thirty two states for some time. Additionally, the controversy over Ward Valley has caused disposal problems for California and Arizona. Thus, storage is often the only option.

Charges for LLRW disposal are based on volume, not amount of radioactivity. And no LLRW can be disposed of in liquid form. When an adsorbent is added, four quarts of liquid become five quarts of solid. Additionally, the use of adsorbents has recently been looked upon less favorably because liquid can still leak out of the adsorbent. Thus, disposal of liquid waste can be very expensive or impossible. Currently, much low level liquid waste is put in the sewage system, an illegal practice in some locations, or is stored on site. Many radioactive isotopes used in biological research degrade rapidly, so they can be stored until the isotopes decay to background levels, usually in less than a year. Although storage of radioactivity is widely used, it is very space consuming and entails expensive record keeping. Additionally, stored liquid waste can be spilled, increasing the problems of the storage site.

Biological and clinical laboratories generate several types of liquid solutions that pose disposal problems. There are dilute solutions of radioactively labeled biological molecules, such as DNA, RNA, and proteins, in water or solvent. An even larger problem, especially in terms of cost, is the disposal of "mixed waste," which contains radioactivity in hazardous solvents. LLRW waste sites won't take the solvents, and hazardous waste sites won't take radioactivity. Thus, special sites are needed, and it can cost up to \$1000/cu.ft. to dispose of.

The costs of disposing of aqueous and mixed radioactive waste at Oregon Health Sciences University (OHSU) are shown in Table 1. For those states that have an LLRW disposal site, the cost trends are similar.

TABLE 1 OHSU Radioactive Waste Disposal Price Schedule

WASTE	1994	1995	1996
Aqueous	\$66/gallon	\$100/gallon	?
Organic solvents	up to \$2000/gallon	up to \$4000/gallon	?

In addition to the disposal issues at biological and clinical chemistry research sites, much radioactive and mixed waste exists in many other industrial and government sites. Much of the waste from the government's nuclear program is in very large volumes and presents both health and environmental threats. Current treatments are either very expensive or marginally effective or both.

THE SOLUTION: RADAWAY™

TMC's RadAway™ products can solve the disposal problems by binding radioactively labeled compounds, thereby reducing the volume of radioactive or toxic liquid waste up to 60-fold. With this volume reduction, the waste can be disposed of much less expensively. These products can also greatly reduce the storage volume and transform the waste into an easily handled solid form.

The RadAway™ units are composed of a three part filter apparatus that contains a top reservoir, an ion exchange-based wet slurry in the middle compartment, and a reservoir on the bottom. A patent for the slurry mixture and the unit design has been applied for.

The first generation units are about the size of a home coffee maker, with the slurry cartridge located where the coffee grounds would go. These units are designed for bench top use and will process about a liter of liquid at a time.

Solutions containing radiolabeled biological molecules are poured into the top compartment and allowed to filter through the slurry. Because of the net charge of the molecules, they stick to the slurry and are removed from the water or solvent that then accumulates in the lower compartment. The water or solvent is tested for purity and disposed of. The slurry containing the concentrated radioactive or toxic compound can be disposed of at a greatly reduced cost as solid waste. Alternatively, if it is a short-lived isotope, it can be stored until the radioactivity has decayed to background levels and then disposed of as nonradioactive waste.

A unique characteristic of these products is their ability to function in any situation so far tested for the target market. Numerous different waste solutions have been tested over RadAway™, as outlined in Table 2. Also tested include a variety of salt concentrations, buffers, tissue culture media, pH ranges, and detergents. The isotopes tested include ³²P, ³⁵S, ¹⁴C, and ¹²⁵I. In all cases, the product bound greater than 99.99% of the waste.

TABLE 2 Compounds Tested*

BIOLOGICAL	TOXIC
Proteins Amino acids Nucleic acids (DNA and RNA) Nucleotides	Ethidium bromide SYBR Green I Sodium Iodide

*Expect all charged and highly aromatic compounds to bind

The RadAway™ products do have a capacity limitation that requires changing the slurry on a regular basis. The capacity, though, is quite large. For dilute solutions, such as DNA sequencing gel buffer, one slurry cartridge (5 cu.in.) can concentrate at least 1 gallon of buffer. For more concentrated solutions, such as tissue culture media, the capacity is less. We expect that the slurry cartridge for a bench top model will need to be replaced every month.

RadAway™ can effectively separate mixed waste by binding the radioactively labeled compounds and allowing the solvent to flow through. Thus, the two types of waste can be disposed of separately and significantly less expensively. TMC has tested the separation of radioactively labeled biological compounds from many of the solvents commonly used in biology labs. Tested solvents include 30% acetonitrile, 50% formamide, 30% methanol, and 5% ethanol. The specific experiments are outlined in Table 3.

TABLE 3 Mixed Waste Experiments

SOLVENT	PROBE	BUFFER
50% formamide	^{32}P RNA	hybridization buffer (high salt and detergent)
30% acetonitrile	^{125}I peptide	tetrafluoroacetic acid (pH 3)
5% ethanol	^{125}I peptide	water
30% methanol	^{125}I peptide	water

The disposal savings to the user will be dramatic. As an example, 5 cu.in. of RadAway™ slurry will concentrate one gallon of DNA sequencing gel buffer. The pre-concentration disposal cost of 1 gallon is about \$100, whereas the cost of disposal of 5 cu.in. of dry solid is about \$1, a 100-fold reduction in cost.

The later generation Away™ products will be designed for larger volumes. A unit that will process about one gallon at a time is being designed for the same initial market, but for companies and universities that tend to use more centralized processing and storage of radioactive and hazardous waste. Even larger volume units are being pursued for the industrial and government markets.

Since the concentration of radioactivity out of solution depends on the radioactivity being part of a charged molecule, it is likely that the device will separate radioactively labelled charged compounds of all types, not just biologicals. Later generation Away™ products will be even larger units for industrial and government markets such as chromatography users, producers of radioactive isotopes and specialty chemicals, and Department of Energy and Department of Defense sites. Scale up to hundreds of gallons a day will require substantial additional engineering, which is currently being investigated.

CONCLUSION

TMC, Inc. is developing and will manufacture and market easy to use devices that concentrate and solidify liquid radioactive waste, thus greatly simplifying disposal. These

devices, the RadAway™ units, contain new technology that has the capacity to easily and inexpensively separate radioactively labelled molecules from water or solvents. The Away™ units can be of any size, from a version suitable for the lab bench to industrial scale. Within the target market, there are no products currently available that perform in the manner of these devices.

ACKNOWLEDGEMENTS

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IDENTIFICATION AND ASSESSMENT OF SITE TREATMENT PLAN
IMPLEMENTATION OPPORTUNITIES FOR EMERGING TECHNOLOGIES

Emile A. Bernard
Environmental Programs Development Office
Sandia National Laboratories
20201 Century Boulevard
Germantown, Maryland 20874
301-916-6808

ABSTRACT

The Department of Energy (DOE), in response to the 1992 Federal Facility Compliance Act, has prepared Site Treatment Plans (STP) for the approximately 2,000 waste streams identified within its mixed waste inventory. Concurrently, emerging mixed waste treatment technologies are in final development. This paper defines a three-phase process to identify and assess implementation opportunities for these emerging technologies within the STP. It highlights the first phase, functional matching of expected treatment capabilities with proposed treatment requirements. Matches are based on treatment type, regulated contaminant and waste matrix type, for both capabilities and requirements. Results identify specific waste streams and volumes that could be treated by each emerging technology. A study for Plasma Hearth Process, Delphi DETOXSM, Supercritical Water Oxidation and Vitrification shows that about 200,000 m³ of DOE's mixed waste inventory can potentially be treated by one or more of these emerging technologies. Actual implementations are small fractions of the treatable inventory. Differences between potential and actual implementations must be minimized to accrue optimum benefit from implementation of emerging or alternative treatment technologies. Functional matching is the first phase in identifying and quantifying benefits, addressing technology system and treatment issues, and providing, in part, the basis for STP implementation decisions. DOE, through EM's Office of Technology Development, has funded this work.

[AUTHOR'S NOTE: AT THE TIME OF THIS SUBMISSION, A REVISED MIXED WASTE INVENTORY REPORT AND UPDATED SITE TREATMENT PLANS WERE SOON TO BE RELEASED. RESULTS BASED ON THE REVISED INVENTORY AND UPDATED SITE TREATMENT PLANS WILL BE PRESENTED AT THE DECEMBER CONFERENCE. A COMPLETE PAPER, WITH THESE RESULTS, WILL BE AVAILABLE AT THAT TIME. RESULTS DO NOT APPEAR IN THIS SUBMISSION. A "TO BE DETERMINED" NOTE APPEARS INSTEAD.]

INTRODUCTION

The Department of Energy (DOE), Office of Environmental Management, Office of Technology Development (OTD) has supported and continues to support the development of new technologies to be used to treat DOE's mixed wastes. The expected treatment capabilities of these emerging technologies are now established. Treatment requirements are now clearly specified in the Site Treatment Plans (STP) for each of its 2,000 or so, mixed waste streams. By matching expected capabilities with specified requirements, individual waste streams where an emerging technology *could be used* can be identified.¹ Furthermore, the STP specify the technologies, both existing and emerging, that *are to be used* to meet these requirements. If another technology is to be used where an emerging technology could be used, a reference is established for judging *relative* merits of using the emerging technology. One must determine, through appropriate analyses and evaluations, whether or not it is better to use an emerging or alternative treatment technology in place of the presently specified technology. These are future activities in the implementation process.

Implementations opportunities are identified for four emerging technologies:

- (1) Plasma Hearth Process (PHP)
- (2) Delphi DETOXSM
- (3) Supercritical Water Oxidation (SCWO)
- (4) Vitrification (VIT).

The functional matching process for these technologies has been validated through the identification of similar implementation opportunities based on the Conceptual STP.²

A common terminology for stating expected treatment capabilities for the emerging technologies and proposed treatment requirement specified in the site treatment plans is needed in order to search the database systems for capabilities/requirements matches. A three-part common basis for stating capabilities and requirements is defined:

- (1) Treatment Type
- (2) Regulated Contaminant
- (3) Waste Matrix Type.

When stated in this form (e.g., "destruction [treatment type] of a hazardous organic [regulated contaminant] in soils [waste matrix type]") it refers equally well to both treatment technology capabilities and specified treatment requirements. Waste stream by waste stream matches establish which ones *can be treated* by a particular emerging technology. For these matches, it can then be determined which ones *are to be treated* by that emerging technology. The difference between the former and latter identify potential implementation opportunities for that particular technology.

The reader is cautioned that identified implementation opportunities are just that, *opportunities*. They provide a starting point for the emerging technology implementation process. This process consist of three phases:¹

- (1) Functional Matching. Expected technology capabilities are matched, by waste stream, with similarly stated treatment requirements. This particular phase is the only one addressed in this work.
- (2) Implementation Analyses. Capability/requirements matches are evaluated to identify and discard less promising matches, e.g., matches that miss the implementation "window of opportunity", and matches where proven and accepted technologies fully meet the treatment requirements.
- (3) Quantitative Evaluations. Emerging technologies for remaining matches are evaluated at the *system* level to determine performance, risk and cost, and results are then compared with those of presently specified technology systems.

With the results from Phase (3) in hand, the case for implementing the emerging technology can then be made.

MIXED WASTE INVENTORIES

Total inventories (Current plus 5 Yr Projected) for Mixed Low Level Waste (MLLW) and Transuranic (TRU) waste are used in this work. These inventories are reported in the Proposed Site Treatment Plans³ (PSTP) and Mixed Waste Inventory Report⁴ (MWIR), and summarized in Table 1. The PSTP inventory is the primary data source. The MWIR augments the PSTP inventory with contaminant information and waste stream descriptions.

Table 1: Summary of DOE Mixed Waste Inventories

Type of Mixed Waste	Current Inventory		5Yr Projected Inventory		Total Inventory	
	No. WSs	Vol (m ³)	No. WSs	Vol (m ³)	No. WSs	Vol (m ³)
Low Level						
TRU						
Total						

There are ten main treatment types defined within the treatment plans⁵: organic destruction, deactivation, neutralization/non-aqueous, stabilization, amalgamation, inorganic debris treatment, mercury separation, soil washing/treatment, and alkali metals and wastewater treatment. The *Treatment Type* part of the capabilities/requirement statement is based on the these treatment types.

Regulated contaminants⁶ are both general and specific. General contaminants are those with toxic, ignitable, corrosive, and reactive characteristics. Specific contaminants include toxic organics and metals, halogens, and mercury. The *Regulated Contaminant* part of the capabilities/requirement statement is based on the these contaminants, altogether, eleven of them.

Finally, the total inventory is categorized into nine main matrix types⁶: aqueous and organic liquids, solid process residues, soils, debris, special and inherently hazardous wastes, unknowns and final waste forms. Each main type is subdivided in to a number of other matrices, making up a total of almost 200 matrix types. The *Waste Matrix Type* part of the capabilities/requirements statement is based on these 200 matrix types.

In the next sections these *Treatment Type/Regulated Contaminant/Waste Matrix Type*

Process Description

DETOXSM is a catalyzed wet oxidation process that used Fe (III) in an acid solution

SUPERCRITICAL WATER OXIDATION (SCWO) IMPLEMENTATIONS

Process Description

SCWO is a relatively low temperature process above the critical point of water (374°C and 22.13 Mpa) that can provide high destruction efficiencies for a wide variety of organics suspended in water. Metals are converted to oxides and retained in the water, and it can be operated in a closed loop mode.⁷ SCWO is now being fielded by MODAR, Inc., Natick, MA; Modell Environmental Corporation, Waltham, MA; Eco Waste Technologies, Austin TX; and General Atomics, San Diego, CA.

Expected Capabilities

An example of a particular SCWO expected capability is "destruction of toxic organics in aqueous liquids". This and other expected capabilities are used to query the database systems to identify SCWO implementation opportunities. The complete set of SCWO expected capabilities can be determined from the following sets of treatment types, regulated contaminants and waste matrix types.¹⁰

<u>Treatment Types</u>	<u>Regulated Contaminants</u>	<u>Waste Matrix Types</u>
Organic Destruction	Toxic Organics	Organic Liquids Aqueous Liquids Organic Sludges Explosives Compressed Gases

Implementation Opportunities

TO BE DETERMINED.

VITRIFICATION (VIT) IMPLEMENTATIONS

Process Description

VIT is the process of converting materials into a glass, glassy substance, or slag. It destroys organics, and immobilizes inorganics and metals. Typical processing temperatures are in the range of 1000°C to 1600°C.⁷

Expected Capabilities

An example of a particular VIT expected capability is "stabilization of toxic metals in organic debris". This and other expected capabilities are used to query the database systems to identify VIT implementation opportunities. The complete set of VIT expected capabilities can be determined from the following sets of treatment types, regulated contaminants and waste matrix types:¹¹

<u>Treatment Types</u>	<u>Regulated Contaminants</u>	<u>Waste Matrix Types</u>
Organic Destruction	No limitation	Inorganic Sludges
Stabilization		Soils
		Organic Debris
		Special Wastes

Implementation Opportunities

TO BE DETERMINED.

SUMMARY OF IMPLEMENTATION RESULTS

TO BE DETERMINED.

CONCLUSIONS AND RECOMMENDATIONS

A method of matching expected treatment capabilities of emerging technologies with specified treatment requirements has been developed and demonstrated. It shows significant differences between mixed waste volumes where emerging technologies *could be used* but are *not presently specified to be used* to treat the DOE mixed waste inventory. These potential implementation opportunities are identified by waste stream, along with the different technologies presently specified to be used. Basic information needed to assess and pursue these potential implementations is provided.

It is recommended that results of this work be used to initiate Phase (2), Implementation Analyses and Phase (3), Quantitative Evaluations of the emerging technology implementation process. In particular, it is recommended that planned and future treatment system studies, and alternative treatment studies that may be dictated by deficiencies that surface in presently proposed treatment systems, utilize the method and results of this work to guide, in part, the initiation and conduct of these studies.

ACKNOWLEDGMENTS

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BIOPROCESSING OF A STORED MIXED LIQUID WASTE

J. H. Wolfram,* R. D. Rogers
Idaho National Engineering Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-2203
208-526-1809

R. Finney, A. Attala, G. Silver, F. Hertweck, Jr.
Mound Applied Technologies
Miamisburg, OH 45353

ABSTRACT

This paper describes the development and results of a demonstration for a continuous bioprocess for mixed waste treatment. A key element of the process is an unique microbial strain which tolerates high levels of aromatic solvents and surfactants. This microorganism is the biocatalysis of the continuous flow system designed for the processing of stored liquid scintillation wastes. During the past year a process demonstration has been conducted on commercial formulation of liquid scintillation cocktails (LSC). Based on data obtained from this demonstration, the Ohio EPA granted the Mound Applied Technologies Lab a treatability permit allowing the limited processing of actual mixed waste.

Since August 1994, the system has been successfully processing stored, "hot" LSC waste. The initial LSC waste fed into the system contained 11% pseudocumene and detectable quantities of plutonium. Another treated waste stream contained pseudocumene and tritium. Data from this initial work shows that the hazardous organic solvent, and pseudocumene have been removed due to processing, leaving the aqueous low level radioactive waste. Results to date have shown that living cells are not affected by the dissolved plutonium and that 95% of the plutonium was sorbed to the biomass. This paper discusses the bioprocess, rates of processing, effluent, and the implications of bioprocessing for mixed waste management.

INTRODUCTION

Mixed waste is any waste form that contains both radioactive and hazardous components. This waste is regulated by the Atomic Energy Act (AEA) and by the Resource Conservation Recovery Act (RCRA), Feldman, J. 1992. Both the commercial and the government sectors generate liquid and solid mixed wastes during their routine activities,

Moghissi, A. et al., 1991. Departments of Energy and Defense are considered the largest generators and have the bulk of the stored mixed waste, US DOE, 1993. Typical liquid mixed waste generated by the DOE are; solvents, laboratory solutions and oils. Liquid scintillation cocktail (LSC) wastes are the bulk of the liquid waste produced in the commercial sector. This waste is generated as a result of research, development, monitoring and medical activities. Although, new biodegradable cocktails are on the market, several practices still produce an LSC that is a mixed waste, not all of which is incinerable. Alternate technologies are needed to process the LSC that cannot be disposed of through incineration, Roche-Farmer, L., 1980.

The work describes the complete process developed and the results from the processing of actual stored "hot" waste. Previously published papers have described the uniqueness of the microorganism utilized in this process, Cruden, et. al., 1992 and the development of the process, Wolfram, J. H., et. a., 1993.

METHODS AND MATERIALS

Chemostat Experiments

Three reactors were plumbed in series. All liquids and gases flowed or were pumped into the first reactor (BR1). The effluents from BR1 were the feeds for the second reactor (BR2) and BR2 effluents were introduced into the vapor-phase reactor (TR1). The effluents from the third reactor went to a waste holding tank. The schematic (Figure 1) shows the bioprocess system that was used in this work. The plumbing to and between the reactors for all liquids was either stainless steel or flexible tubing (Viton). The liquid waste was directly added to the first reactor. The nutrient media containing the necessary inorganic salts as well as a flow of purified oxygen (60 ml/min) were also added directly to BR1. The liquid effluent exiting BR2 was introduced to the top of the vapor-phase reactor (TR1), while the vapor stream was added at the bottom of the TR1 reactor. Vapor-phase bioreactor contained a biofilm of the *Pseudomonas putida* Idaho established on the Manville 535 inert support media. All of the tests were run under this configuration, see Figure 1.

Analytical Support

Biomass loadings in the two CSTR units were monitored almost daily using a cell enumeration plate count method. A sample was aseptically withdrawn from the reactors. Standard microbiological procedures were used to determine the cell count by using a dilution series and spreading plates with 0.1 ml of aliquot from the dilution series. The plates were allowed to incubate at room temperature for several days before counting. The hazardous component was determined via gas chromatography. Samples from the liquid effluents of the reactors and gas samples were taken daily and analyzed for the aromatic component.

RESULTS

Previous testing performed on a similar system showed that a good material balance could be obtained and that cell viability was not inhibited at loadings of the methylated aromatic approaching 3000-5000 ppm, Wolfram and Rogers, 1991. Before introducing actual mixed waste to this system, a series of tests were done using a similar commercial formulation of LSC as was thought to be stored in the drums. The results of those tests are present at this conference by Attala et al., 1995.

The DOE facility that was chosen to demonstrate this bioprocess had accumulated 200, 55 gal drums of stored mixed waste most of which was LSC. The waste inventory of these drums showed that at least two different commercial cocktail formulations had been used, see Table 1. One formulation, Atomlight, was used for the counting of tritium while Insta-Gel a second commercial formulation was used to assay for plutonium. The Atomlight contained the solvent pseudocumene. This hazardous component is governed by RCRA as a characteristic waste. Insta-Gel contained xylene and is a listed waste.

Before any processing could take place, several drums of each radionuclide were opened. Although the waste in the drums was nearly 10 years old, the samples were still in a liquid state in the vials and easily removed for bulking. Two drums of each radionuclide

containing LSC were bulked and a sample sent for complete characterization. Both liquid wastes showed a wide variety of volatile and semi-volatile components. Pseudocumene was the major aromatic component in both of the wastes.

LSC Waste Containing Plutonium

The bioprocessing system was fed cold Insta-Gel prior to the initiation of the hot stored waste in anticipation that Insta-Gel would be the formulation to which the plutonium had been added. The characterization proved this to be in error. The formulation which had been used to count plutonium was a pseudocumene based LSC. The hot waste was transferred to a clean graduate cylinder and a feed rate of 10 ml per 1000 ml of nutrient media was fed to BR1. Samples were withdrawn daily to monitor the pseudocumene content in the liquid and gaseous effluents. After 48 hrs from feed initiation, the metabolic capability in BR1 was able to completely degrade the pseudocumene, see Figure 2. The test was continued for 8 days. No pseudocumene was found in BR2 or in TR1 (vapor-phase reactor). Gas samples were also withdrawn daily and by day 4 most all of the pseudocumene was removed before exiting BR2, see Figure 3. During this first run with hot waste a population enumeration was done, see Figure 4. The cell mass in BR1 took an initial drop when the hot waste was added. However, within 24 h the population was again on the increase. The steady state population was approximately $10E9$ cells/ml. The population in BR2 did not initially decline. After the fourth day the population increased to $10E9$ cells/ml.

Several other feed rates were tested on the remaining three different bulked batches (IGBK, IGHL, and IGCT) although all of the plutonium waste was removed from two barrels. In Table 2, the results of these additional trials are listed. In all the trials of 10-20 ml of hot waste fed, no pseudocumene could be detected in the effluent stream leaving the TR1 reactor. The cell population during all of these runs remained high at $10E9$ cells/ml. No attempt was made to bring the second reactor to steady state since very little substrate (pseudocumene) was leaving BR1. During all of these runs no pseudocumene was found in the vapor-phase reactor effluent. During the final batch of hot waste containing

plutonium, the feed rate was increased to 40 ml/1000 ml of nutrient media. After five days pseudocumene was detected in the effluent stream and the cell number drastically decreased.

During several of the trials, an aliquot of sample was taken from BR2 and centrifuged. The supernatant was counted for the presence of plutonium. The cell pellet was washed with sterile media and the pellet was counted for the presence of plutonium. In all cases the pellet contained 95-97% of the radioactivity(data not shown).

LSC Waste Containing Tritium

Two barrels known to contain LSC-tritium waste were opened and bulked as had been the case with the plutonium waste. Although the viscosity of this waste was greater than the plutonium, a dilution was made in order to pump it into BR1. Again this waste was a pseudocumene based LSC. The tests were done using two different scales of reactors. The data presented in Figures 5, 6 demonstrate that the bioprocess worked well on this second stored waste sample. The system was started up on tritiated waste following the completion of the plutonium waste sample. The first two weeks on tritiated waste, the reactors were fed at a rate of 5 milliliters per day of the waste. The pseudocumene feed level was 465 ppm into the first reactor. No detectable levels of pseudocumene could be found in the effluents of the second reactor or the effluent of the final reactor. The feed rate was increased to 9.6 ml per day of waste. The levels of pseudocumene detected are shown in Figure 5. Only in the effluent of BR-1 was pseudocumene detected. The gas stream was also checked for pseudocumene, see Figure 6. The vapor stream leaving BR-1 showed traces of the aromatic compound. Pseudocumene was completely removed from the vapor stream by the time it had passed through the vapor-phase bioreactor (TR-1). The scale-up data looks very similar to this when we increased the size of the first reactor from 1 liter to 5 liters. At one point we were pumping 275 ml of waste per day through the scaled system. This waste was the rinse water from the vials and contained less pseudocumene. However, the cell count did not decrease nor wash out.

DISCUSSION

Bioprocessing of concentrated hazardous organic liquid waste has received little attention because few organisms have been isolated which can tolerate and grow in high concentrations. This strain of *Pseudomonas putida* Idaho has been shown to grow and use methylated benzene compounds in biphasic mixtures, Cruden et al., 1992. Therefore, this strain is a suitable candidate to test on stored wastes that contain these types of organics in high levels. This strain was also shown to be resistant to high levels of surfactants and emulsifiers. Many DOE facilities as well as some commercial facilities either have stored LSC wastes or have LSC waste that cannot be incinerated due to the level or type of radionuclides contained in them. These results on this characteristic waste show that this organism and the bioprocessing system can remove the hazardous component below the regulated limits, and therefore, treat this mixed waste by removing the hazardous component.

The reactors in this system were typical CSTR units and all the accessories were vendor purchased. The system has operated without any significant problems during the cold commercial formulations of LSC testing as well as the hot phase. There was concern initially that either some chemical changes during storage of the waste for a long period or the radionuclide content might inhibit the bioprocess. These concerns are unwarranted as seen in the results of the trials. When the highest feed rate of 40 ml was attempted some pseudocumene was detected in the effluent and the cell count declined. This was later attributed not to the concentration of the pseudocumene but to the high levels that resulted from the emulsifier. The typical LSC has about 60% solvent and 40% emulsifier with trace amounts of fluors. After the long period of storage only 10-12% solvent remained. The difference is suspected to have evaporated and diffused through the vial caps. Since the emulsifier does not have as high a vapor pressure as the solvent, the emulsifier concentration increased in the solution remaining in the vial. Therefore, in a feed rate of 40 ml about 35 ml was surfactant/emulsifier. At this feed rate, the bioreactor concentration at steady state would be much higher than the 1000-3000 ppm of surfactant used during the cold testing period.

This treatability demonstration was granted by the Ohio EPA under a treatability exclusion. The results confirm that bioprocessing can satisfactorily remove the hazardous component from the mixed waste. The resulting effluent, a low-level radioactive waste can be handled by existing treatment techniques. This technology therefore, is an alternate to incineration and could be considered a more environmentally favorable way of treating this waste. There are no toxic vapor or liquid borne by-products and the radionuclides are still contained. This often is not the case resulting from high temperature combustion treatments.

This system has gone through a scale-up design. Final experiments utilized a 5.5 liter reactor replacing the one-liter BR1 reactor. The results from this tests were successful and a design for a bioprocessing system capable of handling one barrel per day will be performed.

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BIODECONTAMINATION OF CONCRETE

Robert D. Rogers
Idaho National Engineering Laboratory
(208) 526-0685

ABSTRACT

This paper describes the development and results of a demonstration for a continuous bioprocess for mixed waste treatment. A key element of the process is a unique microbial strain, which tolerates high levels of aromatic solvents and surfactants. This microorganism is the biocatalysis of the continuous flow system designed for processing stored liquid scintillation wastes. During the past year, a process demonstration has been conducted on commercial formulation of liquid scintillation cocktails (LSC). Based on data obtained from this demonstration, the Ohio Environmental Protection Agency granted the Mound Applied Technologies Laboratory a treatability permit allowing the limited processing of actual mixed waste. Since August 1994, the system has been successfully processing stored "hot" LSC waste. This paper discusses the bioprocess, rates of processing, effluent, and implications of bioprocessing for mixed waste management.

STABILIZATION OF INORGANIC MIXED WASTE TO PASS
THE TCLP AND STLC TESTS USING CLAY AND
pH-INSENSITIVE ADDITIVES

John S. Bowers*
Jim R. Anson
Socorro M. Painter
Rocco E. Maitino

Hazardous Waste Management Division
Lawrence Livermore National Laboratory
P. O. Box 808, L-621
Livermore, CA 94550
(510) 423-7756 (phone)
(510) 422-3469 (fax)

ABSTRACT

Stabilization is a best demonstrated available technology, or BDAT, as defined by the U. S. Environmental Protection Agency (EPA) in Title 40, part 268, of the Code of Federal Regulations (40 CFR 268). This technology traps toxic contaminants (usually both chemically and physically) in a matrix so that they do not leach into the environment. Typical contaminants that are trapped by stabilization are metals (mostly transition metals) that exhibit the characteristic of toxicity as defined by 40 CFR part 261. The stabilization process routinely uses pozzolanic materials. Portland cement, fly ash-lime mixes, gypsum cements, and clays are some of the most common materials. They are inexpensive, easy to use, and effective for wastes containing low concentrations of toxic materials.

In many instances, materials that can pass the Toxicity Characteristic Leaching Procedure (TCLP[^]Othe federal leach test) or the Soluble Threshold Leachate Concentration (STLC[^]Othe California leach test) must have high concentrations of lime or other caustic material because of the low pH of the leaching media. Both leaching media, California's and EPA's, have a pH of 5.0. California uses citric acid and sodium citrate while EPA uses acetic acid and sodium acetate[^]Othe concentration in the leachate is approximately ten times higher for the STLC procedure than the TCLP. These media can form ligands that provide excellent metal leaching. Because of the aggressive nature of the leaching medium, stabilized wastes in many cases will not pass the leaching tests.

At the Lawrence Livermore National Laboratory (LLNL), additives such as dithiocarbamates and thiocarbonates, which are pH-insensitive and provide resistance to ligand formation, are used in the waste stabilization process. Attapulgite, montmorillonite, and sepiolite clays are used because they are

forgiving (recipe can be adjusted before the matrix hardens) when formulating a stabilization matrix, and they have a neutral pH.

By using these clays and additives, LLNL's highly concentrated wastewater treatment sludges have passed the TCLP and STLC tests. The most frequently used stabilization process consists of a customized recipe involving waste sludge, clay and dithiocarbamate salt, mixed with a double planetary mixer into a pasty consistency. TCLP and STLC data on this waste matrix have shown that the process matrix meets land disposal requirements.

BACKGROUND

The disposal of low-level mixed waste must meet land disposal restrictions under the federal regulations (40 CFR 268). For this reason, LLNL's Environmental Protection Department has undertaken waste stabilization, deeming it to be the BDAT for waste disposal that adheres to regulations.

To assure that stabilization technology is effective, the processed material must undergo the regulatory leach tests, which are Toxicity Characteristic Leaching Procedure (TCLP) and the California Assessment Manual Waste Extraction Test for Soluble Threshold Leachate Concentration (CAM-WET STLC). The CAM-WET is a much more aggressive test, applying to many more constituents, and frequently requires verification of success and customization in stabilization processes.

Currently, mixed wastes that exhibit the characteristics of corrosivity (D002), low total organic carbon (TOC) ignitability (D001), or toxicity for pesticides (D012 through D017) must be treated for all underlying constituents to meet land disposal requirements. Table 1 summarizes regulatory threshold limits for metals, their EPA codes, and underlying constituents.

The waste requiring stabilization at LLNL is filter-aid sludge from processing wastewaters generated through various systems within the LLNL site. This filter-aid sludge does not exhibit characteristics that require LLNL to treat underlying constituents. However, to dispose of the waste at the Nevada Test Site, State of California regulations apply, and

these require LLNL to pass the STLC test. The metals analyzed in the STLC are the same as the underlying constituents in EPA's Universal Treatment Standard (40 CFR 268.48).

EPA recognizes that stabilization is a BDAT. Therefore, it does not require stabilized wastes to be sampled to verify that they meet land disposal restrictions. However, the Nevada Test Site requires verification of 10% of the LLNL low-level wastes sent there for disposal. For this waste, TCLP extract concentrations and the STLCs are applied for those waste constituents listed in the Constituent Concentrations In Waste Extract (CCWE) table (40 CFR 268.41). Table 2 lists the metals analyzed and the CAM-WET threshold limit for hazardous waste.

The Nevada Test Site also requires that California constituent radioactive wastes be treated prior to disposal. LLNL's work with California constituents will help in developing techniques to meet the universal treatment standards when promulgation requires treatment of underlying constituents for metal characteristic codes. The differences between the federal (TCLP) and the California State (STLC) leaching tests are subtle but provide substantial differences in test results. The differences in these tests for the stabilized wastes are summarized in Table 3.

Table 3 shows that the California State leaching test is more rigorous in all categories except pH and extraction fluid weight ratio. The citrate buffer it uses has greater soluble ligand formation properties than does the acetate buffer used in the federal test. Both anions form soluble complexes with metals, but citrate has much larger formation constants and can form bidentates and tridentates with metals in the presence of hydrogen (as in a pH of 5.0). Both buffer strengths are the same for this type of waste. Wastes that are not pasty are ground up to a certain particle size. The particle size for the STLC is five times smaller than for the TCLP, providing the STLC with a steeper internal diffusion gradient. The leachate

Table 1. Metal Constituents, Characteristic Codes, and Federal Regulatory Threshold Limits.

Metal Constituent	Characteristic EPA Code	TCLP (mg/L) Regulatory Levels	TCLP (mg/L) under Universal Treatment Standards
Antimony	N/A	N/A	2.1
Arsenic	D004	5	5
Barium	D005	100	7.6
Beryllium	N/A	N/A	0.014
Cadmium	D006	1.0	0.19
Chromium	D007	5.0	0.86
Lead	D008	5.0	0.37
Mercury (retort)	D009	0.2	0.2
Mercury (other)	D009	0.2	0.025
Nickel	N/A	N/A	5.0
Selenium	D010	1.0	0.16
Silver	D011	5.0	0.3
Thallium	N/A	N/A	0.078
Vanadium	N/A	N/A	0.23
Zinc	N/A	N/A	5.3

Table 2. Metal Constituents and California Regulatory Threshold Limits.

Metal Constituent	CAM - WET STLC Threshold Limits (mg/L)
Antimony	15
Arsenic	5.0
Barium	100
Beryllium	0.75
Cadmium	1.0
Chromium	5.0
Cobalt	80
Copper	25
Lead	5.0
Mercury	0.2
Molybdenum	350
Nickel	20
Selenium	1.0
Silver	5.0
Thallium	7.0
Vanadium	24
Zinc	250

Table 3. Comparison of Federal and California State Leaching Tests.

Criterion	TCLP (Federal)	STLC (California)
Extraction Fluid Type	Acetate buffer	Citrate buffer
Approx. Extraction Fluid pH	5	5
Approx. Solids Diameter (Max.)	0.01 meters	0.002 meters
Leaching Time	18 hours	48 hours
Extraction Fluid Weight Ratio	20:1	10:1

time for STLC is longer, so more contaminants leach out. Although there is twice as much extraction fluid in the TCLP, this may not be significant. While more fluid provides for a larger diffusion driving force, this is not significant for lower concentrations (parts per million range).

RAW WASTE CHARACTERIZATION

The waste to be stabilized originates as aqueous waste. The metal constituents in the wastes are precipitated predominantly with hydroxide ion. The waste is then filtered through a rotary-drum vacuum-filter to remove the hydroxide precipitate, which is trapped by diatomaceous earth (filter-aid). This spent filter-aid sludge is periodically cut from the rotary drum during the aqueous waste treatment process and sent to LLNL's processing building for stabilization. The sludge contains about 60% water, with the balance of the material being diatomaceous earth, metal contamination, and often organics such as oil and carbon. The metal contamination in the sludge varies widely from batch to batch, since the waste streams processed are widely varied. Typically, one 5—m³ aqueous waste batch will yield one to two 0.2—m³ drums of diatomaceous earth waste. A typical example of the filter-aid sludge in a drum that requires stabilization is given in Table 4.

The diatomaceous earth waste itself has little resistance against either the federal or California leaching test. This is to be expected since hydroxide precipitates cannot hold up against any mild acid buffer regardless of their ability to form soluble complexes with metals. Metal hydroxide solubilities can be calculated from first principles using hydroxide

formation constants, solubility products, and assuming unity for activity coefficients. Cadmium, lead, and zinc appear to be completely soluble at a pH of 5.

Table 4 demonstrates the wide variety of metal constituents found in the filter-aid sludge. The highest in the subset shown is nickel at 2,076 mg/kg. Usually the largest concentration of metal contamination in the waste sludge does not exceed 5,000 mg/kg. The more concentrated sludges at LLNL are from spent plating baths (electro and electroless plating), which seldom contain arsenic, antimony, and selenium. These metals usually have to be precipitated as anion complexes and ion-exchanged prior to filtration because they will not precipitate as a hydroxide. Fortunately, LLNL does not see much of these metal contaminants.

THE CLAY MATRIX USED IN STABILIZATION

The primary clays used in LLNL's stabilization process are sepiolite, montmorillonite, and attapulgite. These clays have defined alumina or magnesium oxide-silica layers upon hydration. These clays were chosen because they have demonstrated effective stabilization in TCLP testing. They also tend not to increase the total waste volume to the extent that other clays (e.g., bentonite clay) do.

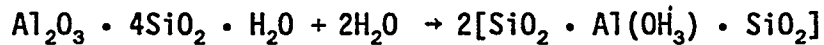
The clays also possess the ability to hydrate and adsorb hazardous constituents. They form thixotropic fluids when hydrated and have minimal compression strength, but are considered solids from a regulatory standpoint (they pass the EPA SW846 9095, Paint Filter Liquids Test).

Montmorillonites are impure forms of $\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$. The impurities are magnesium, potassium, calcium, titanium, and iron. The clay is an expanding type which forms a smectite when hydrated. Its structure consists of an aluminum hydroxide octahedral in between two sheets of silica tetrahedral. During the formation of the clay,

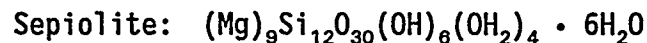
Table 4. Typical Diatomaceous Earth Sludge Batches.

Analysis Type:	mass balance	mass balance	mass balance	mass balance
Batch Number:	92-06	92-15	92-20	92-32AT/A
Sample Number:	N/A	N/A	N/A	N/A
Mass, kg:	246	143	90	50
CAM-WET Metals, mg/kg:				
Antimony	-	-	-	-
Arsenic	0.0	0.2	1.6	-
Barium	79.0	4.4	11.7	-
Beryllium	34.0	-	-	-
Cadmium	-	11.0	-	-
Chromium	252.5	126.0	81.8	4.0
Cobalt	0.0	-	-	31.7
Copper	389.0	779.6	294.4	245.7
Lead	183.0	52.4	-	-
Manganese	111.5	40.4	517.0	-
Mercury	35.4	0.2	0.0	-
Molybdenum	0.0	26.3	5.4	114.9
Nickel	96.9	2076.4	58.5	83.2
Selenium	-	0.1	-	-
Silver	42.6	-	42.6	-
Thallium	-	-	-	-
Vanadium	0.7	20.9	0.7	114.9
Zinc	144.9	-	750.0	107.0
Rad Analysis, Bq/kg:				
alpha	232	-	110	6.5
beta	6.9	-	139	2.2
tritium	4.4	0.126	14.1	1.8

cationic impurities disrupt the clay matrix by replacing the alumina ions. This is most profound when the two aligning tetrahedrals (above and below the octahedral) have substituted alumina for other metal oxides. In the case of this clay, the replacement cations have a less positive charge than the alumina. This results in a net negative charge in the clay lattice, giving it the ability to hold cations in place, or "sorb" them. The hydration reaction in its simplest view is given below.



Attapulgites and sepiolites have a similar behavior to montmorillonite but their structures are different. Attapulgite and sepiolite are not just alumina sandwiched between silica. They have a ribbon-like structure in which alternating twists in the ribbon are silica and metal oxides. The structure is stable and replacement of the metal oxides is less evident than in montmorillonite. This gives less adsorption capacity but provides a lower expansion upon hydration. The chemical composition of attapulgite and sepiolite is given below.



These formula are based on the Nagy and Bradley model and are discussed in Weaver (1975). The clays contain aluminum as an impurity but at a much lower volume than magnesium.

pH-INSENSITIVE ADDITIVES

Because pH, complex formation, and diffusion are the primary driving forces for leaching in the TCLP and STLC tests, it is important to limit these phenomena as much as possible.

The instance of molecular diffusion, although modeled in many situations and scenarios (sometimes in very complex detail), is small in this waste stabilization case. The diffusion of interest is between two solid phases: a successfully precipitated metal that is physisorbed to an active site, diffusing through a layer of clay. The potential of such a case is orders of magnitude smaller than solid-liquid phase diffusion.

The chance for complex formation between a citrate and metal is also relatively small. The formation constants of the bidentates and tridentates are orders of magnitude smaller than most inorganic solubility products. Acetate salt formation is an even smaller possibility. Hydroxide precipitates do not hold up well against the mild acid buffers of the leaching tests.

However, the use of pH-insensitive additives is required when high concentrations of metals are found in the waste sludge. There are many precipitating agents marketed under a variety of names; they are usually sold for wastewater treatment. The primary non-hydroxide chemicals sold for precipitation are iron and sodium sulfide, thiocarbamate, and thiocarbonate. These chemicals are all relatively pH-insensitive but still work better in alkaline solutions or high lime concentrations. The solubility products of sulfide or sulfur-bearing organic salts are all much lower than hydroxides. Care must be taken in using these materials because they are toxic in their own right.

MIXING EQUIPMENT

This process uses a double planetary, open paddle mixer. It is a "change-can" mixing device that uses a standard 55-gal (0.2—m³) drum as the mixing vessel or change-can. Its power source is a 15-hp (11,200-W), totally enclosed fan-cooled (TEFC) motor operating at 1,800 rpm. The motor shaft is connected to a worm that reduces speed by 40:1. The worm gear is attached to a shaft that is itself attached to a flat circular gear engaging two other gears, attached to each other and floating freely about the center shaft. These two gears each have a shaft attached to an open paddle. When the central shaft turns clockwise, the two opposing gears and their paddles spin counterclockwise. At the same time that the two paddles spin counterclockwise about their own axis, they spin together clockwise about the center gear. Thus, each paddle behaves as a planet spinning on axis, rotating around the sun (center gear). All three gears are approximately the same size and thus spin at about 45 rpm. This would appear slow (less than 1 revolution per second) if one did not see three motions occurring at once.

This mixing action is needed because the clay and diatomaceous earth mixture is a thixotropic pseudoplastic. It has extremely high viscosity until a high shear is applied, and it is a free-standing monolith when it is not being forced to move. Low speed, high shear mixing is more appropriate for this type of material than high speed, low shear mixing.

PROCESS DESCRIPTION

The stabilization process is implemented making use of water already present in the diatomaceous earth sludge. Stabilizer is added in an amount calculated to solidify the water in the sludge, not the entire weight of the sludge. Initially, much of the preliminary stabilization product was too soupy due to addition of too much water to the sludge. Now, a moisture determination is made before stabilization begins. This is performed in a standard laboratory oven at approximately 600°C and 600 grams of waste. The average moisture content is about 55%, varying between 33% and 80%, depending on the aqueous waste treated. The amount of clay added to the waste is determined by using the following formula:

$$M = (0.6)(X)(Z),$$

where

$$\begin{aligned} M &= \text{mass of clay to add,} \\ X &= \text{mass fraction of water in the waste,} \\ Z &= \text{mass of waste sludge.} \end{aligned}$$

This formula gives a consistent, stiff matrix. It allows for easy cleaning of the equipment because the clay matrix sticks to itself much more than to the open paddles. Also, it does not dehydrate readily when sealed in a drum to cure.

Additives are used when metal concentrations are too high for the clay alone. In such instances, clay alone provides little fixation. Table 5 shows the original raw material concentrations of metals with the STLC values after stabilization. A fair comparison can be made if one takes the STLC value,

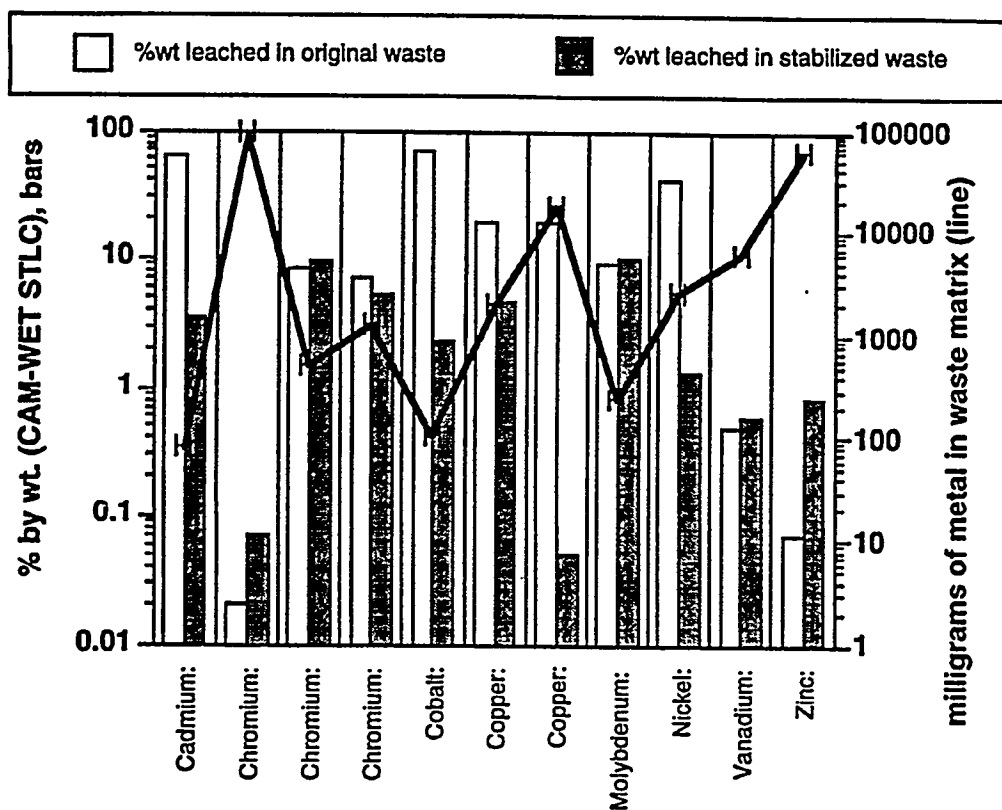


Figure 1. Direct Comparisons of Stabilization, Clay Only.

multiplies it by 10 (this is the dilution caused by the citrate buffer), then multiplies by the ratio of stabilized net mass to mass balance net mass. This will show that fixation does not occur in many cases and dilution is the main effect (the Table 5 values for zinc demonstrate this). Figure 1 shows a good way to present data to demonstrate the fixation of a metal constituent. The total constituent mass is calculated, then the percentage of the amount of

metal leached is calculated. A direct comparison of the amount leached in the original waste form and the stabilized waste form can then be made.

PROCESS ANALYSIS

Figure 1 shows the results of stabilization with clay only. For many metals at moderate concentrations, fixation with clay is adequate. Cadmium and cobalt show an order of magnitude reduction in leachate concentration upon stabilization with clay only. Nickel shows greater than one order of magnitude reduction and copper shows varying reductions in leachate concentration up to two orders of magnitude.

If the waste sludge contains greater than a few hundred grams of the metals mentioned above or contains metals such as chromium, molybdenum, vanadium, and zinc, additives are required to perform the stabilization successfully. Additives were first added at stoichiometric ratios plus 10% excess. This proved unsuccessful. Often, stabilization was not successful unless 100 times stoichiometry was used. Currently, 12% by weight of waste is used and only dithiocarbamate (DTC) has been successful at this concentration.

LLNL found that the sequence of stabilization is very important and that two mixing stages are needed. First, the pH-insensitive precipitating agent is added, and the waste sludge and additive are allowed to mix. The mixing continues for two to five minutes, at which point the waste and additive are well mixed and reprecipitation has occurred. Next, the clay is added and mixed. This locks the reprecipitated metals in the media and physisorbs it and any other materials still free in the matrix.

Table 5. Results of a Few Stabilized Wastes, Using Only Clay (Mass Balance, Total Constituent Concentrations, Stabilized, STLC Values).

Analysis Type:	mass balance	stabilized	mass	stabilized	mass balance	stabilized	mass balance	stabilized
Batch Number:	92-28 AT	92-28 AT	92-33 AT/A	92-33 AT/A	92-35 AT/A	92-35 AT/A	92-36 AT/A	92-36 AT/A
Sample No.:	N/A	9401764	N/A	9401740	N/A	9401677	N/A	9401765
Net Waste Mass (kg):	80	132	55	91	85	153	64.5	157
CAM-WET Metals:	mg/kg	mg/L (ppm)	mg/kg	mg/L (ppm)	mg/kg	mg/L (ppm)	mg/kg	mg/L (ppm)
Antimony	-	ND	-	ND	-	ND	-	0.18
Arsenic	-	ND	-	ND	-	ND	-	0.21
Barium	-	2.9	6.43	2.4	5.94	2.7	3.31	1.96
Beryllium	-	0.086	-	0.22	-	0.1	-	0.09
Cadmium	-	ND	-	ND	-	ND	-	0.01
Chromium	685.46	0.35	5.36	0.5	5.83	0.3	4.59	0.47
Cobalt	-	ND	1.11	ND	0.05	ND	0.76	0.03
Copper	988.87	ND	37.31	ND	37.48	ND	29.22	0.54
Lead	-	ND	-	ND	-	ND	-	0.02
Mercury	315.50	ND	-	ND	-	ND	-	0.10
Molybdenum	-	ND	3.09	ND	1.31	ND	1.51	0.12
Nickel	-	ND	13.77	ND	12.83	ND	14.70	0.06
Selenium	-	ND	-	ND	-	ND	-	0.18
Silver	-	ND	-	ND	-	ND	-	0.02
Thallium	-	ND	-	ND	-	ND	-	0.17
Vanadium	-	ND	1.64	0.41	2.79	0.38	3.17	0.61
Zinc	736.21	3.7	143.92	23.5	112.02	15.2	91.63	6.87

Figure 2 below shows a similar chart for stabilized wastes using DTC. In every case except for barium, fixation has occurred. There was essentially no detection of nickel or silver in the leachate of stabilized wastes. This clay and DTC showed very low leachate fractions for metals except for arsenic, which does not readily precipitate with DTC and usually exists in anionic form in wastewaters. Nevertheless, some reduction in arsenic leaching was observed.

Figure 3 shows the decrease in leachate concentration with the addition of DTC. The decrease is dramatic when the DTC additive is between 3% and 12% by weight of raw waste. These wastes originally had 3,200 mg/kg nickel, 745 mg/kg copper, 429 mg/kg zinc.

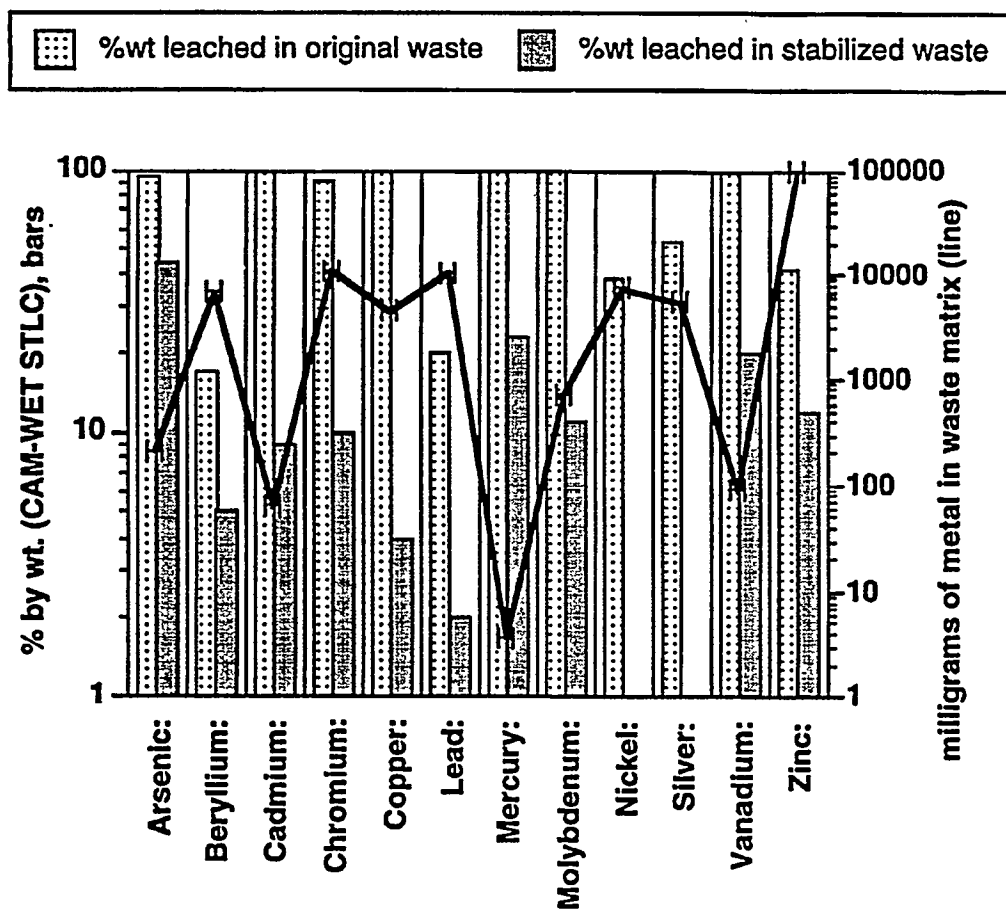


Figure 2. Direct Comparisons of Stabilization, Clay and 12% DTC.

Leachate concentrations for these wastes after stabilization with clay and DTC were less than 1mg/L; all stabilized wastes passed the TCLP and STLC tests.

CONCLUSION

In many cases the use of clay alone can fix metal constituents in a waste form. In other cases, fixation must be augmented. Using clay alone when metal concentrations are high will not fixate metals enough to pass the STLC test. The pH-insensitive additives, such as DTC or other sulfide-bearing compounds, may need to be used. Without the use of pH-insensitive additives, metal salts become available to the leaching fluid because the interaction of the clay and the metal hydroxide is weak. With the salts available and at a pH of 5.0, metal

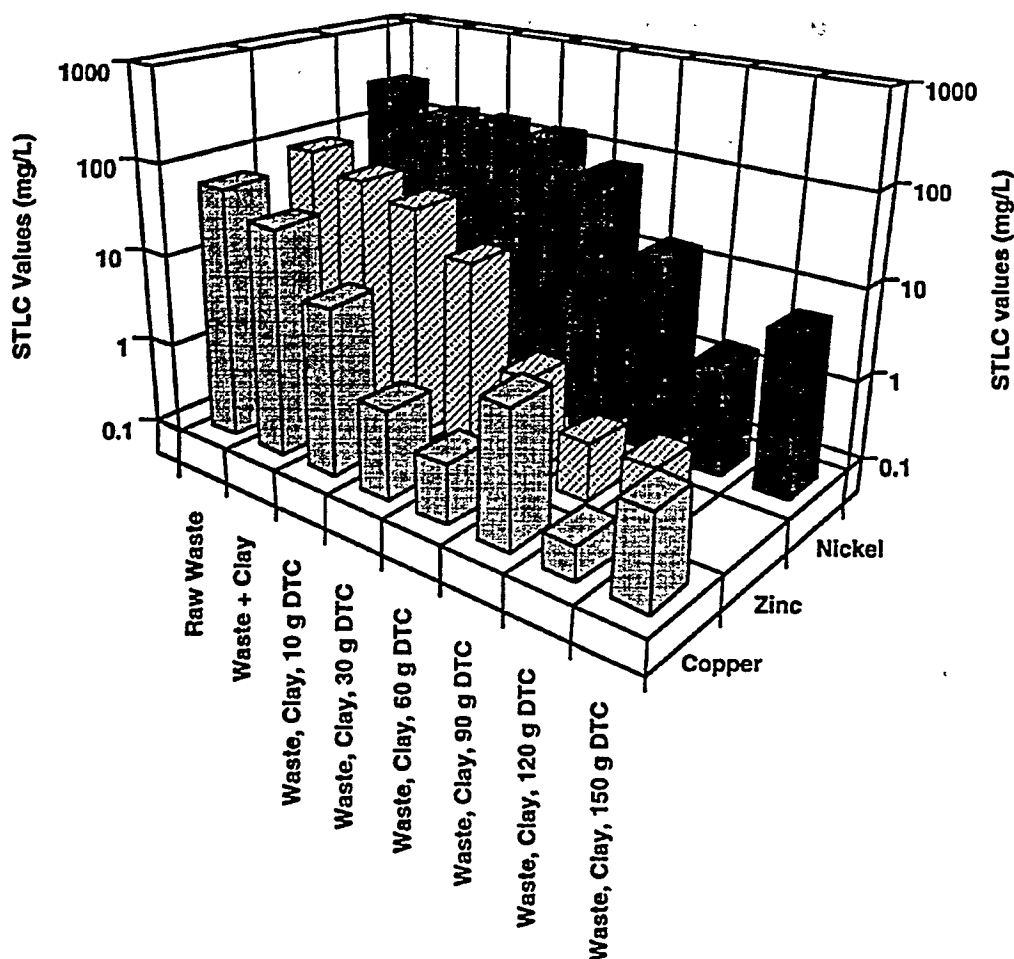


Figure 3. Comparisons of STLC Values for Various Concentrations of DTC, Raw Waste, and Stabilized Waste without Additives, Based on 1 Kg of Raw Waste.

hydroxide dissolves into the bulk extractant in the form of citrate or acetate salts and salt complexes. The addition of DTC at concentrations between 6% and 12% of the raw waste precipitates metals so that the clay matrix passes the STLC test.

ACKNOWLEDGMENTS

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MACROENCAPSULATION DEVELOPMENT AT PANTEX

Jeffrey S. Yokum
Battelle Pantex
P.O. Box 30020
Mail Stop T9-061
Amarillo, TX 79177

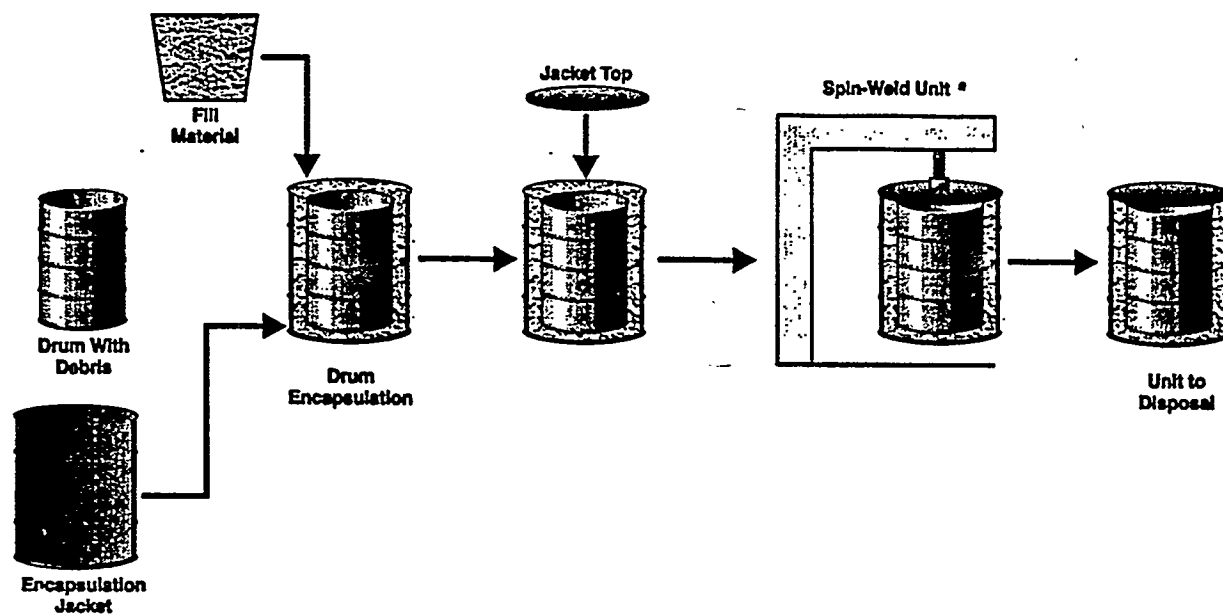
ABSTRACT

The Pantex Plant is developing an innovative skid-mounted macroencapsulation technology (called a mobile treatment unit, MTU) that will economically dispose low-level radioactive mixed waste debris. Pantex's macroencapsulation technology spin-welds a polyethylene top onto a polyethylene receiver to form a jacket that encapsulates a fifty-five (55) gallon steel drum of compacted low-level radioactive and mixed waste debris. The annulus formed by the fifty-five gallon drum and the polyethylene jacket is filled with a material (either foam or grout) to eliminate voids in the final waste form. The US EPA verified that the use of a polyethylene jacket constitutes macroencapsulation in a letter to Chemical Waste Management, Inc., dated September 19, 1995. The EPA letter stipulated that this treatment technology should not be used for D008, radioactive lead solids, and that the final waste form should be structurally sound and resistant to degradation.

MACROENCAPSULATION AT PANTEX

This paper briefly describes the macroencapsulation development project at the U.S. Department of Energy's Pantex Plant in Amarillo, Texas. The Pantex macroencapsulation project is being sponsored by the DOE Albuquerque Operations Office (DOE-AL) Mixed Waste Treatment Program and the DOE Amarillo Area Office (DOE-AAO).

Macroencapsulation is defined 40 CFR 268.45, Table 1, as "Application of surface coating materials such as polymeric organics (e.g., resins and plastics) or use of a jacket of inert inorganic materials to substantially reduce surface exposure to potential leaching media." Pantex plans to meet this treatment standard by developing a macroencapsulation technique that places a drum of compressed debris inside a polyethylene receiver (larger drum); fills the void space between the drum and receiver with grout or foam; and spin-welds a polyethylene top onto the receiver (figure 1).

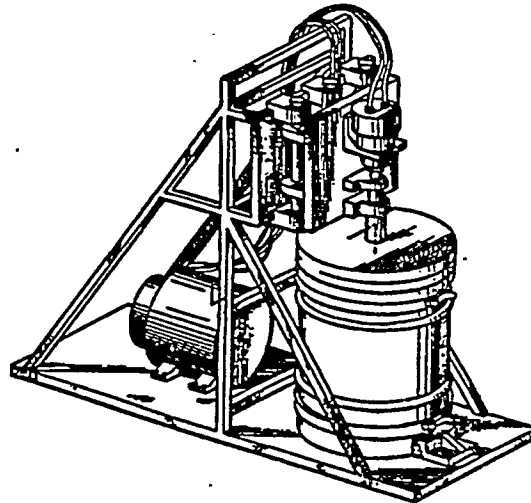


The US EPA verified that use of a polyethylene jacket (as shown in figure 1) constitutes macroencapsulation in a letter to Chemical Waste Management, Inc., dated September 19, 1995. The EPA letter stipulated that this treatment technology should not be used for D008, radioactive lead solids, and that the final waste form should be structurally sound and resistant to degradation.

Pantex reviewed several macroencapsulation technologies prior to selecting spin-welding. The technologies Pantex reviewed included: 1) Brookhaven's process (extrusion); 2) Rocky Flats' process (extrusion into a receiver containing debris); 3) preformed macroencapsulants (e.g., pipes, overpacks, specially designed receivers, etc.); 4) polybutadiene/polyethylene; and 5) coating/spraying processes. Pantex selected spin-welding based on state of technical development; ability to comply with regulatory requirement for debris; ability to meet waste acceptable criteria; ease of implementation; and life-cycle cost.

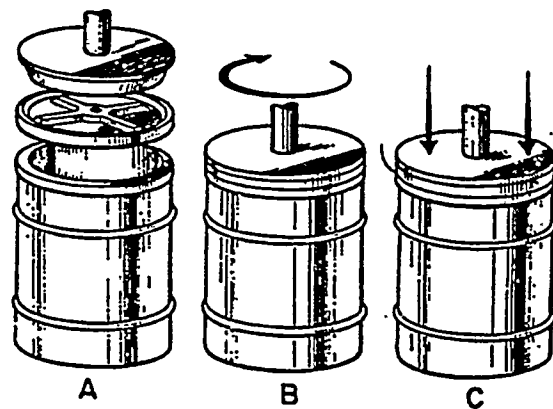
The spin-welding process selected by Pantex is based on a project that was conducted by the US EPA's Cincinnati Laboratory. The EPA project resulted in a United States patent, and a paid-up license for the US federal government. Pantex is using the federal government's license to develop spin-welding macroencapsulation technology on a production

scale. The spin-welding machine used by EPA (figure 2) is being obtained by Pantex to further investigate the procedures and materials required to implement the spin-weld macroencapsulation technique. The EPA machine will also be used to produce surrogate waste forms for testing and evaluation.



Spin-welding consists of rotating, and simultaneously pressing, a preformed polyethylene top onto a preformed polyethylene receiver to form a jacket around a 55-gallon drum. The friction between the rotating top and the fixed receiver generates sufficient heat to melt the polyethylene. After the rotational motion stops, the opposing welding surfaces cool and solidify to form a seamless weld joint (figure 3).

Pantex is currently issuing a contract for the development of a macroencapsulation machine based on the U.S. government's paid-up license. The mobile spin-weld macroencapsulation treatment unit being developed by Pantex will spin-weld a preformed polyethylene top onto an 85-gallon preformed polyethylene receiver to jacket a compacted 55-gallon drum of mixed debris. The void space between the 55-gallon drum and the 85-gallon polyethylene jacket will be filled with either cement or foam. The spin-welding process is computer controlled. Once loaded, the spin-welding macroencapsulation machine requires no operator intervention to achieve a reliable weld.



A unique attribute of the Pantex spin-welding process is the ability to spin-weld a 85 gallon jacket. Other macroencapsulation techniques are not capable of encapsulating an entire 55 gallon drum in one operation. The capability to encapsulate an entire drum in one operation means lower operating costs. It also appears that macroencapsulation, as described in this article, minimizes the expansion factor for treated debris, thereby lowering disposal costs.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy's Amarillo Area Office and Albuquerque Operations Office under U.S. Government Contract DE-AC04-91AL-65030.

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2. Letter from Mr. R. Kinch, Chief, Waste Treatment Branch, U.S. Environmental Protection Agency to Mr. K. Igli, Vice President, Environment, Health, and Safety, Chemical Waste Management, Inc., dated September 19, 1995.

PACKAGED LOW-LEVEL WASTE VERIFICATION SYSTEM

Kevin Tuite (WMG, Inc.), Michael R. Winberg, Charles V. McIsaac
Idaho National Engineering Laboratory
(914) 736-7100

ABSTRACT

The Department of Energy through the National Low-Level Waste Management Program and WMG Inc. have entered into a joint development effort to design, build, and demonstrate the Packaged Low-Level Waste Verification System. Currently, states and low-level radioactive waste disposal site operators have no method to independently verify the radionuclide content of packaged low-level waste that arrives at disposal sites for disposition. At this time, the disposal site relies on the low-level waste generator shipping manifests and accompanying records to ensure that low-level waste received meets the site's waste acceptance criteria. The subject invention provides the equipment, software, and methods to enable the independent verification of low-level waste shipping records to ensure that the site's waste acceptance criteria are being met. The objective of the prototype system is to demonstrate a mobile system capable of independently verifying the content of packaged low-level waste.

EXPEDITING THE COMMERCIAL DISPOSAL OPTION: LOW-LEVEL RADIOACTIVE
WASTE SHIPMENTS FROM THE MOUND PLANT

Susan Rice
Envirocare of Utah, Inc.
(801) 532-1330

Robert Rothman
US Department of Energy
Miamisburg Office

ABSTRACT

In April, Envirocare of Utah, Inc., successfully commenced operation of its mixed waste treatment operation. A mixed waste which was (a) radioactive, (b) listed as a hazardous waste under the Resource Conservation and Recovery Act (RCRA), and (c) prohibited from land disposal was treated using Envirocare's full-scale Mixed Waste Treatment Facility. The treatment system involved application of chemical fixation/stabilization technologies to reduce the leachability of the waste to meet applicable concentration-based RCRA treatment standards. In 1988, Envirocare became the first licensed facility for the disposal of naturally occurring radioactive material. In 1990, Envirocare received a RCRA Part B permit for commercial mixed waste storage and disposal. In 1994, Envirocare was awarded a contract for the disposal of DOE mixed wastes. Envirocare's RCRA Part B permit allows for the receipt, storage, treatment, and disposal of mixed wastes that do not meet the land-disposal treatment standards of 40 CFR (Code of Federal Regulations) 268. Envirocare has successfully received, managed, and disposed of naturally occurring radioactive material, low-activity radioactive waste, and mixed waste from government and private generators.

The DOE Mound site received an exemption to 5820.2A to ship Low Level Radioactive Waste (LLRW) to a commercial facility. Particularly noteworthy, shipping to the commercial facility was started only four (4) months from the date the exemption process was initiated. This paper will outline the process in which this was accomplished and also identify the benefits of shipping LLRW to a commercial facility. The benefits recognized by DOE included: 1) cost savings; and 2) time savings.

Envirocare of Utah, Inc. owns and operates a treatment and disposal facility in the west desert of Utah, approximately 75 miles west of Salt Lake City. This facility is capable

of managing Natural Occurring Radioactive Material (NORM), Low Level Radioactive Waste (LLRW), 11e.(2) Mill Tailing Byproduct Material (11e.(2)) and Mixed Waste for treatment and/or disposal. Operations began in 1988 with one square mile of land. The approximate capacity of the site ranges from 14-18 million cubic yards (13.8 million cubic meters). The life of the facility is estimated through 2015.

With the extensive capabilities of Envirocare, the federal government has taken advantage of utilizing the facility for management of their waste inventories. The Department of Energy (DOE), Environmental Protection Agency (EPA), and Department of Defense all have shipped large volumes of waste material to Envirocare. The process in which the federal government utilizes a commercial facility differs from agency to agency.

The DOE-Miamisburg (DOE-MB) office at the Mound Plant, expedited the system in receiving an exemption from the DOE headquarters office to ship LLRW to Envirocare. The whole process of preparing an exemption, submitting the exemption to DOE headquarters, approval of the exemption from DOE headquarters, profiling the waste, and shipping the first shipment to Envirocare was completed in less than four (4) months.

The first step in preparing the exemption request to the DOE Order 5820.2A which states DOE LLRW must be disposed of at DOE facilities, DOE-MB submitted a written exemption request to EM-30. This request highlighted the economic rationale for the exemption. DOE-MB stated, "With budget cuts continuously eroding our programs, it is essential that we find efficient and business-wise alternatives to fulfill our mission." DOE-Miamisburg performed a cost analysis that compared shipments from Mound to a DOE facility with shipments from Mound to Envirocare.

The next steps in the process were the submittal and approval of the exemption request. These steps proved to be very critical in the overall process. DOE-Miamisburg facilitated the approval process by doing two things; 1) DOE-Miamisburg program counterpart at DOE Headquarters had effectively informed DOE-EH key personnel of DOE-MB's desire and need to ship waste to an existing commercial waste disposal site; and 2)

DOE-MB “walked” the exemption request through the approval chain and was present to immediately address questions and concerns. The exemption request focused on cost and time savings.

Profiling the waste for acceptance at Envirocare upon receipt of the exemption approval came next. This process included collecting samples, analyzing the sample results, completing and submitting Envirocare’s profile forms. The essential issue in this step was the close communication between DOE-MB and the disposal facility, Envirocare. “Face-to-face” meetings and continuous communication resulted in reducing the time needed to complete the profiling process. This allowed for expedited approval to ship of waste material for disposal that met Envirocare’s license conditions.

The exemption given by DOE Headquarters (DOE-HQ) allowed DOE-MB to commercially dispose of 70,000 cubic yards of soil and debris and 6,000 drums of solidified operations waste. Criteria required to be met under the exemption prior to shipment of any waste material included:

1. preparation of appropriate NEPA documentation;
2. preparation of manifests for waste shipments;
3. preparation of appropriate procurement or contracting documents;
4. review of permits, licenses, approvals, and regulatory records of the proposed disposal facility;
5. waste shall be accurately characterized to ensure acceptance within license limits of prospective disposal facility;
6. notification of waste type, volume, and destination to Waste Management’s Program Integration Division, EM-33, prior to beginning the shipping campaign;
7. confirmation of the regulatory status of facility; and
8. periodic reviews/audits of the commercial facility to be conducted. These reviews/audits can be referenced to a similar effort by another DOE entity.

As previously stated, an economic analysis was performed to identify the costs of shipping waste to Envirocare, a commercial facility, versus a DOE disposal site. The major categories were also presented where potential differences in cost or time could be expected. DOE-MB used the scheduled Miami-Erie Canal (OU4) remediation as a model in analyzing the cost comparisons at a potential volume of 26,520 cubic yards. The detailed items outlined in the analysis included transportation modes, i.e., truck and rail, types of containers to be used, characterization/sampling of waste, material handling, container preparation, and disposal.

Four (4) options were reviewed: 1) truck to DOE disposal facility; 2) truck to Envirocare; 3) rail to Envirocare (upgrade existing rail spur); and 4) rail to Envirocare (construct new rail spur). The highest cost option was truck to a DOE disposal facility at a total approximate cost of \$19 million. The most cost-effective option was rail to Envirocare (new rail spur) at a cost of approximately \$9 million.

The major differences in cost resulted in the container, characterization, transportation and disposal categories. DOE-MB is limited to shipping only 100 ft³ boxes to the DOE disposal facility at \$500/box. Envirocare is licensed to receive drums, boxes, supersacks, and bulk shipments. DOE-MB's cost for a supersack is \$30/bag. The potential cost savings to be realized by DOE-MB regarding the containers is over \$3 million.

Characterization criteria for the DOE disposal facility differs from Envirocare criteria for acceptance of waste material into the facility. DOE-MB must provide extensive characterization and sampling data to the DOE disposal facility. The Envirocare facility's characterization requirements are not as extensive and therefore, require less cost for DOE-MB when characterizing waste to Envirocare. The cost comparisons show a difference of approximately \$703,544.

DOE-MB is limited to shipping waste material by truck when shipping to the DOE disposal facility. With the amount of waste material projected, this estimate for truck shipments is \$4,455,360. DOE-MB, when shipping to Envirocare, has the option of

shipping the waste material by rail car. This option is more economical at an estimated cost of \$2,600,367. The cost difference between the truck option versus the rail option is \$1,854,993.

Lastly, the disposal cost comparison between the DOE facility and Envirocare showed a potential cost savings of \$3 million. With the unit disposal cost per cubic foot of waste lower than the DOE disposal facility, the commercial disposal option served as the most economical option for the subject remediation.

The commercial option will benefit DOE-MB in the following ways:

1. approximately \$10 million of cost savings for a single remediation;
2. move waste material offsite in a shorter timeframe;
3. meet deadline for the "DOE to private sector" transition;
4. maintain continuous shipping schedule;
5. minimize long-term health and safety concerns;
6. satisfy stakeholders;
7. minimize costs for reviews/audits, continued onsite storage, and related delays;
and
8. satisfy regulators by obtaining another disposal option.

In summary, the DOE-MB researched the available options for the disposal of the Mound Plant's OU4 low level radioactive waste remediation. This process was performed to identify the most cost-effective and the most timely option in completing the OU4 remediation. The result of their research indicated use of a commercial disposal facility, Envirocare of Utah, Inc., would be the best option. Through an economical analysis, DOE-MB showed the commercial option would meet the immediate needs of the Mound Plant, DOE-Miamisburg., and DOE-Ohio and also potentially save \$10 million. This selection generated the need for an exemption approval to DOE Order 5820.2A. DOE-MB prepared the exemption request, received approval from DOE-HQ, and shipped the first waste shipment to Envirocare all within a four (4) month timeframe.

ALTERNATIVE DISPOSAL OPTIONS FOR ALPHA-MIXED LOW-LEVEL WASTE

G. G. Loomis and M. J. Sherick
Idaho National Engineering Laboratory
P.O. Box 1625
Idaho Falls, Idaho 83415-3710
(208) 526-9208, (208) 526-6802 Fax

ABSTRACT

This paper presents several disposal options for the Department of Energy alpha-mixed low-level waste. The mixed nature of the waste favors thermally treating the waste to either an iron-enriched basalt or glass waste form, at which point a multitude of reasonable disposal options, including in-state disposal, are a possibility. Most notably, these waste forms will meet the land-ban restrictions. However, the thermal treatment of this waste involves considerable waste handling and complicated/expensive offgas systems with secondary waste management problems. In the United States, public perception of offgas systems in the radioactive incinerator area is unfavorable. The alternatives presented here are nonthermal in nature and involve homogenizing the waste with cryogenic techniques followed by complete encapsulation with a variety of chemical/grouting agents into retrievable waste forms. Once encapsulated, the waste forms are suitable for transport out of the state or for actual in-state disposal. This paper investigates variances that would have to be obtained and contrasts the alternative encapsulation idea with the thermal treatment option.

INTRODUCTION

This paper presents several disposal options for the Department of Energy alpha-mixed low-level waste (AMLLW). The AMLLW contains 10–100 nCi/g of transuranic contamination and was primarily generated by the Rocky Flats Plant. There is presently no disposal option for this waste; however, the mixed nature of the waste favors the thermal treatment option resulting in iron-enriched basalt or glass encapsulation of the main contaminants. The popularity of the final waste form is well-founded in that much of the hazardous material is destroyed during the process, and the other particulate contaminants are "locked up" in a glass matrix that has natural analogs considered geologically stable.

Melter design and offgas systems are being examined to process much of the transuranic waste, including the AMLLW. Even though this plan of attack is under way,

there exists a potential problem for the thermal treatment option that may render it unworkable, and that is one of public acceptance of radioactive offgas systems. Because of this uncertainty, it behooves the DOE complex to have alternatives available for consideration.

As an example, at the Idaho National Engineering Laboratory (INEL) alone in above ground storage there is about 36,000 m³ of transuranic waste commingled with 24,000 m³ of alpha low-level waste containerized in 55-gal drums and 4 x 4 x 7-ft boxes. The primary contaminants are micron-sized particles of plutonium/ameridium oxide intermingled with cutting oils and volatile organic solvents. Retrieval and segregation of this waste is currently under way as a waste management operation, with the material assayed as transuranic slated for ultimate disposal at the Waste Isolation Pilot Plant.

However, the AMLLW has no identified disposal option. Without an identified disposal option, costly temporary interim storage is required. Even though the interim storage capability is currently under construction, long-term management of this material in interim storage is also costly.

The thermal treatment option is strongly recommended for treatment of this class of waste by special crosscutting task forces involving all phases of DOE's Environmental Management. Unfortunately, the costs associated with the thermal treatment options are expensive (up to \$16,000/ton).¹ Because of the cost and the potential problems with public acceptance of offgas systems, it behooves the DOE complex to aggressively pursue cheaper disposal options that can be instituted in a timeframe at least commensurate with the transuranic waste disposal option. This paper presents several alternatives for the AMLLW.

This work builds on work done for alternative options for retrieved buried transuranic waste as well as stored transuranic waste at the INEL and represents a collaborative effort between the DOE Office of Technology Development and Waste Management. This paper focuses on nonthermal disposal options applicable for both out-of-state or in-state disposal.

NONTHERMAL DISPOSAL OPTION

The concept of disposing of stored AMLLW is technically feasible, and by imposing improved confinement techniques to the waste along with simple shallow-land burial, the concept can gain public acceptance.

Previous work on potential disposal of AMLLW at the INEL² claims that siting the AMLLW in shallow-land burial can meet the performance assessment for final waste forms, including glass, iron-enriched basalt, and some forms of cementation encapsulation. In that study, two locations for internment of the encapsulated waste were considered, including one site near the present Radioactive Waste Management Complex and Well Site 14 at the central part of the INEL. Simultaneously, the INEL Environmental Restoration Program is performing risk assessments that show E-6 additional cancer deaths for leaving the buried transuranic waste in the current shallow-land burial with some improved confinement.¹ At E-6 additional cancer deaths, the "no action" alternative or, in this case, leaving the waste buried in shallow-land burial is considered a viable option in the Record of Decision.

Buried waste at the INEL is approximately equal in volume and consistency to the stored waste; therefore, addition of the AMLLW to the currently buried waste increases the source term by less than a factor of 2. It is therefore technically defensible to consider disposal of the stored AMLLW in Idaho at the INEL; however, by improving the confinement and providing an in-depth safety factor, public acceptance can be enhanced.

It is not clear at this time whether improved in-state disposal will have more public acceptance than thermal treatment at the INEL and out-of-state disposal. That question should be explored by decisionmakers, including members of the public, at early stages of decisionmaking. What follows are details of the in-state disposal option.

¹Personal communication with Doug Kuhns, manager of the Environmental Restoration Program transuranic pits and trenches.

The in-state disposal option involves using encapsulating techniques developed by the Office of Technology Development for buried transuranic waste disposal. These techniques were developed for subsurface application in buried wastes for in situ disposal of transuranic waste but apply equally to stored AMLLW. This option involves creating retrievable monoliths by encapsulating and agglomerating the waste with materials that have natural analogs and are chemically compatible with the surrounding environment.

The monoliths are placed in shallow-land burial and covered with a simple clay cap meeting dose-limit requirements.² On top of the cap will be placed an intruder cap consisting of large-diameter (greater than 1.22 m mean diameter) basaltic cobble. The basaltic cobble layer renders the waste disposal site unsuitable for residential and farming use, and the monolithic structure of the waste seam itself is immune from subsidence. A society capable of removing 1.22-m-diameter cobble for future building material will be capable of deciphering universal warning symbols on top of the waste material. This waste disposal option has no secondary waste stream as will occur with the thermal treatment option.

For this option, the stored waste is first homogenized using the demonstrated CRYOFRACTURE shredding technique.³ In this process, the waste is frozen to liquid nitrogen temperatures, brittle fractured, and sheared. A test matrix, in which typical Rocky Flats waste material in 55-gal drums and in 2 x 2 x 8-ft boxes were shredded with the CRYOFRACTURE technique, resulted in a mean size of debris described as follows: 76-94 wt% of the debris fell through a 3-in. screen and 97-100 wt% of the debris fell through a 6-in. screen.³

The advantages of using the CRYOFRACTURE technique over the conventional shredders⁴ is the inherent contamination control aspects of the cryogenic process, in that it agglomerates the particles together into larger particles that are not easily aerosolized. In addition, the ultracold temperatures associated with the cryogenic techniques (-320°F) eliminate the potential for fire and explosion during the shredding process that is assumed to be required for the thermal process. Also, the volatile organic material in the AMLLW will

be rendered to the solid phase during the cryofracture operation and therefore is not prone to volatilization.

Next, the homogenized waste is blended with a chemical or grouting agent and poured into movable retrievable shapes. The material is formed into convenient-sized blocks for creating a monolith. In this manner, the waste is stabilized against subsidence and packed into a retrievable matrix mimicking a naturally occurring mineral or material that is stable in a wide range of expected climatic conditions. Finally, the top soil and intruder cap are installed with local materials.

Nonthermal plastic grouting agents that are of interest to the Technology Development Office buried waste work are classified as either cementation grouts, organic polymers, inorganic polymers, or blends of these materials. Some of these materials are thermal-setting or high heat of hydration reactions but are generally less than 240°F. Preliminary criteria for the grouting materials have been developed by the Landfill Focus Area, and a list of potential encapsulating agents are being evaluated against the list.

The list of grouting agents currently includes the following materials:

CEMENTATIONS GROUTS: Portland Type 1 (neat-1:1 by wt. water/Portland), plasticized latex cement developed by Brookhaven National Laboratory, INEL-developed iron-oxide solutions to form Hematite, Pacific Northwest Laboratory-developed phosphoric solutions to form apatite, TERRAN-developed solutions to form calcite, INORGANIC POLYMERS: Polysiloxane (PSX-10-Dow Corning) to form a flint-like material, Ludox-Dupont to also form a flint-like material, ORGANIC POLYMERS: Acrylic developed by 3M with a natural analog of amber, proprietary materials developed by HELO and Ernie Carter (KEI, Inc. in Houston), and Montan Wax (Romanta Amsdorf in Germany).

Preliminary criteria for this material include (1) the grout must have low enough viscosity to be jet groutable, (2) the resulting soil/waste/grout matrix must have a resulting hydraulic conductivity of $E-7$ cm/s, (3) the soil/waste/grout matrix must be retrievable, (4) the soil/waste/grout matrix must be chemically stable and the hazardous materials must be

compatible with the grouting agent, (5) the grout must have a natural analog or be demonstrated to surpass a similar natural analog based on durability studies, (6) the material must result in compressive strengths at least 50 psi and may be as high as 800 psi. Materials already examined by the Landfill Focus Area for the transuranic pits and trenches include Portland cement,⁵ Hematite,⁶ and acrylic polymer.⁷

As an aside, the same process can be applied to the waste for out-of-state disposal, most likely at the Nevada Test Site in shallow-land burial.

The identical process for forming the monoliths will be applied to the waste; however, the material will be placed in inexpensive polyethylene boxes. These boxes could be shipped via common carrier or train to a DOE-approved disposal site. The most likely disposal site for this material is the Nevada Test Site, in that ground water is not a concern at that site.² The waste would be shipped in about five escorted convoys involving the state police, national guard, and U.S. military as escorts.

To save operating costs and provide a reasonably manageable program that does not span multiple presidential elections, the waste would be shipped to the disposal site within 5 years. One report claims that glass and cementation waste forms meet the performance criteria at the Nevada Test Site.² The usual problems associated with politics will render this idea on hold until there is a national push at the presidential/congressional level to solve the disposal site issues.

An alternative to the Nevada Test Site is the Waste Isolation Pilot Plant near Carlsbad, New Mexico. The politics of opening that system for the stored transuranic waste have been intense and compromises may be required to limit the waste to the original amount—the stored transuranic waste only. The actual out-of-state disposal option is beyond the scope of this paper; however, presumably, the option at Nevada would involve shallow-land burial of the retrievable waste forms created in Idaho, and the option at the Waste Isolation Pilot Plant would create more drifts in the salt matrix and simply place the waste in the drifts.

WAIVERS ARE REQUIRED

The proposed nonthermal disposal option for the AMLLW does not meet all the treatment requirements specified by the Resource Conservation and Recovery Act (RCRA) for hazardous waste. Specifically, this approach would not satisfy the treatment criteria established in the Land Disposal Restrictions, which require that the hazardous components of the waste be reduced below certain concentration limits or that the treatment be accomplished using the best demonstrated available technology. Therefore, in order to implement this option, a variance or waiver would have to be obtained from the regulatory authorities (U.S. Environmental Protection Agency and State of Idaho Department of Environmental Quality).

There are two alternatives for variances provided by RCRA: (1) a "No-Migration" Petition, and (2) a "Delisting" Petition (delisting the hazardous waste to lift the requirements imposed by the Land Disposal Restrictions).

The No-Migration Petition is a waiver that allows disposal of RCRA hazardous waste that has not been treated to Land Disposal Restrictions. In order for the No-Migration Petition to be granted, the applicant must show that in the particular environmental setting, the contaminants in question will not migrate outside the boundaries of the disposal facility.

A Delisting Petition allows for a "listed" hazardous waste, as defined by RCRA, to be exempt from regulation under RCRA. In order for a Delisting Petition to be granted, the applicant must show that the reason the contaminant in question was listed as being hazardous under RCRA is no longer valid/applicable to that particular waste stream.

Waivers will have to be obtained for the volatile organic compounds, transuranics, and heavy metals. However, there are circumstances that affect migration of these materials: (1) volatile organic compounds have a short half-life in nature due to microbial attack and evaporative loss, (2) there is no known migration mechanism for the insoluble plutonium/americiu particulates through the surrounding soils or in the inner-bed soil

sandwiched between basaltic flows below the disposal site, (3) many of the proposed encapsulating agents tend to capture and hold heavy metals and transuranics. In addition, the region has proved hostile to agricultural use and is currently uninhabited.

Basically, when making the final decision on which option to approach for disposal of AMLLW, the public acceptance of offgas systems will have to be weighed against the difficulties of obtaining RCRA waivers. In the environmental arena, there is a tendency toward more cost-effective risk-based decisions. The cost of making offgas systems acceptable to the public may outweigh the difficulties of obtaining RCRA waivers.

CONCLUSIONS

Implementing ideas offered in this paper would require changes in thinking about acceptable waste forms, performance assessments, and disposal sites. Additionally, special waivers would be required to place encapsulated mixed waste in the ground. This paper was not meant to criticize the thermal treatment option; rather, it was designed to stimulate thinking by offering alternative ideas in the eventuality that the thermal treatment option cannot be realized for either financial or political reasons.

It is concluded that there are a multitude of encapsulating materials that have natural analogs and are chemically compatible with the waste material as well as the surrounding geology. In addition, there are no substantive technical problems for disposal at either the INEL or out-of-state sites because of the long-term encapsulating nature of the material.

As with any new technology, technical issues would have to be addressed. Some of these issues may include hydrogen generation in the matrix caused by radiolysis, and integrity of the waste material caused by plutonium recoil. However, by applying an in-depth encapsulation approach with capping and armored barriers, these issues may be rendered moot.

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FEATURES, EVENTS, PROCESSES, AND SAFETY
FACTOR ANALYSIS APPLIED TO A NEAR-SURFACE LOW-LEVEL RADIOACTIVE
WASTE DISPOSAL FACILITY

M.E. Stephens,* G.M. Dolinar, B.A. Lange, and J.H. Rowat
Waste Management and Decommissioning
Atomic Energy of Canada Limited (AECL)
Chalk River, Ontario
Canada, K0J 1J0
(613) 584-3311

ABSTRACT

An analysis of features, events, processes (FEPs) and other safety factors was applied to AECL's proposed IRUS (Intrusion Resistant Underground Structure) near-surface LLRW disposal facility. The FEP analysis process which had been developed for and applied to high-level and transuranic disposal concepts was adapted for application to a low-level facility for which significant efforts in developing a safety case had already been made. The starting point for this process was a series of meetings of the project team to identify and briefly describe FEPs or safety factors which they thought should be considered. At this early stage participants were specifically asked not to screen ideas. This initial list was supplemented by selecting FEPs documented in other programs and comments received from an initial regulatory review. The entire list was then sorted by topic and common issues were grouped, and issues were classified in three priority categories and assigned to individuals for resolution. In this paper, the issue identification and resolution process will be described, from the initial description of an issue to its resolution and inclusion in the various levels of the safety case documentation.

INTRODUCTION

AECL is proposing to construct a near-surface low-level radioactive waste (LLRW) disposal repository called the Intrusion Resistant Underground Structure (IRUS) at its Chalk River Laboratories (CRL) in Chalk River, Ontario. IRUS is a below-ground reinforced concrete vault that will receive about 1900 m³ of baled and bitumenized CRL LLRW. More details on the IRUS facility and site can be found in the 1994 proceedings of this same conference.¹

*person to whom correspondence should be addressed

In seeking a construction licence from the Atomic Energy Control Board (AECB, the national nuclear regulatory authority in Canada) to build IRUS, AECL is preparing a safety case called the IRUS Preliminary Safety Analysis Report (PSAR). To guide preparation of the PSAR, the IRUS Project Team carried out a safety issue analysis, a systematic process for identifying and evaluating the issues that are important to the level of safety IRUS will provide. The process used for the analysis is derived from a scenario analysis procedure developed by Sandia National Laboratories for a transuranic disposal project,^{2,3,4} and drew on studies for the Swedish used fuel disposal program^{5,6,7} and the Canadian Nuclear Fuel Waste Management Program⁸ on fuel waste disposal, and an expert group report for the OECD Nuclear Energy Agency.⁹

The analysis was broadened beyond the considerations usually examined in scenario analysis to include not only the physical features, events and processes (FEPs) that could impact on the safety provided by IRUS, but also more generic issues such as the impact of modelling assumptions, which have not generally been considered as FEPs.

As a result of the analysis, safety issues have been treated in a comprehensive manner in the PSAR and substantial information has been generated in support of the safety case. This paper will present some of the details of the process that was followed and review how these issues were included in the safety case.

ROLE OF THE SAFETY ISSUE ANALYSIS IN PREPARING THE IRUS PSAR

IRUS will be subject to the influence of numerous interacting FEPs and other factors which can be best assessed with a systematic process. FEPs include the evolving characteristics of the engineered repository and its natural surroundings, perturbing external or internal events that might occur, and human and non-human biota that might disturb the repository or be affected by the waste it contains. Performance of disposal facilities are commonly assessed by examining identified FEPs both individually, and together as the elements of an integrated disposal system.

In addition to the FEPs, other safety related factors may also be important to the acceptability of the estimated level of safety IRUS will confer. Such factors include:

- Deviations of the real facility from the reference design evaluated in the performance assessment (e.g., different placement of the waste, different characteristics of the concrete in the vault walls and roof, emplacement of backfill and buffer material);
- Limitations of the methods and modelling used in the performance assessment (e.g., applicability of assumptions and models).
- Evolution of regulatory requirements.¹⁰

AECL staff working on the IRUS project felt that considerations such as those listed above as well as FEPs should be examined in building the safety case for IRUS. The FEPs and these additional considerations were together termed safety issues to be addressed in the PSAR and its supporting documentation.

It was deemed essential to use a systematic approach in identifying and evaluating safety issues, to give confidence that all the issues significant to safety had been identified and that each had been dealt with appropriately. The approach that was adopted for the issue analysis addresses:

- The large number of diverse and interacting factors that may influence the closed vault and its surroundings;
- The extended period of time over which IRUS performance must be assessed to meet AECB requirements;¹¹
- The need to define clearly the scenarios to be evaluated with the integrated system models.

- The fact that different tools would be employed to address different issues, the results of which would then need to provide a coherent, comprehensive evaluation of IRUS performance. The different levels of analysis were expected to include:
 - the use of integrated system model codes (NSURE and GENII), for calculating the impact of releases to groundwater and of human intrusion into the vault;
- separate calculations on specific issues such as releases from IRUS to the atmosphere, and releases in groundwater to a nearby swamp;
- qualitative evaluations of the significance to safety of diverse events such as meteorite strikes, or impacts of artillery shells from the nearby Canadian Forces Military Base.

The process employed to carry out the IRUS safety issue analysis consisted of four steps:

- 1) List the safety issues considered potentially important to IRUS performance;
- 2) Screen the issues to judge their significance to safety, and decide on an appropriate approach and the tools to use in addressing each issue;
- 3) Sort the issues as to where they should be dealt with in the documentation for the entire IRUS Project (e.g., the PSAR or its supporting documents, or the Final Safety Analysis Report (FSAR) to be submitted to the AECB before waste is emplaced into IRUS);
- 4) Document the disposition of each issue.

METHODS AND RESULTS OF THE SAFETY ISSUE ANALYSIS

The following sections provide some details on how the individual steps in the process were carried out and discusses the results of this analysis in terms of the number of issues streamed into the various categories.

List the Safety Issues Considered Potentially Important to IRUS Performance

Significant efforts had already been made in developing a safety case for IRUS before this safety issue analysis was started.^{12, 13} The information from this earlier work was incorporated into the analysis. The initial work on the detailed safety case provided the project team with a good understanding of the system definition and was therefore very beneficial to the FEP process.

A workshop was held to introduce to the IRUS Project Team the prior work on scenario analysis in the Canadian Nuclear Fuel Waste Management Program (CNFWMP) for the postclosure assessment of the fuel waste disposal concept.⁸ Lessons learned about the practicality of applying scenario analysis were reviewed, as were the implications of the different scopes of the two projects - the CNFWMP scenario analysis was for a scoping assessment of a disposal concept, whereas the IRUS team's analysis would be for the specific IRUS design and site in support of a licensing application. The ensuing brainstorming session identified 219 FEPs for the IRUS disposal system.

This initial collection of issues was supplemented by selecting FEPs documented in other programs,^{5, 6, 7, 8, 9} as well as AECB comments on an earlier safety document on the project.¹³ Some 351 safety issues were identified related to IRUS performance following closure, plus 69 issues related to public and worker safety during the operational phase of waste emplacement in IRUS. Over the following three months, seven half-day meetings of the Project Team were devoted to clarifying the intent of each of the 351 post-closure issues.

Screen the Issues

The next step in this process was to screen the issues by judging their significance to safety, and to decide upon an appropriate approach and the tools to use in addressing each issue.

As a result of this extensive review, 46 of the 351 issues were set aside as being physically unreasonable. The remaining issues were consolidated into 148 more broadly defined issues. Each of the 148 issues was then classified as either:

- **WRE** - originating in the characteristics of the waste or repository;
- **NP** - resulting from natural phenomena that might occur in the disposal system, or
- **HA** - connected with human activities involved in the IRUS Project (including the performance assessment itself).

The 148 issues were cross-referenced to the NEA and CNFWMP classification schemes, and where possible they were cross-referenced to the comments received from the AECB on the earlier version of the PSAR. In addition the description of, and approach to dealing with each issue were scoped out, so that a reasonably well-defined work package could be assigned to individuals or teams for resolution.

Set Priorities

Each of the 148 issues was assigned a level of priority for resolution in the PSAR, depending on its judged importance to safety, the feasibility of significantly improving existing knowledge, and the total effort available. As part of this same step the issues were sorted as to where they should be dealt with in the documentation for the IRUS Project.

Priority A To be addressed in the PSAR or its supporting documents, because it may affect the design and construction of IRUS or the issue has been raised by the

AECEB, or the FEP has sufficient technical importance that it must be addressed now;

- B** Important, but not needing to be addressed in the PSAR (FEP document or supporting document), but some effort was required to resolve the issue;
- C** Not of sufficient importance to address beyond a few quantitative, convincing, and definitive paragraphs in a PSAR supporting document describing the FEP and safety issues analysis.¹⁴
- C+** (An interim classification) Requiring further discussion with other experts to see if the issue warrants being treated as an A, B, or C.

Document the Disposition of Each Issue

One of the important elements in this process was the ability to document the disposition of issues. To this end a table was produced which includes the final list of issues, the priority assigned to each issue, the lead person assigned to deal with it, and the results of the actions taken on the issue. For the safety issues classified as priority "A", which are to be discussed in the PSAR itself, a reference is also given to the section of the PSAR where the primary discussion of the issue appears.

In the case of priority B and C issues, primary discussion of the issue occurs within the FEP documentation itself.¹⁴ Two priority C+ were eventually classed as priority A issues, and are discussed in the PSAR. The remaining 16 C+ priority issues were treated as C priority issues.

CONCLUSIONS

The safety issue analysis for IRUS included not only an examination of the physical features, events and processes that could impact on the safety provided by the facility IRUS, but also more generic issues such as the impact of modelling assumptions, which have not generally been considered as FEPs.

The safety issue analysis process proved to be a useful technique for developing- assembling a comprehensive list of factors which require consideration within the safety assessment. One of the results of this process is the development of a set of FEPs, issues and factors applicable to near surface LLRW disposal. Secondly, the process also proved useful for setting priorities and determining and defining suitable work packages which aided resolution. Finally, the process also enabled the tracking of the issues, from their identification to the documentation on their resolution.

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EXITING RCRA SUBTITLE C REGULATION DATA SUPPORTING A NEW
REGULATORY PATH FOR IMMOBILIZED MIXED DEBRIS

Craig L. Porter
Jetseal, Inc.
P.O. Box 50186
Idaho Falls, ID 83405-0186
(208) 529-3006

Susan D. Carson and Wu-Ching Cheng
Sandia National Laboratories
P.O. Box 5800, MS 0720
Albuquerque, NM 87185-0720
(505) 845-8713

ABSTRACT

This paper presents analytical and empirical data that provide technical support for the position that mixed debris (debris contaminated with both radioactive and hazardous constituents) treated by immobilization in accordance with 40 CFR 268.45 can exit RCRA Subtitle C requirements at the time the treatment is complete. Pathways analyses and risk assessments of low-level waste and RCRA mixed waste disposal facilities show that these two types of facilities provide equivalent long-term (> 100 years) performance and protection of human health and the environment. A proposed two-tier approach for waste form performance criteria is discussed.

INTRODUCTION

As a result of the Final Rule on Hazardous Debris (Debris Rule) promulgated by the Environmental Protection Agency (EPA) as part of the Phase I Land Disposal Restrictions (LDR) rule, hazardous debris treated by an extraction or destruction technology is allowed to exit RCRA control, provided that the treated debris does not exhibit a characteristic of hazardous waste (57 FR 37222, August 18, 1992). At the time the Debris Rule was enacted, the EPA chose not to allow debris treated with an immobilization technology to exit RCRA Subtitle C controls. The rationale for this was the concern that, absent Subtitle C management, contaminants might migrate from immobilized debris at levels that could pose a hazard to human health and the environment (57 FR 37240). However, the EPA indicated that it would reopen and request comment on whether immobilized debris should be excluded

from Subtitle C regulations as part of the Phase II LDR rulemaking (58 FR 48144, September 14, 1993).

To provide technical justification for the proposal that immobilized mixed low-level debris disposed of in a low-level waste (LLW) disposal facility is protective of human health and the environment (absent Subtitle C controls), five fundamental questions must be considered:

- 1) What is the nature of the debris to be immobilized?
- 2) What is the level of protection afforded by immobilization?
- 3) Can final waste form performance criteria be specified such that immobilized debris presents a minimum risk to human health and the environment?
- 4) What is the performance of a LLW disposal facility that meets the performance criteria of 10 CFR 61 or Department of Energy (DOE) 5820.2A relative to that of a RCRA Subtitle C facility?
- 5) For debris, does the combination of immobilization and a regulated LLW disposal facility provide protection to human health and the environment that is at least equivalent to the protection afforded by a RCRA Subtitle C facility?

These questions are addressed in the remaining sections of this paper.

MIXED WASTE DEBRIS

The nature of mixed waste debris is independent of whether it is generated commercially or by DOE. The volume of commercial mixed debris is a small fraction of the DOE inventory. Therefore, this section uses data from the large volume of DOE mixed debris to describe the composition of mixed waste debris.

The total existing and projected (5 years) DOE debris inventory is approximately 45,000 cubic meters.^a Of this total approximately 27,000 cubic meters is considered to be inorganic or heterogeneous (contains both inorganic and organic components) debris that can be treated via immobilization. However, these numbers represent only a small portion of the mixed low-level debris that is expected to be generated, since the majority of the hundreds of nuclear facilities scheduled for decontamination and decommissioning (D&D) are not slated for D&D until after the 5-year projection period. It is reasonable to expect that long-term mixed waste debris volumes could be an order of magnitude higher than the current 5-year estimate.

Nearly 90% of DOE mixed heterogeneous debris is predominantly inorganic, and approximately 80% of mixed inorganic debris is metal debris. Based on process knowledge, the major hazardous contaminants are the characteristic toxic metals chromium, cadmium, lead and silver and surface contamination residues of organic solvents. About 60% of DOE mixed low-level debris contains both D and listed waste codes; therefore, even if the waste form passed the Toxicity Characteristic Leaching Procedure (TCLP), under existing regulations it could not exit RCRA management. Less than 0.06% of this waste contains waste codes other than those for metals or F-listed solvents. The volatility of standard solvents such as acetone, benzene and chlorinated hydrocarbons, coupled with the requirement of DOE Order 5820.2A that liquids must be "- 0.5% of the waste processed to a stable form" (5820.2A III3.i.(5)(b)), ensures that organic solvent residues are only incidentally present as residual surface contamination in DOE mixed low-level debris that would be immobilized. Because the long-term risk from RCRA contaminants in immobilized mixed debris lies with the toxic metals, not the organics, the following discussion analyzes the ability of micro and macroencapsulation materials to successfully contain toxic metals, absent Subtitle C management. These are generally present as part of alloys such as stainless steel, as protective coatings, or as fines and residue in media such as filters and process equipment. Metals present as part of alloys or protective coatings are essentially inert and

a. Quantitative data on mixed low-level debris are based on waste stream volumes taken from the March 1995 update of the Mixed Waste Inventory Report (MWIR) database.

will not readily leach out. From process knowledge, metals fines and residues in immobilized debris are present in low concentrations. Therefore, the hazards associated with the RCRA constituents of immobilized mixed debris can reasonably be assumed to be small relative to the radiological hazard.

PROTECTION PROVIDED BY DEBRIS IMMOBILIZATION

Technologies for immobilization/encapsulation of solids can be classified as either microencapsulation or macroencapsulation, depending on whether the encapsulant is interspersed with the waste (microencapsulation) or only surrounds the waste (macroencapsulation). Although the EPA currently recognizes polymeric organic materials as acceptable macroencapsulating agents and only Portland cement and lime/pozzolans (fly ash and cement kiln dust) as acceptable microencapsulants,¹ the performance of several other encapsulating agents, including sulfur polymer cement, polyethylene, phosphate ceramics, epoxies, urea formaldehyde polymer and asphalt, is comparable or superior to that of the accepted microencapsulants. Data on waste form leachability and/or permeability, biodegradation, radiation stability, and long-term environmental stability of these materials have been obtained from an extensive search of the literature on encapsulating materials and technologies.²⁻²⁶ These data are summarized in Table 1.

Permeability/Leachability

The low permeability (Table 1) of Portland cement and pozzolanic materials inhibits the release of toxic metals; however, these materials may not successfully (as measured by the TCLP) immobilize high concentrations of lead and mercury.^{4,6} Both sulfur polymer cement and polyethylene pass TCLP for cadmium and lead at waste loading rates that are significantly higher than those normally used for cementitious materials,^{18,21} making them more efficient encapsulating agents. Since phosphate ceramics are a new technology relative to the other encapsulants, little performance data are available; however, a study by Wagh and Singh²⁶ achieved TCLP reduction factors for immobilized ash, sludge and salts of 310

Table 1. Waste Form Performance Summary

Agent	Limitations	Water Permeability / Leaching	Immob. Due to Chemical Action	Compression Strength	Resistance to Biological Attack	Resistance to Irradiation	Waste Loading
Portland Cement, Lime/Pozzolans	Not good for Hg waste or high concentrations of Pb, Na, Cl. Not good for IX resins at high loadings.	Leaching has some effect on matrix. Pozzolan permeability $\sim 10^{-8}$ cm/s.	Precipitation of many metals as hydroxides at high pH.	Highly variable, generally greater than 1000 psi.	Some attack due to sulfate and nitrate chemistry.	Irradiation has no effect on matrix.	Low for heavy metals.
Sulfur Polymer Cement	Not compatible with $> 10\%$ NaOH, wet waste, nitrate salts, organics, ion-exchange resins.	Impervious to water, spalling occurs due to absorption of water by ion exchange resins at surface of waste form.	Yes. If Na_2S is added, sulfides precipitate.	4000 psi	No bacterial or fungal growth after 21 days (ASTM G-21 and G-22 tests). Need to test using thiobacillus.	No effect for low radiation; gains strength at high radiation.	40 to 55%
Phosphate Ceramic	Relatively new waste form, do not know limitations yet.	Slight weight loss and strength loss due to immersion.	Very significant bonding of waste to ceramic.	About 7000 psi	Not tested.	Not tested.	50% to 70%
Polyethylene Micro-encapsulation	Not recommended for radioactive materials able to deliver $> 10^8$ rad.	Leaching rates below TCLP.	No.	2500 psi	Polyethylene is not degraded by microbes due to high molecular weight.	H_2 production and structural deterioration not a problem for MLLW. ¹	20 to 70% depending on waste type.
Polyethylene Macro-encapsulation	Practically no limitations.	Impermeable to water, no leaching.	No.	2400 psi HDPE ² 600 psi LDPE ³	Polyethylene containers show no loss of strength.	H_2 production and structural deterioration not a problem for MLLW.	Not determined

¹MLLW = Low Level Waste

²HDPE = High Density Polyethylene

³LDPE = Low Density Polyethylene

for cadmium, 1600 for chromium and 500 for lead. Phosphate ceramics also have the potential for high waste loading rates.

Biodegradation

Degradation of Portland cement and concrete sewage lines has been observed in the presence of bacteria capable of producing nitric or sulfuric acid.¹¹⁻¹³ However, production of these metabolites is only possible when significant amounts of carbonaceous material are present, a situation highly unlikely in mixed waste debris slated for immobilization. Using the American Standard Testing Methods (ASTM) test procedures for bacterial and fungal growth, sulfur polymer cement was inert under ideal growth conditions and compressive strength was unchanged.¹⁵

The majority of synthetic polymers, including polyethylene, are highly resistant to microbial degradation. Potts et al.²² found that only relatively low molecular weight polymers (400-500 daltons) are susceptible to biodegradation; the molecular weight of low-density polyethylene used for encapsulation is 10,000 to 100,000 daltons. Even low molecular weight polymers are not biodegradable when they are branched or cross-linked.²³

Radiation Effects

No significant increase in leachability or loss of compressive strength has been observed in Portland cements at gamma ray doses up to 10^8 rad.¹⁴ Irradiation at 10^8 rads of six samples of sulfur polymer cement containing 39 wt. % dried sludge from the Oak Ridge Y-12 facility produced no statistically significant change in sample mean compressive strength.¹⁵ Little or no damage to polyethylene encapsulant is seen below 10^7 rad and the material is suitable for most encapsulation applications up to 10^8 rad.²⁴

Kalb et al. have analyzed expected doses to encapsulants.¹⁵ Waste forms from boiling water reactors contain activities of about 10 Ci/ft³; the calculated dose to the waste form is 2×10^7 rad in 1000 years. By comparison, waste forms containing 43% incinerator ash from

the Idaho National Engineering Laboratory's incinerator have an activity of only 2×10^4 Ci/ft³, five orders of magnitude less. The latter activity can be considered an expected activity level for immobilized debris; therefore, a performance requirement that encapsulant materials be resistant to 10^8 rad of gamma irradiation would be quite conservative.

Long-Term Environmental Stability

Ancient structures such as the Great Wall of China and Greek and Roman temples provide the best evidence for the long-term stability of Portland cement and pozzolanic materials. For example, a sample from an ancient Roman bath built in 150 B.C. has shown a compression strength of 4700 psi.¹⁶ Although sustained compression strength is not directly translatable to leachability, it does indicate that degradation, which increases leachability, has not been significant over 2000 years.

Since sulfur polymer cement has been used as a construction material only since the late 1970s, there is no "long-term" environmental stability data analogous to that for cements and pozzolans. However, studies cited by Darnell¹⁷ indicate that sulfur polymer cement is more robust in corrosive environments than Portland cement. After being exposed to sulfuric acid and copper electrolytic solutions for nine years, sulfur concrete, a sulfur polymer cement/aggregate mix, showed no evidence of corrosion or deterioration. In a six-year test in a chemical processing plant, Portland cement concrete was attacked and completely destroyed in some cases while sulfur concrete showed practically no evidence of strength loss or material degradation. The longest environmental test involves 1100 sulfur concrete negative buoyancy pipeline weights installed in Canada in 1981. Sulfur polymer cement was chosen because the swampland through which the pipeline runs experiences intermittent submersion under water and the sulfate conditions deteriorate Portland cement. The weights, 5600 kg each, show no signs of degradation after 14 years.

Long-term stability data on polyethylene encapsulating material is largely limited to the fact that plastic piping has been in use for only 50 years. However, its predicted long-term stability is inferred from evaluation of the High Integrity Container (HIC), a high density

polyethylene overpack for low-level waste, which was granted a 300-year life rating by the South Carolina Department of Health. The technical package which produced this rating included data on creep strain, tensile strength, impact data, compressive strength, hardness, dimensional stability, melt index, heat deflection, thermal cycling, water absorption, permeability/diffusion, ultraviolet light, irradiation effects, longevity, toughness and durability.²⁵

Based on the performance data in the preceding summaries, it can be concluded that microencapsulation using Portland cement, pozzolanic materials, sulfur polymer cement and phosphate ceramics and macroencapsulation using polyethylene and other polymeric materials provide a significant level of protection from release of contaminants. In general, sulfur polymer cement, polyethylene and phosphate ceramics are superior to Portland cement due to their lower leachability and higher strength.

WASTE PERFORMANCE CRITERIA

To assure that mixed waste debris treated by encapsulation/immobilization and placed in a regulated disposal facility will be sufficiently protective of human health and the environment, performance criteria should be set for the waste forms. Any waste form that meets these criteria would qualify for exit from RCRA Subtitle C, with the understanding that it would have to satisfy the waste acceptance criteria for a designated low-level waste disposal facility. This approach would remove existing limitations on the types of microencapsulating materials and allow the use of new, improved materials as they are developed.

It is recommended that waste form performance criteria be based on a two-tiered system first proposed by Brookhaven National Laboratory.²⁷ Recommended tests are:

First Tier:

- Microencapsulated waste: Toxicity Characteristic Leaching Procedure (TCLP) as per EPA Method 1311 or Accelerated Leach Test.²⁷
- Macroencapsulated waste: TCLP using an encapsulated coupon of the debris and waste form integrity testing via a non-destructive test (NDT) such as real-time radiography, ultrasound or x-ray.

Second Tier:

To be performed only if the waste passes the applicable first tier test. For both micro and macroencapsulated waste, this would be a series of waste form stability tests that may include compressive strength NDT, long-term immersion in water, radiation stability, biodegradation, freeze-thaw cycling and wet/dry cycling, depending upon the waste acceptance criteria of the LLW disposal facility. It should be noted that these tests are essentially those tests required to qualify a final waste form for disposal at a LLW disposal facility.

It is further recommended that waste form performance testing be performed each time there is a change in the immobilization process or encapsulant material, and annually as a quality assurance (QA) check for ongoing (as opposed to batch) processes. The rationale for the proposed battery of tests is that (1) the ultimate property of concern is leachability, (2) the stability of the waste form affects leachability and (3) stresses, such as irradiation, biodegradation and thermal cycling, can cause cracking, and thus affect stability, and, ultimately, leachability.

PERFORMANCE OF LOW-LEVEL WASTE VS. RCRA DISPOSAL FACILITIES

From the preceding discussion, it is concluded that mixed debris treated via an immobilization technology provides long-term isolation of hazardous waste constituents from

the environment. In this section, the relative performance of RCRA and DOE LLW disposal facilities is examined in terms of design and performance requirements and modeling data on the long-term performance of the two types of facilities. The section concludes with a discussion of existing empirical data on the migration of hazardous constituents from low-level waste disposal facilities.

Disposal Facility Design and Performance Requirements

Since the vast majority of mixed waste debris is generated by DOE, this section focuses primarily on DOE disposal facilities. However, the conclusions also apply to disposal facilities designed to meet the performance criteria of 10 CFR 61.

The basic requirements for RCRA Subtitle C and DOE disposal facilities are shown in Table 2. Both sets of requirements have a common goal - to maximize the protection of human health and the environment from the hazards contained in each type of facility. The two types of facilities also have several common elements. Both limit the amount of free liquids that may be present, require groundwater monitoring, and specify a period of active institutional control after site closure. The primary difference between the two types of facilities is the RCRA requirement for facility liners and a leachate collection system.

The EPA waste management philosophy under RCRA is to treat hazardous constituents to safe residual levels before land disposal. Radioactivity, on the other hand, cannot be treated to safe levels (excluding transmutation), but can only be eliminated as a result of natural decay. This has led to the waste management philosophy of immobilizing/isolating radioactive waste from the public and sensitive environments until natural decay renders the residuals safe. The extent of immobilization/isolation varies from hundreds to thousands of years, depending on the half-lives of the radionuclides and the curie content of the waste.

As seen in Table 2, EPA uses a very prescriptive approach to disposal facility design that relies on engineered controls (the liners and leachate collection system) to eliminate any release during the active life of the facility. In contrast, DOE takes a performance-based

approach to radioactive waste disposal and allows the disposal site owner to design and operate the facility as appropriate to achieve the performance standards of 5820.2A. Depending upon the characteristics of the disposal site, designs can range from simple shallow land burial to containment in above or below-ground concrete enclosures. Facility acceptability is determined via a performance assessment that verifies the ability of the facility as designed and operated to meet the performance objectives of 5820.2A.

Facility Performance

Given the differences in facility design and performance requirements cited for RCRA and LLW disposal facilities, the question then becomes, "Does a facility engineered to provide acceptable protection against the hazards of ionizing radiation for 10,000 years²⁸ also provide acceptable protection against the chemical hazards that may be present in immobilized mixed debris?" Several

- In 1991 the Advisory Committee on Nuclear Waste (ACNW) reviewed the problems and issues associated with mixed waste disposal and concluded that "dual jurisdiction of the regulatory process for mixed wastes appears to be wasteful of resources and lacks justification on the basis of benefit to the public."²⁹
- A study by the Nuclear Management Resources Council (NUMARC) that sought to determine whether there are discernible environmental impact differences between disposing of mixed waste in a mixed waste disposal facility licensed under 10 CFR 61 and permitted under 40 CFR 264, and a LLW disposal facility licensed only under 10 CFR found that the performance of the two types of facilities was comparable.³⁰

Table 2. A Comparison of RCRA Subtitle C and DOE Order 5820.2A Requirements for Waste Disposal Facilities

RCRA Subtitle C*	DOE Order 5820.2A**
Waste may contain no free liquids (264.314). Containers must be chemically compatible with contents to minimize leakage (264.172).	Waste acceptance criteria shall be established for each disposal site (III.3.e(2) and (5)). Void spaces in waste containers must be minimized (III.3.i(5)(a)). Liquids must be $\leq 1\%$ of the waste volume in the container or $\leq 0.5\%$ of waste processed to a stable form (III.3.i.(5)(b)).
Disposal area must have at least two liners with a leachate collection system above and between the liners (264.301).	Facilities must assure that the effective dose equivalent to any member of the general public does not exceed 25 mrem/yr from all exposure pathways (III.3.a.(2)). Engineered modifications such as barriers shall be developed as necessary to meet this requirement (III.3.i.(2)).
Groundwater monitoring and a leak detection system are required (264.97, 264.303).	Groundwater resources must be protected in accordance with federal, state, and local requirements (III.3.3b.(3)). Facilities shall be monitored by an environmental monitoring program (III.3.k.).
Groundwater monitoring and maintenance of the waste containment system must continue for 30 years after closure (264.117). Facilities must be provided with a cover at closure (264.310).	Active institutional facility control shall be maintained for 100 years (III.3.a.(3)). Termination of monitoring and maintenance shall be based on an analysis of site performance at the end of this period (III.3.j.(6)). Assure that inadvertent intruders after the 100-year control period shall not receive an effective dose equivalent in excess of 100 mrem/yr for continuous exposure or 500 mrem for a single acute exposure (III.3a.(3)).

*References refer to sections of 40 CFR.

**References are sections of the Order.

theoretical studies have specifically addressed this issue by comparing the performance of RCRA Subtitle C and LLW disposal facilities:

- A 1987 study by Rogers and Associates that compared six standard concepts for LLW disposal (shallow land disposal, intermediate depth disposal, subsurface vaults, above-ground vaults, modular concrete canister disposal and earth-mounded concrete bunkers) reached the same conclusion as the NUMARC study; i.e., with the exception of above-ground vaults, performance of all six designs was equivalent.³¹ Although this analysis focused on LLW disposal facility designs, the conceptual design for a mixed waste disposal facility is basically a subsurface or above-ground vault with a double-liner/leachate collection system. Consistent with the assumptions used in the study, such an engineered system could only be relied upon during its design life plus post-closure period. Since high-density polyethylene liners are guaranteed by the manufacturer for 20 years and have an expected lifetime of 50-100 years,³² assuming a

facility design life of 30-50 years and a 30-year post-closure period, the maximum period of protection afforded by a liner system would be about 100 years.

Consequently, the enhancement could provide temporary benefit but would not affect long-term performance.*

- A comparative study carried out as part of DOE's mixed waste program concluded that, over a 10,000-year time frame, there was essentially no difference in the mean annual effective dose equivalent (mrem/yr, all pathways) at a point 100 m down-gradient from the disposal facility for RCRA and LLW disposal facilities.³³ While the study considered only the migration of radionuclides, this conclusion would also be valid for the migration of toxic metals because the primary property of any soil contaminant that affects its migration, namely, its sorption coefficient, (K_d ; the equilibrium ratio of contaminant concentration in soil to contaminant concentration in groundwater) is independent of whether or not the material is radioactive. Mean K_d 's for radioactive and nonradioactive metals are comparable for the four basic soil types - sand, loam, clay and humus.³⁴
- In order to provide a more detailed and realistic comparison of the performance of RCRA and LLW disposal facilities vis a vis RCRA waste, Sandia National Laboratories calculated the maximum permissible contaminant concentration of toxic metals in soil at the base of a disposal facility assumed to be located at each of the six DOE sites that currently have LLW disposal facilities - Savannah River, Oak Ridge, Los Alamos, Hanford, the Nevada Test Site and the Idaho National Engineering Laboratory.³⁵ It was assumed that metal concentrations 100 m from the edge of the disposal facility could not exceed the applicable Maximum Concentration Limits (MCLs) at any time after facility closure. Groundwater transport analyses carried out for arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver. The analysis supported the conclusion that for the arid (Nevada) and semi-arid (Los Alamos, Idaho and Hanford) sites, the TCLP leach rates are low enough that the resultant concentrations of toxic metals in the soil are below the MCLs. These results are without a RCRA liner and leachate collection system and with highly conservative assumptions. Humid sites such as Oak

Ridge and Savannah River would require a more site-specific analysis to accurately characterize local environmental concentration attenuation.

- In his paper on "Risk Assessment of Designs for RCRA and CERCLA Sites" Frank L. Parker³² assesses the ability of high-density polyethylene liners to contain three representative contaminants: benzene, which is easily degradable; heptachlor, a pesticide which is less easily degradable; and lead, which does not degrade. Hydrogeological conditions of an actual disposal site, the Velsicol Disposal site in Hardeman County, Tennessee were used in the evaluation. The analysis evaluates lifetime individual fatal cancer risk 1000 m down-gradient from the site for the two organics. Since it is not a carcinogen, actual concentrations are calculated for lead. The data demonstrate that the effectiveness of liners is most pronounced for short periods of time up to 100 years. At 100 years for heptachlor and 1,000 years for lead there is virtually no difference in the risks between lined and unlined landfills. Even for benzene, which degrades rapidly, the risk at five years for an unlined facility (3.2×10^{-4}) is comparable to the lifetime fatal cancer risk (5×10^{-4}) underlying EPA's proposed annual committed effective dose equivalent of 15 mrem from all pathways from the disposal of LLW (40 CFR 193).

Empirical Data

Since mixed waste cannot currently be disposed of in a LLW disposal facility, there is very little empirical data to support the conclusions of pathways analysis and risk assessment modeling studies concerning the migration of hazardous constituents from such facilities. However, in 1985, knowing that LLW containing hazardous constituents had been disposed of at LLW disposal facilities prior to the institution of current regulations, the NRC undertook to assess the nonradiological quality of groundwater at several NRC LLW disposal sites.³⁶ The facilities examined (Barnwell in South Carolina and Sheffield in Illinois) serve as a rough full-scale test for the migration of hazardous constituents from the shallow land burial design concept. Since both facilities were sited prior to promulgation of 10 CFR 61, neither facility meets current NRC siting criteria. Therefore, they are not representative of

current NRC-regulated LLW disposal technology and practice, and can be considered worst-case examples, particularly since both sites are in humid environments. At both sites, principal RCRA contaminants are considered to be toluene and xylene from scintillation cocktails, chromium from reactor waste, and lead shielding.

Results of chemical analysis of samples from groundwater monitoring wells at both sites led to the following conclusions:

- Groundwater at the Sheffield site is contaminated with elevated levels of organics, primarily chlorinated solvents. However, the source of this contamination is ambiguous, because the site is adjacent to a previously used unlicensed chemical waste burial area, and organic contamination from this site has migrated into the Sheffield site.
- Concentrations of individual organics at the Barnwell site are very low in on-site wells and are below detection at boundary wells. "The highest organic constituent concentration from this study was 14 $\mu\text{g/l}$ for chloroform at a well about 10 ft from a disposal unit".³⁶
- Hazardous metals were at or below detection limits or at background levels at both sites. Actual concentrations were at least an order of magnitude below the proposed EPA non-wastewater TCLP limits³⁷ for all samples.
- Toluene and xylene were not detected at Sheffield. Barnwell samples were not analyzed for xylene; toluene was not detected.
- Tritium has migrated into the groundwater at both sites; however, concentrations are below 10 CFR 20 limits.

In addition to the above results, data from previous sampling at commercial LLW disposal facilities at Maxey Flats, Kentucky, West Valley, New York and Richland,

Washington were also discussed in NRC's report. The data for Maxey Flats are particularly interesting, because while high concentrations of toluene were found in trench leachates in 1979 and 1981, none was detected in 1982 after disposal at this site had ceased. This is an indication that the rates of bioremediation and/or soil adsorption are significant for this contaminant at this site. Analysis for toxic metals was not performed. At West Valley, the organic contaminants in trench water samples were determined to be "remarkably similar to water samples from sanitary landfills in Pennsylvania, Illinois, and Wisconsin" (General Research Corp., 1980) and were determined to likely be derived from buried cleaning agents, surfactants and paints, not reactor-related activities.

Richland is the only arid site for which data were available. Samples from off-site groundwater wells adjacent to the Richland site did not exhibit elevated levels of organic contamination. Toxic metal data were not obtained.

The preceding studies of commercial LLW disposal facilities are, to the best of our knowledge, the only ones that have sampled LLW disposal sites for RCRA contaminants. We have not found any more recent data; however, at least one recent study has examined the migration of toxic metal in an undeveloped environment. Support for the slow migration rate of lead predicted by Parker has been provided in a recent study by Wang et al. conducted at the Hubbard Brook Experimental Forest in Connecticut.³⁸ This study determined that simple mineral soil is also an effective heavy metal filter, at least for lead. In estimates of total lead outflow in streams, over 80% was found to be associated with particulate matter derived from erosion of surface soil debris; virtually none was contributed by soil percolates. This particular ecosystem was characterized as "an excellent 'filter' that completely retains industrial contaminant lead in its soil profile"³⁸.

From these studies, it is apparent that empirical data support the following conclusions of modeling analyses:

- Organic contaminants are likely to be removed via biodegradation before they experience significant migration.

- Soil migration of toxic metals is extremely slow.

SUMMARY AND CONCLUSIONS

Assessment of DOE's debris waste inventory, evaluation of immobilization materials and waste containers, analysis of RCRA vs. DOE regulatory requirements for waste disposal, comparison of the long-term performance of LLW and RCRA disposal facilities, assessment of the relative risk associated with the disposal of radioactive and chemically toxic components, and evaluation of the migration of hazardous chemicals under worst-case conditions have led to the following major conclusions:

- Mixed waste debris does not typically contain high concentrations of hazardous contaminants. The majority (~80%) of DOE's mixed waste debris is mixed due to heavy metal contamination.
- In addition to Portland cement and lime/pozzolans, sulfur polymer cement, phosphate ceramics and polyethylene are suitable microencapsulating agents. Performance of the latter three materials in terms of permeability/leachability, biodegradation, radiation resistance and long-term environmental stability is equal or superior to that of cements and pozzolans.
- Pathways analyses and risk assessments of LLW and RCRA mixed waste disposal facilities show that these two types of facilities provide equivalent long-term (> 100 years) performance and protection of human health and the environment.
- Available risk assessment data indicate that disposal of immobilized mixed low-level debris in a LLW disposal facility that meets the performance requirements of 5820.2A would be a risk that is equivalent to, or less than that associated with a RCRA Subtitle C facility.

- As of 1986, chemical contaminants that were disposed of in formerly used LLW disposal sites had not been detected in off-site monitoring wells. Since sites were developed prior to promulgation of 10 CFR 61, they provide worst-case data.

The preceding conclusions demonstrate that disposal of immobilized debris in a LLW disposal facility is as protective of human health and the environment as disposal in a RCRA Subtitle C facility. The performance of encapsulating materials provides isolation from the disposal environment for a time period comparable to a RCRA liner lifetime. RCRA facility liners are generally considered to have a maximum performance lifetime of approximately 100 years. Regardless of their performance-rated lifetimes, once these engineered barriers begin to break down, analyses have shown that the performance of the two types of disposal facilities are equivalent. As migration through the soil begins, both radioactive and non-radioactive metals will react to site conditions in the same manner. Since the RCRA contaminants of primary concern are the toxic metals, a facility designed to protect human health and the environment from radioactive materials for 10,000 years will also protect against toxic metal contaminants.

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Westinghouse Hanford Company

Donald E. Wood

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Jay E. Rhoderick and R. Eric Williams, facilitators

PANEL DISCUSSION

No abstract available

Panel Members:

Terry Tyborowski
DOE-Headquarters, EM-4
202 586-6302

Michael Sherick
Idaho National Engineering Laboratory
208 526-6922

Carol Henry
DOE-Headquarters, EM-6
202 586-7150

Jonathan P. Carter
Carter, Brock & Hinman
208 336-1776

H. Elliot Chakoff
Consultant

Risk-Based Decisionmaking (Panel)

Thomas H. Smith, facilitator

PANEL DISCUSSION

By means of a panel discussion and extensive audience interaction, explore the current challenges and progress to date in applying risk considerations to decisionmaking related to low-level waste. This topic is especially timely because of the proposed legislation pertaining to risk-based decisionmaking and because of the increased emphasis placed on radiological performance assessments of low-level waste disposal.

Panel Members:

Carol Henry
DOE-Headquarters, EM-6
202 586-7150

Andrew Campbell
US Nuclear Regulatory Commission
301 415-6897

Fritz A. Seiler
IT Corporation
505 262-8908

Harold S. Blackman
Idaho National Engineering Laboratory
208 526-0245

DNFSB 94-2 IMPLEMENTATION PLAN

Gregory J. Duggan, facilitator

PANEL DISCUSSION

The session will open with a general introduction to the Defense Nuclear Facility Safety Board Recommendation 94-2. Opening remarks and introductions will be followed by a brief discussion on progress to date on the Implementation Plan deliverables. Other topics of interest to the audience will be discussed by the panel.

Panel Members:

Greg Duggan
DOE-HQ, EM-332

Derek Widmayer
SAIC

Martin Letourneau
DOE-HQ, EM-332

Elmer Wilhite
WSRC

Ed Regnier
DOE-HQ, EH-232

USING THE BASELINE ENVIRONMENTAL MANAGEMENT REPORT
TO EXAMINE ALTERNATE PROGRAM SCENARIOS

Terry Tyborowski
Project Manager
Baseline Environmental Management Report
EM-4.2/1H-053/FORS
1000 Independence Ave.
U. S. Department of Energy
Washington, DC 20585
(202) 586-6302

Keith Kristofferson
Advisory Engineer/Scientist
Technical Support Program
Lockheed Martin Idaho Technologies
Idaho National Engineering Laboratory
Idaho Falls, ID 83415
(208) 526-9363

ABSTRACT

The U.S. Department of Energy's (DOE) Office of Environmental Management (EM) released the first Baseline Environmental Management Report (BEMR) in March, 1995. The Congressionally-mandated report provides life-cycle cost estimates, tentative schedules, and projected activities necessary to complete DOE's Environmental Management Program. This "base case" estimate is based on current program assumptions and the most likely set of activities. However, since the future course of the Environmental Management Program depends upon a number of fundamental technical and policy choices, alternate program scenarios were developed. These alternate cases show the potential cost impacts of changing assumptions in four key areas: future land use, program funding and scheduling, technology development, and waste management configurations. Several cost and program evaluation tools were developed to support the analysis of these alternate cases. The objective of this paper is to describe the analytical tool kit developed to support the development of the 1995 Baseline Report and to discuss the application of these tools to evaluate alternate program scenarios.

INTRODUCTION

To manage the environmental legacy remaining from the Cold War production of nuclear weapons, the Department of Energy established the Office of Environmental Management (EM) in 1989. This office manages one of the largest environmental programs

in the world with more than 130 sites and facilities in over 30 States and territories. EM is organized into four key mission areas: (1) the Waste Management Program; (2) the Environmental Restoration Program; (3) the Technology Development Program; and (4) the Nuclear Material and Facility Stabilization Program. The primary focus of the Environmental Management Program is to reduce health and safety risks from radioactive and hazardous waste contamination resulting from the development, production, and testing of nuclear weapons.

The National Defense Authorization Act for Fiscal Year 1994 requires the Department to provide an annual report to Congress on the estimated total cost and complete schedules for activities under the Environmental Management Program.¹ In response to this requirement, DOE submitted the first annual Baseline Environmental Management Report (BEMR) to Congress in March, 1995.² The report describes the activities and potential costs required to address the waste, contamination, and surplus nuclear facilities that are the responsibility of DOE's EM Program. In doing so, it represents the Department's most comprehensive effort to date to develop a clearer picture of the "Cold War Mortgage." The report is divided into two volumes. The first volume summarizes the base case and evaluates program alternatives. The second volume presents the site-specific data used to generate the report.

Under the base case assumptions, the life-cycle cost estimate to complete the Environmental Management program ranges from \$200 - 350 billion with a mid-range estimate of \$230 billion. This estimate is based on a 75 year program and assumes that all existing compliance agreements are met. For the mid-range estimate, 49% is for waste management activities, 28% is for environmental restoration activities, 10% is for stabilizing nuclear material and facilities, 5% is for technology development efforts, and the remaining 8% is for Federal salaries and overall program management. The five largest EM sites represent over 70% of the total life-cycle costs: Hanford Site (21%); Savannah River Site (21%); Rocky Flats Environmental Technology Site (10%); Oak Ridge Reservation (10%); and Idaho National Engineering Laboratory (8%).

The EM program is subject to a large number of technical and policy uncertainties. The future course of the Environmental Management program depends on a number of fundamental choices in these areas. First, there are a number of significant land use decisions to be made. For example, if DOE cleans up all contaminated sites to a "green field," the cost is orders of magnitude greater than if the land were held under institutional control with limited remediation. Second, the level of program funding can influence the pace and scheduling of program activities. For example, accelerating site closures may significantly reduce life-cycle costs by avoiding long term site landlord and other support costs. Third, life-cycle costs can be affected by the availability of new, less costly technologies. In this case, should the treatment of waste proceed with present technology or should the waste be stored while it is waiting for the development of improved technology? Finally, the economies associated with centralizing or decentralizing treatment facilities could influence the life-cycle costs. More important, these treatment facility siting decision have substantial implications for the local communities and for other communities affected by transporting the wastes.

The 1995 Baseline Report lays the foundation to engage the Nation in a broad based discussion of the risks, costs, and tradeoffs associated with different approaches. This paper presents the approach used in the 1995 Baseline Report to develop and evaluate alternate program scenarios. This discussion includes a more detailed examination of the tools developed at DOE Headquarters to assist in this analysis. In addition, the paper discusses alternate program scenarios to be examined in the 1996 Baseline Report.

BEMR Approach to Alternate Cases

The development of alternate program scenarios is premised on a defensible and credible base case. In fact, most of the effort to develop the 1995 Baseline Report focused on the base case. The challenge facing the Department in building the base case was to provide a plausible, comprehensive estimate of the total cost and schedule for the Environmental Management Program even when the total range of problems have not been fully identified or characterized. With some guidance and a great deal of work, field

personnel developed estimates of the life cycle costs, schedules, and activities to complete environmental programs at their sites. In some cases, cost and scheduling estimating tools had to be developed at headquarters to assist the field in developing their base case estimates. Two major tools were developed or modified for this purpose. For waste management activities, the System Cost Model (SCM) was used to assist the field in estimating the cost of treatment, storage, and disposal facilities for low level, mixed low level, and transuranic wastes. This model previously had been developed for the Department's Programmatic Environmental Impact Statement (PEIS) and was modified for the BEMR project. The second tool was developed based on the U.S. Army Corps of Engineers' Micro Computer Assisted Cost Engineering System (MCACES) and was used to estimate the costs of nuclear material and facility stabilization activities.

Once these estimates were received from the field, an approach for assembling, integrating, and reviewing these data had to be developed. Once again, Headquarters had to develop a tool to accomplish this task. The Integration Tool served several roles. First, it provided a repository for the massive amount of field information. Second, it provided the ability to reschedule anticipated project start dates to meet funding limits or to match waste generation with treatment, storage, and disposal capacity. The Integration Tool was designed to assist in performing several of the steps required to develop the base case. These steps included:

- 1) The final set of field data representing the base case was assembled and loaded into the Integration Tool.
- 2) Waste volumes and cost were calculated over time and a schedule developed for low level, low-level mixed, transuranic and legacy waste loads. Environmental restoration, facility stabilization, and waste loads from other Environmental Management programs also had to be calculated over time.
- 3) All waste volumes were then compared to treatment, storage and disposal capacity either in existing or in planned facilities.

- 4) Treatment, storage and disposal needs over time were then identified and placed in five year vintages.
- 5) The System Cost Model was then used to calculate costs over time for new facilities where those facilities were non-existent.
- 6) Total cost over time was then calculated for all new facilities and added to the cost represented in the input data.
- 7) The total program cost was then compared to expected funding levels.
- 8) Some facilities and programs were rescheduled to more closely match the expected funding levels over time.
- 9) The "adjusted" base case was reviewed by program managers at the sites and DOE-HQ.
- 10) Final documentation of the base case was completed and incorporated in the 1995 Baseline Report.

Once the base case was developed, a number of alternative program scenarios were developed. Alternative cases were developed by DOE Headquarter personnel to show the potential cost impacts of changing assumptions in four key areas: land use planning, program funding and scheduling, technology development and waste management configurations. The analyses were performed using selected hypothetical situations or postulated cases where it is thought a change in schedule or technical option might have a noticeable fiscal impact. All of scenarios employed a variety of regulatory, technical and scheduling changes that might have the greatest chance for cost savings to the American taxpayer in future years.

The process for developing the costs of an alternate scenario generally followed the 10 step process identified above with some modifications. The modifications generally

consisted of either changing the input data at the start of the process or assumptions at specific steps during the process. The Integration Tool proved to be more flexible than it was originally designed in that it was well suited for the alternate program funding and scheduling scenarios. Another tool developed for the Department's Programmatic Environmental Impact Statement (PEIS), the Automated Remedial Assessment Methodology (ARAM), was used extensively for the alternate land use cases. No special tools were developed for examining technology development alternatives although a spreadsheet model was used to integrate existing information. Finally, the waste configuration analysis relied on a wide variety of tools developed for the Waste Management Programmatic Environmental Impact Statement.

The process looked at fundamental questions and types of decisions likely to affect Environmental Management life cycle costs:

- Land Use - What are the range of ultimate uses for currently contaminated lands and waters at each installation?
- Funding and Schedule - How much money is spent on Environmental Management activities and how rapidly is this money being spent?
- Technology Development - What types of new technologies are available and when will they be implemented?
- Waste Management Configuration - At what installations will treatment, storage and disposal of wastes occur?

Results of the Alternate Case Analysis

The four alternative program scenarios yielded interesting results in terms of the overall life-cycle costs of the EM program. However, some care must be taken in interpreting these results. First, a great deal of uncertainty underlies the basic data (see

discussion above). Second, the 1995 Baseline Report represents the first EM-wide cost analysis of these issues. The 1996 Baseline report is placing more effort on refining the assumptions, improving the data, and working with field personnel to improve the analysis. Below, the four alternative program scenarios are described in more detail.

Land Use

How land will be used after environmental remediation dictates the type and extent of certain approaches. The base case estimate is a bottoms up approach using a large amount of data and assumptions collected from the sites rather a centralized approach. Consequently, a number of varying land use assumptions were used to develop the base case estimate. To examine alternate scenarios, the Department looked at more restricted land use cases involving containment of the existing contamination at the generating site and restriction of public access thereafter as well as unrestricted land use alternatives. The least restricted cases were those that looked at removal or in-situ destruction of the contaminant in all of the environment. The five cases ranged from iron fence to maximum feasible green fields and additionally included a modified containment case, the base case, a modified removal case. The life cycle costs ranged from \$175 billion to \$500 billion depending on the level of cleanup.

Program Funding and Scheduling

Another set of analyses address the impacts of more or less available funding for the program. Assuming additional funding, the impacts of accelerating stabilization activities and early closure of sites were analyzed. In addition, cases examined reduced funding and the impacts associated with a reduced scope. Some of the results of this analysis found that surveillance and maintenance could be reduced to \$500 million from \$4 billion if pre-stabilization surveillance maintenance could be reduced from 10 years to 1 year. Furthermore, almost \$5 billion could be saved if the Department closed the Rocky Flats, Oak Ridge K-25 Plant and the Fernald sites earlier (20-40 years). Further savings could be realized if funding were significantly reduced beyond the year 2000. This "minimal action

case" would require \$170 billion or almost 27% lower than the base case through 2070. The minimal action case would not include environmental restoration, decontamination and dismantlement, future treatment and disposal of low-level, low-level mixed and transuranic wastes. However, annual surveillance and maintenance costs would be \$500 million, which is much greater than the cost in the base case.

Technology Development

An in-depth analysis of 15 technologies that could be applied to high-cost remediation projects found that potential savings could range from \$9 - \$80 billion (on a life-cycle basis). The large variation in potential cost savings is driven by future land use decisions and assumptions regarding the availability of the technologies before 2010.

Waste Management Configuration

Using the results of recently completed configuration strategies for the Waste Management Programmatic Environmental Impact Statement, the life cycle costs could increase the base case by \$9 billion or decrease it by \$5 billion. These differences mainly result from the added economies of centralizing facilities. However, a great deal of uncertainty surrounds these estimates and further analysis is underway using 1996 Baseline Report information.

Looking Forward to BEMR II

A data call was issued in late July 1995 to all sites to develop the base case for the 1996 Baseline Report. To gather the site EM activity, cost, and schedule data, each program area developed extensive guidance and a supporting computer database application. To accelerate the process, the database was seeded with data from existing sources. For waste management activities, the database was seeded with the 1995 Mixed Waste Inventory Report (MWIR) information. The environmental restoration and the nuclear material and facility stabilization application seeded information from the 1995 Baseline Report and from other sources. The database was then distributed to the sites for revision and addition of missing

data. More attention is being placed on the integration of site activities for the 1996 Baseline Report. In several cases, the Integration Model is being used by the sites to assist in the site integration process. All integrated and reviewed base case information should be received at DOE Headquarters by December 15, 1995.

One of the goals of the 1996 BEMR is to improve the alternate cases that were included in the 1995 BEMR. This year's report will focus on three alternate cases: program scheduling, land use, and minimum effort. This year's cases will be analyzed in more detail for the five largest sites: Hanford Site; Savannah River Site; Rocky Flats Environmental Technology Site; Oak Ridge Reservation; and Idaho National Engineering Laboratory. For each alternate case, four program outcomes will be evaluated: program cost, duration, risk and end state. In addition to the alternate cases, sensitivity analyses will be conducted to assess the results of varying levels of funding on pollution prevention and technology development.

In the 1996 Baseline Report, health and environmental risk will be evaluated as an outcome of the various alternate cases. Sites will be requested to assess risk at sites where existing tools and data are available. The analysis will include an evaluation of risk before, during and after an activity is complete. Potential impacts to on-site personnel, the public and the environment will be assessed; cultural risk will be included where appropriate. The focus of the risk analysis will be to estimate how risks may change between the base case and each alternate case.

The 1996 Baseline Report will expand upon and improve the program scheduling and land use cases developed for the 1995 Baseline Report. The objective of the minimum effort case is to develop a scenario that will minimize the total cost of the EM program over the next 75 years without increasing risk to off-site population, on-site workers, or the environment. This scenario will require strategies for implementing the EM program which differs significantly from those outlined in the base case. The minimum effort scenario combines elements of urgent risk reduction, mortgage reduction, minimum action, regulatory relief, good management practices and institutional controls into an overall strategy aimed at

stabilizing and safely containing waste and surplus material on site and minimizing the cost of safeguarding these materials in the future.

The 1996 Baseline Report is due to Congress within 30 days of the submittal of the President's budget. The 1996 Baseline Report will continue the work started in the 1995 Baseline Report to develop a timely, credible, and effective analytical capability for evaluating program alternatives.

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ESTIMATING AND UNDERSTANDING DOE WASTE MANAGEMENT COSTS*

Michael J. Sherick
Idaho National Engineering Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-2420
(208) 526-6922

Jonathan S. Kang
U.S. Department of Energy, EM-30
Trevion II Bldg.
Washington, DC 20585-0002
(301) 903-7178

ABSTRACT

This paper examines costs associated with cleaning up the U.S. Department of Energy's (DOE's) nuclear facilities, with particular emphasis on the waste management program. Life-cycle waste management costs have been compiled and reported in the DOE Baseline Environmental Management Report (BEMR). Waste management costs are a critical issue for DOE because of the current budget constraints. The DOE sites are struggling to accomplish their environmental management objectives given funding scenarios that are well below anticipated waste management costs. Through the BEMR process, DOE has compiled complex-wide cleanup cost estimates and has begun analysis of these costs with respect to alternative waste management scenarios and policy strategies. From this analysis, DOE is attempting to identify the major cost drivers and prioritize environmental management activities to achieve maximum utilization of existing funding. This paper provides an overview of the methodology DOE has used to estimate and analyze some waste management costs, including the key data requirements and uncertainties.

INTRODUCTION

The DOE is in the process of establishing plans and agreements to clean up its nuclear facilities that are spread across the country in what is commonly referred to as the "weapons complex." The weapons complex consists of laboratories, research facilities,

* Work supported by the U.S. Department of Energy, Office of Environmental Management, under Idaho Operations Office Contract DE-AC07-94ID13223.

testing areas, production plants, waste disposal sites, waste storage buildings, and a variety of support structures. The environmental legacy of the nuclear research, testing, and production activities includes: large quantities of several different types of hazardous, radioactive, and mixed (hazardous and radioactive) waste that need to be processed and disposed; contaminated sites that need to be cleaned up, stabilized, or restored; and a multitude of facilities that need to be decontaminated, decommissioned, or demolished. Collectively, these cleanup activities make up DOE's Environmental Management (EM) Program.

There are several organizational elements of the DOE EM Program. One of these is the Office of Waste Management (EM-30). EM-30 encompasses all of DOE's waste management activities, which include waste handling, storage, treatment, and disposal. Estimates have shown that the life-cycle costs of DOE's planned waste management activities represent almost one half of the total EM Program costs. One of the tools that has been developed by EM-30 to estimate and analyze some of DOE's waste management costs is the System Cost Model (SCM). This paper provides an overview of the data requirements for the SCM and identifies areas of uncertainty associated with data collected and modeling activities performed to date for EM-30. The issues and recommendations presented, although developed in reference to the SCM, can be considered generally applicable to any of DOE's waste management cost estimating and modeling activities.

BASELINE ENVIRONMENTAL MANAGEMENT REPORT

Total Program Estimate

The initial BEMR was submitted to Congress in March of 1995.¹ This report provided a first ever look at DOE's potential total environmental liability. In order to account for all of the relevant total program costs, DOE had to establish a planning basis for the BEMR that encompassed the life-cycle of activities at each DOE site. The BEMR also forced DOE to integrate planning between the various programs (Waste Management—EM-30, Environmental Restoration—EM-40, Technology Development—EM-

50, and Facility Stabilization and Maintenance—EM-60). The total EM Program estimate includes not only the costs of each of these individual programs, but also the cost impacts resulting from interactions between the programs. For example, some EM-30 costs may be the result of treatment or disposal of waste generated by EM-40 or EM-60 activities.

Life-Cycle Cost Estimates

The total program estimate provided in the BEMR forecasts life-cycle costs for all planned environmental management activities necessary to cleanup DOE's approximately 130 sites. Life-cycle costs are those required to provide cradle-to-grave management of the wastes and facilities at the DOE sites. For the BEMR, the life-cycle was interpreted to be the time required to complete all environmental management activities related to the clean-up of legacy waste at each of the DOE sites. For most of the DOE sites, this life-cycle is expected to extend beyond the year 2020, and for some sites, beyond 2050.

The life-cycle encompasses all phases of a project or facility, including engineering studies, bench-scale testing, conceptual design, construction, startup, operations and maintenance, shutdown, and decommissioning. In the special case of disposal facilities, the life-cycle includes each of the elements listed above, along with closure and post-closure monitoring throughout the institutional control period.

Waste Management Activities

The EM-30 Program consists of all activities necessary for: 1) management of all DOE legacy waste, 2) management of waste generated by ongoing DOE activities, and 3) management of waste generated by EM-40 and EM-60. Cradle-to-grave waste management includes all activities between waste generation and final disposition. Typical waste management activities include the broad categories of pretreatment, storage, transportation, treatment, and disposal. Within each of these broad categories of waste management activities, there is a wide array of specific processes, technologies, or functions. For a particular waste stream, a waste management plan will include all steps required for safe and

compliant disposition. The waste management activities that are identified are based on the contaminant types and concentrations present in the waste stream, the form and characteristics of the waste stream, all applicable regulations, and a variety of "other factors." Some of the "other factors" that influence waste management plans include: stakeholder concerns, political agreements, economics, health risks, schedules, residual/effluent quantities, etc.

Role of System Cost Model in Baseline Environmental Management Report Process

For the most part, the 1995 BEMR cost estimates were prepared by the individual DOE sites. However, in order to better understand the potential range of life-cycle costs of the total integrated EM Program, the DOE headquarters BEMR task force performed additional cost analyses. The sensitivity analyses were used to establish the variability of the total program estimate with respect to key programmatic strategies and decisions. This is an important aspect of the BEMR because the out-year planning basis is so speculative. Rather than have the sites estimate life-cycle costs for several different scenarios, DOE developed and applied models that were calibrated based on the site baseline estimates. The SCM was used in these analyses to estimate life-cycle costs of waste management activities required for some waste types.

DATA REQUIREMENTS FOR MODELING WASTE MANAGEMENT ACTIVITIES WITH THE SYSTEM COST MODEL

Waste Types Addressed By the System Cost Model

The SCM estimates waste management costs as a function of the waste quantities that are being managed and the characteristics of the waste being managed. The SCM can be loaded with site-specific waste, facility, processing, and schedule information to provide a somewhat customized model of the planned waste management activities for the DOE complex. Since SCM produces waste management costs for several different waste types and subtypes, waste and facility data can be input for each waste type and subtype being modeled. The SCM is currently capable of estimating costs for three waste types—low-level

waste (LLW), mixed low-level waste (MLLW), and transuranic waste (TRUW). Low-level waste and MLLW can be broken down into three subtypes: alpha-contaminated, nonalpha-contaminated, and remote-handled. Transuranic waste can be broken down into four subtypes: mixed, nonmixed, mixed remote-handled, and nonmixed remote-handled.

Waste Data

The waste data needed for cost modeling includes both current inventories and projected generation rates over the period of interest. The SCM requires that each waste stream for a given waste type/subtype be placed into one of thirty-two waste matrix categories. These waste matrix categories are defined in DOE's Mixed Waste Treatability Group Guidance,² and are consistent with the format used to compile DOE's Mixed Waste Inventory Report. The waste information is usually available in the form of volumetric quantities. However, since SCM uses both mass and volume flow rates, densities of each waste matrix category are also required so the necessary conversions can be made.

Facility Data

Existing facility information is required to support modeling efforts in order to establish the waste management capabilities that exist at a particular site and what new capabilities need to be provided (and costed). The existing facility information required includes capacities or throughputs, anticipated operating life, waste types/subtypes accepted or prohibited, known operating and maintenance costs, operating hours per year, waste processing methods, secondary wastes generated as a result of specific facility operations, and waste volume and mass changes resulting from each facility.

Treatment, Storage, and Disposal Scenario

The treatment, storage, and disposal (TSD) scenario defines where each waste management step is planned to be accomplished for each waste matrix category within a particular waste subtype. For example, some waste may be treated and disposed onsite,

while some waste may be treated onsite and disposed at another DOE site (i.e., Waste Isolation Pilot Plant), and still other waste may be sent to an offsite commercial facility for treatment, with the residuals shipped back to the generating site for disposal.

Cost Curves and Modules

The SCM utilizes cost versus capacity curves developed in a series of Waste Management Facilities Cost Information (WMFCI) reports.^{3,4,5,6} The WMFCI breaks down treatment, storage, and disposal activities into discrete functions referred to as "modules." The SCM contains different sets of cost curves for a variety of modules. Some of the more common modules used in SCM include: waste retrieval, receiving/inspection, waste characterization, open/dump/sort, shredding/compaction, decontamination, aqueous waste processing (neutralization, precipitation, ion exchange, evaporation, carbon adsorption, distillation/extraction, etc.), incineration, grout stabilization, polymer stabilization, vitrification, oxidation, thermal desorption, storage, shallow land disposal, and engineered disposal.

Module Flow Scheme

In order to model waste management costs with the SCM, a set of modules must be identified for each waste stream to represent the desired TSD functions, based on regulatory, economic, logistical, and institutional constraints. For most waste streams, as few as 2 or 3 or as many as 10 or 12 modules may be required to represent all of the planned cradle-to-grave waste management activities. This module flow scheme information allows SCM to calculate costs from the module cost curves that are presented in the WMFCI reports.

Site Schedules

Another important category of information needed for the modeling of waste management activities is schedule data. What is the planned construction start date for a specified facility? How long is construction anticipated to last? What is the work-off period

for a given quantity of waste? Does the waste need to sit in storage for any period of time between generation and treatment or between treatment and disposal? Each of these schedule-related questions, as well as many others, should be answered so modeled costs are spread across the right time frame. If any of this type of schedule data is unknown, a set of defaults within the SCM can be used.

Cost Factors and Labor Rates

The final category of data required to model waste management activities and their associated costs in the SCM is cost factors. Factored costs are those that are calculated from other costs, and not estimated independently. For example, maintenance costs are factored from equipment costs, and design costs are factored from construction costs. A default set of cost factors is available in SCM, but when site-specific data is known, it should be used. Likewise, fully burdened labor rates are required to estimate labor costs through each phase of a particular waste management activity. Different labor rates for different skill levels can be input to SCM, and these rates can be customized at the site level.

FACTORS CONTRIBUTING TO UNCERTAINTY IN MODELED WASTE MANAGEMENT COST ESTIMATES

Data Limitations

Because the SCM relies on waste loads as the basis for all costs, any uncertainties in the waste data are passed directly into the cost estimates. Generally, waste inventory data is more established than waste generation projections. However, even data on the current waste inventory is limited because there is still a lot of uncharacterized and unknown waste at several DOE sites. The Federal Facilities Compliance Act required DOE sites to gain a better understanding of their mixed waste inventories, and the information needed for modeling and cost estimating is generally available for mixed waste in the form of the Mixed Waste Inventory Report. However, nonmixed LLW and TRUW data have not been developed and kept current at the same level of detail. Consequently, different sources yield different waste loads, and this contributes significantly to modeling and cost estimating

uncertainties.

Some waste generation projections are based on the continued operation of current facilities with known waste output rates; however, most projections are based solely on educated guesses (by knowledgeable site personnel) about proposed or hypothesized future activities and processes. This is a primary source of variability, since site plans change often and no real sound basis exists for future waste generation rates.

Differences in Site-Level Assumptions

Recently, DOE has made an effort to involve the state and local stakeholders in developing waste management plans. This has resulted in site-specific solutions to some of the waste problems. In some cases, negotiated agreements at one site may be built around a different level of compliance than those reached at another site. Both approaches may be perfectly valid; however, these differences in plans can be difficult to address from a modeling standpoint. Although models like the SCM are capable of being customized at the site level, some more generic assumptions are usually applied to simplify the analytical process.

Difficulty in Estimating Support Costs

One of the biggest challenges in modeling DOE's waste management costs is in estimating support costs. The DOE Waste Management Program (EM-30) budget includes costs for activities other than waste treatment, storage, and disposal. Some of these other categories of waste management costs include waste minimization programs, stakeholder involvement programs, environmental monitoring, oversight, program management, etc. Collectively, these activities make up what is referred to as support costs. These can be a significant portion (40–60%) of a site's waste management budget. Estimating and modeling these costs is difficult because some of these costs are buried in facility operations costs, while others may be shared across several facilities, programs, or waste types, and still others may be paid for by overhead accounts. Furthermore, some support costs are

fixed—they remain constant over time—and others are variable, usually a function of time, site budget, site mission, total waste processed, or some other factor that is difficult to predict. For all of these reasons, support costs contribute significantly to the uncertainty of life-cycle waste management cost estimates.

Another related factor that influences estimating waste management costs with the SCM is the fact that some site out-year estimates are not activity-based, or at least not dependent upon waste throughputs. Some DOE waste management facilities cost about the same whether they process 1,000 or 10,000 cubic meters of waste a year. In other words, these facility costs are head-count based rather than activity-based. This situation is difficult to model with the SCM, since the SCM was designed to calculate cost as a function of waste quantities processed.

Varying Levels of Integration Between EM-30, -40, -50, and -60 Programs

Another inconsistency between sites that impacts the accuracy of modeling and cost estimating is the level to which the various EM programs (30, 40, 50, and 60) have been integrated. Some sites have developed integrated baselines. That means that common or shared facilities have been considered and both EM-40 and EM-60 have identified waste types and quantities that they will generate and turn over to EM-30 for treatment or disposal. Integration also means EM-60 has worked out a schedule of when it will turn facilities over to EM-40 for decommissioning.

Many of the DOE sites have not fully integrated their baseline plans. Consequently, there may be gaps or overlaps between the plans of the EM programs. Due to these potential problems, a high level of uncertainty exists for any sites that have not developed a fully integrated baseline.

Some Processes Use Unproven or Undeveloped Technologies

In order to establish out-year baselines, the sites have been forced to plan the types of

waste management activities that they anticipate will be necessary to treat and dispose of known and projected quantities and types of waste. In some cases, sites may be planning on using technologies or processes that have not yet been proven on a production scale. For these types of plans, cost estimates are very speculative. Where there is no cost history or basis for modeling to use, uncertainties are extremely high. Along with the cost uncertainties, these unproven processes also contribute to schedule and performance issues.

Difficult to Estimate Impacts from Cost Savings Programs

In estimating the life-cycle waste management costs, DOE has tried to identify potential impacts from various cost savings programs. Among these are waste minimization, technology development, and productivity initiatives. Impacts from these types of programs are very difficult to quantify, and usually are based solely on assumptions. Consequently, cost savings programs also contribute to uncertainty in the final estimates, especially after cost to implement is considered.

External Factors—Changing Regulations, Political Environment, Stakeholders

Finally, and perhaps most significantly, there are several outside influences that create large uncertainties in life-cycle waste management cost estimates. These include impacts to planned waste management activities resulting from institutional, political, and regulatory forces. These types of influences are virtually unpredictable. Once again, in order to quantify any cost impacts from these external forces requires a set of assumptions to be applied over the life cycle of the program.

SUMMARY

Importance of Estimating DOE's Life-Cycle Waste Management Costs

The ability to estimate life-cycle waste management costs is very important to DOE. Cost information can be used to support strategic planning and policy/decision making

activities. Life-cycle costs need to be evaluated as one of the key parameters used to prioritize projects and compare alternatives. Because of all of the uncertainties associated with the out-year cost estimating basis, it is not critical that DOE be able to nail down the exact costs for future waste management activities. However, it is very important that DOE apply a valid, consistent cost estimating methodology that considers the major variables. In doing this, DOE can use the resulting life-cycle cost information to help assess the potential financial implications of its decisions.

Recommendations for Improving Life-Cycle Waste Management Cost Estimates

In order to estimate life-cycle waste management costs, DOE needs to establish a baseline set of planning assumptions and apply a consistent methodology for quantifying out-year costs. The SCM has been developed to provide a cost estimating basis for typical waste management activities, and it can be customized to reflect site-specific differences. However, in order to estimate out-year waste management costs, the DOE sites must develop a data set that can be used as the basis for estimates developed with or without the SCM. Since all of the data needed for cost analysis is not readily available, it must be developed based on the sites' baseline plans. More uncertainty is introduced into cost analysis as the planning horizon is stretched out to encompass the life-cycle of waste management activities at the DOE sites. Although this uncertainty cannot be eliminated, there are some areas where future efforts can be focused to try to keep it to a minimum:

- A more comprehensive set of waste data needs to be developed for the DOE complex. Specific attention needs to be placed on out-year projections for both mixed and nonmixed wastes and any current inventory of nonmixed waste. For cost estimating purposes, the type of data needed includes waste volumes and waste matrix categories.
- A work breakdown structure that is generally applicable for all waste management costs and detailed enough to provide specific categories for all support costs needs to be assigned. All sites' waste management costs should

be developed in a format consistent with this EM-30 work breakdown structure.

- Cost savings from programs like waste minimization and technology development should not be arbitrarily applied to baseline estimates. If there is a sound basis for a particular cost avoidance or reduction, and a quantified savings can be attributed to a specific activity, then it should be included. This also applies to productivity initiatives.
- A large uncertainty is introduced to life-cycle estimates by external factors (changing regulations, politics, institutional issues, stakeholder priorities, etc.). These factors can be minimized by involving the appropriate stakeholder groups in the baseline planning process.

CONCLUSION

The DOE has now developed a life-cycle baseline for its EM Program. In formulating this total program estimate, DOE and the various sites have had to put some thought into what future activities will be necessary to clean up the complex. In order to establish the basis and variability of waste management costs, information about these future activities has been assembled and used in models that provide life-cycle cost estimates. To date, the information needed for modeling waste management activities has come from several sources, and carries a high level of uncertainty. The DOE's life-cycle waste management cost estimates can be improved if the uncertainties associated with the site data can be decreased. EM-30 has taken a step in this direction by instituting a data call as part of the 1996 BEMR development process. Further improvements in modeling and cost estimating of waste management activities can be expected as the sites firm up their out-year planning basis.

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THE ROLE OF RISK AND COST BENEFIT IN PROGRAM BUDGETING

Carol J. Henry, Ph.D. and Justine Alchowiak
U.S. Department of Energy
Office of Environmental Management,
Office of Integrated Risk Management
1000 Independence Ave., S.W.
Washington, DC 20585
(202) 586-7150

ABSTRACT

The primary Environmental Management (EM) program mission is protecting human health and the environment. EM is currently facing a decreasing budget while still having to deal with competing requirements and risks to workers, public, and environment. There has been no consistent framework for considering in an integrated fashion the multiple types of risks and hazards present in the nuclear weapons complex. Therefore, to allocate resources during the budget process, EM is using risk, long term costs, mortgage reduction, compliance issues, and stakeholders concerns to prioritize the funding of activities. Risk and cost-benefit analysis are valuable tools to help make decisions to reduce risks to health, safety, and the environment in a sensible and cost-effective manner. Principles for priority setting using risk analysis are to seek to compare risks by grouping them into broad categories of concern (e.g., high, medium, and low); to set priorities in managing risks to account for relevant management and social considerations; to inform priorities by as broad a range of views as possible, ideally with consensus; and, to try to coordinate risk reduction efforts among programs. The Draft Risk Report to Congress, *Risks and the Risk Debate: Searching for Common Ground "The First Step,"* provides the first link between budget, compliance requirements, and risk reduction/pollution prevention activities. The process used for the report provides an initial framework to capture the spectrum of risks associated with environmental management activities and to link these risks in a qualitative fashion to compliance and the budget.

INTRODUCTION

The Department of Energy's Office of Environmental Management was created in 1989 to manage the legacy of 50 years of nuclear weapons production and research at 137 sites in over 30 states and territories. Environmental Management's program's responsibility is to address the most immediate, urgent risks to human health and the environment as well as manage the long-term contamination and safety threats.

EM is currently facing a decreasing budget while still having to deal with competing requirements and risks to workers, public, and environment. The Department recognizes that credible risk assessment and good risk management are needed to meet its primary mission of protecting human health and the environment.

As stated by Mr. Thomas P. Grumbly, Assistant Secretary for Environmental Management, in a speech on August 21, 1995, to the National Research Council's National Forum on Science and Technology Goals: Environment, that one of the principles that must guide and inform our goals in environmental policy making is the application of risk management into our environmental programs in order to drive down costs.

The Department of Energy favors the use of sound science in the conduct of risk assessment, and the use of risk assessments and cost benefit analysis as tools for decision making and in establishing priorities and sequencing work. A properly structured risk assessment program can have significant benefits for the Environmental Management Program. Incorporating risk management into the policy making and goal setting processes forces institutions to pose the question: "how much risk reduction at what cost?" Most important in this process is allowing society to become involved in the debate as to how much should be spent to address specific risks. The paper will provide guidance on how risk and cost benefit analysis may be integrated into Environmental Management's programs.

USE OF RISK AND COST BENEFIT ANALYSIS FOR PRIORITY SETTING

While many different risk analysis systems exist within the Department of Energy complex, there was no consistent framework for considering in an integrated fashion the multiple types of risks and hazards present across all programs within a site or across all sites. In addition, these systems are not linked to the Department's budgeting and planning process. Since the Department can not attempt to address all risks simultaneously or address certain relatively lower risks as rapidly as some stakeholders would like, an integrated risk analysis and risk management process that meets the current and future need of the Department decision-makers and their stakeholders is needed. There are a number of tools

that can be used to prioritize activities. Risk is one management tool which can be use for priority setting and to help managers sequence the work to reduce risks.

Cost-benefit and cost effectiveness analysis are other tools which can be used to help managers make informed decisions on resource allocation issues. As stated by the National Research Council in *Ranking Hazardous Waste Sites*, cost-benefit and cost-effectiveness approaches share three basic ways of structuring priorities:

- select the activities in order of increasing cost (rank activities that achieve a specified level of output with the least cost);
- select the activities in decreasing order of benefit or effectiveness within a given budget constraint (maximize benefits subject to a specified level of cost);
- allow activities and their decision parameters to vary, evaluate the resulting variations in costs and benefits, and then rank activities according to the ratio or the difference (whichever is more appropriate) between benefits and costs.

The Office of Management and Budget in Circular A-94 defined benefit-cost analysis as a systematic quantitative method of assessing the desirability of government projects or policies when it is important to take a long-term view of future effects and a broad view of possible side-effects, and cost-effectiveness as a systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits for a given objective. In identifying and measuring costs and benefits, the assumptions used in the analysis must be explicit, the rationale behind them must be documented, and their strengths and weaknesses must be reviewed in order for the analysis to be credible and can be replicated by independent reviewers. In addition, the sources and nature of uncertainty in the data used to do these types of analysis must be characterized. Decision makers should recognize that both tangible and intangible benefits and costs need to analyzed. For example, a “traditional cost benefit” analysis may rely on a quantitative risk assessment that provides number of lives lost combined with an estimated dollar value per life to determine an estimate of the “benefit” of saving these lives. However, if the many assumptions and estimates made in this quantitative analysis are not transparent and agreed upon by all of the affected groups, then the analysis may not be appropriate; particularly, on the benefits side.

Therefore, "who" bears the costs, risks, and benefits matters as well as who does the various analysis in order to have a credible tool that can be used to assist managers in prioritization processes.

The Congress urged the Department to begin to develop a risk-based approach for sequencing or prioritizing its activities. Specifically, the Conference Report of the Energy and Water Development Appropriations Subcommittee for Fiscal Year 1994, indicated that the Department "...needs to develop a mechanism for establishing priorities among competing cleanup requirements." In response to the Congressional request, the Department initiated a major effort to define its risks in a site-by-site basis are in a systemic way. The Department announced its intent to establish more credible and consistent methods of conducting risk assessments at its sites and facilities.

The Department of Energy has adopted a set of principles for using risk analysis developed by an interagency working group. The principles are designed to be a first cut at defining risk analysis, its purposes, and the principles to be followed by the Department of Energy if it is to be done well and credibly. These principles include four major categories:

- Risk Assessment. Use the best available information from all sources; all judgements and assumptions should be explicitly stated.
- Risk Management. Analyze the distribution of risk and costs/benefit of potential risk management strategies, using the best available tools and techniques.
- Risk Communication. State risk management goals, assumptions, uncertainties and comparisons clearly, accurately, and meaningfully; provide public access in a timely manner.
- Priority-Setting. Compare risks by grouping them into broad categories of concern (e.g., high, medium, low) and identifying the population at risk; include as broad a range of views as possible, ideally with consensus.

The Department's draft Risk Report to Congress entitled *Risks and the Risk Debate: Searching for Common Ground* (hereafter referred to as the Draft Risk Report) represents a first step toward developing a consistent approach to evaluating the risks to human health,

worker safety, and the environment posed by conditions at the Department's sites and facilities. The process used for the report provides an initial framework to capture the spectrum of risks associated with environmental management activities and to link these risks in a qualitative fashion to compliance and the budget.

An integrated qualitative risk evaluation process was developed by the Office of Integrated Risk Management within the Environmental Management program for the Draft Risk Report. The intent of the qualitative approach is to develop a consistent, Environmental Management-wide framework for capturing and communicating the information from the various site-developed prioritization approaches. The process is not designed to replace existing approaches, but rather to use risk information from them and aggregate it to a higher level to make it more relevant to senior managers thereby increasing the understanding of risk activities particularly as related to compliance requirements and budget allocations across the EM programs. Department of Energy field program managers with expertise about these activities at their site categorized the activities. This allowed the Department to capture the full spectrum of risks associated with all currently planned environmental management activities and to determine how Environmental Management is currently funding its risk/prevention activities.

The information provided a baseline which both DOE and its stakeholders can use to engage in dialogue about the risks and costs associated with the various Environmental Management activities at the site, the assumptions used to categorize the risks, and types of information that is available or that needs improvements both risk communication and risk prioritization. This baseline information was used in the FY 1997 internal budget review process as one tool in the decision making process to determine where Environmental Management should allocate its funding and establishing priorities or sequencing work.

To allocate resources during the Fiscal Year 1998 budget process, EM is using risk, long term costs, mortgage reduction, compliance issues, and stakeholder concerns to prioritize the funding of activities. Risk and cost-benefit analysis are valuable tools to help make decisions to reduce risks to health, safety, and the environment in a sensible and cost-

effective manner. Principles for priority setting using risk analysis are to seek to compare risks by grouping them into broad categories of concern (e.g., high, medium, and low); to set priorities in managing risks to account for relevant management and social considerations; to inform managers of as broad a range of views as possible, ideally with consensus; and, to try to coordinate risk reduction efforts among programs.

FUTURE CHALLENGES

Additional effort is needed to provide a common understanding and consistent framework for comparing risks and hazards throughout the complex. Improvements are needed in the qualitative evaluation process to link risk prioritization, the budget, and compliance activities. To assist in this effort, external review and advice was sought. The Environmental Management Advisory Board, an advisory group chartered under the Federal Advisory Committee Act, was requested to review the Draft Risk Report and the qualitative evaluation process used to develop information linking risk, compliance, and budget for all Environmental Management activities. The Environmental Management Advisory Board recognized the process used to develop the Draft Risk Report as an important first step in linking risk, compliance, and budget information. The Board endorsed the use of the process and endorsed the recommendations made to improve the data quality and assure consistent application and interpretation of those data. The recommendations were:

- The categorization of activities needs to be consistent across sites, clear , recognizable and meaningful.
- A “tiered approach” should be implemented by the Department to further improve the risk assessment/risk management process at the site level, across the sites, and at the Departmental level. The tiers would consist of experts (internal and external to the Department of Energy), stakeholders, and regulators. This method would ensure cross-site input, thereby reducing bias, promoting consistency, and building credibility for the process.
- Future land use and land use assumptions are critical components of the process.
- The entire process should be fully integrated with the budget, long-term cost projections, future land use planning, and stakeholder involvement.

As Environmental Management goes forward to use this process/framework in the FY 1998 budget and planning process, implementation plans are being prepared to these recommendations are being incorporated. However, the process is iterative as policy decisions such as land use options are determined for each site, or as new requirements such as new regulations or compliance agreements are implemented, and as risk information improves and more data are available to reduce uncertainties and to increase the confidence level of the data. The Department believes that to have this framework fully developed and implemented will take more than one year but that the lessons learned each year will be incorporated into the framework and that the Department will continue to work on enhancements for risk evaluations throughout the year.

The Department must continue to make progress in its clean up activities and in reducing risks at its sites. Since the budget planning cycle is yearly, the Department must use the tools it has available each year in making the budget decisions. The qualitative risk evaluation process has indicated data gaps and uncertainties and the Department will continue to improve its data collection process. However, the process must be evolutionary to take into account data on individual risk assessments and other data sources to enable managers to use a risk based decision making process and to set priorities for allocation of resources across the complex.

The Department recognizes that stakeholder involvement is important to both the quality of information and the credibility and validity of the decision making process. A variety of approaches are needed to meaningfully engage stakeholders in the risk and budget issues so that stakeholders have access to accurate, understandable, and timely information; sufficient time to be able to assimilate the information; and an opportunity to be heard during the decision making process. For example, the Department assisted stakeholders in participating in the 1997 budget process by preparing a guide entitle *Public Participation in the Fiscal Year 1997 Office of Environmental Management Budget*. This document laid out the decisions to be made, key documents that provide the decision-makers with information upon which to base their decision, and identification of opportunities for stakeholder involvement. As we go forward, the Department needs to improve its communications tools

for both risk and budget issues so that stakeholders can continue to participate in the process in a meaningful way.

The Environmental Management program must continue to improve the discussion and framework for risk analysis and cost benefit analysis, including more development of principles for cost benefit analysis. Environmental Management is using qualitative methods for these analysis to allow managers to use both qualitative and quantitative data in the process and to balance all of the competing priorities in the decision making process and to allocate the resources in ways that are cost-effective and cost-efficient. In addition, the process used to reach the decisions should be transparent so that stakeholders can have access to and provide input to the information used in the various analysis that were used in the decision making process.

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A PERSPECTIVE ON THE STATES' ROLE IN THE DEPARTMENT OF ENERGY'S
OFFICE OF ENVIRONMENTAL MANAGEMENT BUDGET PROCESS

Jonathan P. Carter and Peggy Hinman
Carter, Brock & Hinman, P.A.
877 W. Main St., Suite 610
Boise, ID 83702
(208) 336-1776

ABSTRACT

Responding in 1994 to proposed budget reductions and predicted funding shortfalls, the Office of Environmental Management at the Department of Energy began working closely with its regulators and stakeholders to prioritize activities. In a series of national and site specific meetings held with representatives of states, the Environmental Protection Agency, Indian tribes and the public, the Department of Energy brought regulators and other stakeholders into its budget development process in a "bottoms up" approach to the prioritization of activities at each of its sites.

This paper presents an overview of this process which began last year and will highlight its unique cooperative nature. This paper will assess ways of institutionalizing this process. It also identifies issues to be addressed in resolving matters related to future budgets. Areas of concern to the Department of Energy's host states and their regulators will be identified as they relate to waste management, cleanup and facility transition activities.

BACKGROUND

In early 1994 the Department of Energy (DOE) acknowledged that proposed budget reductions and predicted funding shortfalls meant it would not be able to meet its obligations established by compliance and clean-up agreements entered into with states. By the end of 1994 it became very clear that the days of ever increasing budgets would not be enjoyed by Tom Grumbly, Assistant Secretary for the Office of Environmental Management (EM), who was then encountering a Congress elected to balance the budget.

DOE and the states were confronted with the unpleasant task of choosing to litigate over these agreements, renegotiate them, or otherwise come to a mutually acceptable accommodation. Most states that are host to DOE facilities are the primary environmental regulators at those sites pursuant to their authority under the Resource Conservation and

Recovery Act and cleanup agreements entered into under the Comprehensive Environmental Response Compensation and Liability Act. Accordingly, the states and not the Environmental Protection Agency (EPA) were the focus of DOE's attention regarding budget shortfalls.

In the Summer of 1994, Tom Grumbly met with key governors at the annual meeting of the Western Governors' Association in Lake Tahoe to lay before the governors DOE-EM's funding predicament. The governors agreed it made no sense to litigate, but they insisted that DOE provide them with sufficient information to assess the nature and extent of projected shortfalls. If convinced of the seriousness of such shortfalls, the governors also agreed that they would work with DOE. Mr. Grumbly and the governors also agreed on the need for a process giving states a stronger role in the formulation of the DOE-EM budget to ensure that limited funds would be spent on those activities in their states that were of greatest concern to state regulators and local stakeholders.

Subsequently, the states agreed that DOE would confront a funding shortfall adversely affecting its ability to comply with milestones and schedules contained within compliance and cleanup agreements. The nature and extent of the shortfall remained an issue of debate.

Despite some misgivings by the Office of Management and Budget (OMB), DOE-EM began a process of working with its regulators and stakeholders to open up its budget process and prioritize EM activities at DOE sites. In February 1995, DOE held a national meeting with representatives of states, tribes and the EPA to discuss DOE-EM's budget and related compliance agreement issues, including implementation of the Federal Facility Compliance Act (FFCA). In remarks at that meeting, Tom Grumbly presented a proposal for "doing more with less." His goal was to develop a budget/prioritization process for activities identified in DOE-EM's budget for fiscal year (FY) 1997 that included active participation by regulators and local stakeholders. The four major aspects of his proposal dealt with resource allocation, productivity savings, economic development, and compliance agreements.

This budget/prioritization process was implemented primarily through DOE's FFCA implementation process by DOE's Policy Coordination Group (PCG) and the National Governors' Association's (NGA) FFCA Task Force. A Steering Committee of representatives of relevant DOE-EM offices directed the budget/prioritization process for the department.

The keys to this process included a new method of "resource allocation" which used a "bottoms-up" integrated prioritization of EM activities at each of the DOE sites, "unfencing" of funds, and equitable allocation of funds to sites. Compliance agreements were proposed to be restructured to reflect budget realities and priority activities. DOE proposed enforceable two to three year "rolling" milestones tied to multi-year appropriations that would commit it to perform identified activities. It was proposed that short-term milestones would be consistent with longer term plans at each site and that existing long term milestones would not be enforceable.

As the process developed, the focus of the sites and states turned to the resource allocation and compliance agreement issues as the most urgent matters and the two elements over which the participants believed they had some degree of control. Economic development became less important as it became clear that DOE did not even have enough funding to meet the requirements of compliance agreements. Participants agreed with the concept of productivity savings, but implementation was problematic due to a failure to agree on a method of incentivising those savings at the site level.

Efforts were made in the budget process to "unfence" funds from program lines and allocate those funds instead by site. DOE was constrained, however, by its appropriation structure which focuses on the type of activity being conducted rather than on where the work is being done. DOE-EM and the states agreed that allocation of the budget by site rather than program would provide more flexibility for each site to engage regulators and stakeholders in good faith discussions on how to set priorities based upon the greatest risks and needs at that site.

Some states and public interest groups argued against any type of prioritization. Their concerns were that "prioritization" was simply an excuse by DOE for not abiding by its compliance and cleanup commitments. Under this view, any agreement to prioritize would result in less compliance and less cleanup. These interests argued for nothing short of full funding. Further, many states argued that a nationwide prioritization scheme based on risk would result in funding at their DOE sites being diminished in comparison to other sites.

DOE-EM attempted to address these issues. It responded to states' concerns about a headquarters-based "centralized priority system" that determined schedules and priorities by creating a "bottoms-up" approach that would prioritize activities at the site level. The success of this approach depended on a good dialogue between sites and regulators early in the budget process, so that states would be "partners" in identifying funding and planning for activities at their sites.

Further, DOE agreed to allocate funding to DOE sites based on the "fair share" concept discussed in the Keystone dialogue, where the sites' budget allocation was a percentage of the previous year, and where the percentage was similar for all sites. This "equitable" allocation of funding was modified, however, to provide additional funding for certain priority activities and to reward sites for special achievements. For example, additional money was budgeted to Fernald to reward a commitment to future land use and to INEL to fund a proposal that removed "stovepiping" by integrating waste streams for treatment and disposal to gain national efficiencies and cost savings.

In prior years, DOE attempted to fund all compliance agreement requirements first. For FY 97, DOE-EM took an integrated approach to the budget and looked beyond compliance requirements to focus on funding the highest risks in the complex (e.g., Recommendation 94-1 of the Defense Nuclear Facilities Safety Board regarding special nuclear materials). Draft priority lists were developed by operations offices for EM activities at sites and shared with regulators and stakeholders for comments. Sites worked closely with host states, tribes and local stakeholders to identify priorities in FY 97 EM budget proposals at each site. This input was provided to DOE-HQ for discussion at the EM Internal Budget

Review (IRB) in May 1995 and for incorporation into the FY 97 budget. DOE-HQ's criteria for "decisions at the margins" to be made during the IRB meeting were communicated to regulators and stakeholders and use in prioritizing activities at sites.

A second national meeting was held in April 1995 among representatives of DOE, states and EPA to review the FY 97 budget process and the status of site/state budget discussions. As a part of that meeting, DOE conducted a "workshop" on compliance agreement issues and explained the concept of rolling milestones. In May, EM held the IRB meeting and made recommendations on sites' budgets. Field offices prepared fact sheets describing the changes in each site's budget request as a result of the IRB deliberations and the rationale for, and impact of, those changes. These fact sheets were shared with regulators and stakeholders at each site and feedback was requested. Sites were directed to identify any outstanding regulator or stakeholder concerns regarding budget priorities and impacts on existing and pending compliance agreements. This input was compiled by DOE-HQ for discussion at a third national meeting that was held in early June 1995.

At the June meeting, Mr. Grumbly provided an overview of the DOE-EM FY 97 budget submission which was based on site budgets and priorities developed at the site level with regulators and stakeholders. He also discussed the results of IRB meeting and of "decisions at the margin." Opportunities were provided for participants to make additional recommendations on the FY 97 budget, site priorities, compliance agreements and related issues. States and stakeholders generally agreed that the process had worked well and should be refined and continued in the future years as DOE-EM budgets were projected to become even tighter.

BUDGET PROCESS

Through the "bottoms up" nature of the FY 97 budget review and prioritization process, regulators and stakeholders gained a better understanding of the EM budget and the projected limitations on funding for FY 97 and out years compared against the department's milestone commitments and obligations. This understanding created an environment where

regulators and stakeholders were more willing to prioritize EM activities at their sites and fostered a more collaborative "ownership" approach to resolving EM issues. In most cases, when regulators and stakeholders understood budget limitations and their impacts on specific activities, they were more likely to soften their demands. DOE sites, likewise, gained a better understanding of their host states' and local stakeholders' concerns and priorities. A key to the department's success was the good faith and trust engendered by closely working with representatives of the states and stakeholders. The NGA Task Force established to implement the FFCA provided an appropriate mechanism for DOE to work with the states collectively and served as a good conduit for the exchange of information.

Participation by state and local stakeholder representatives in the budget process quelled much opposition to funding reductions. DOE site officials should continue to work with Site Specific Advisory Boards (SSAB), other local stakeholders and site regulators by holding briefings and working meetings to develop priority lists and activity data sheets before submitting them to headquarters. This participation in the development of each site's budget proposal will strengthen that proposal and improve understanding and teamwork.

The states indicated that the budget/prioritization process initiated for the FY 97 budget was good. Most states worked well with their counterparts at DOE sites. Certain states had concerns that specific budget items were not adequately addressed by DOE-EM's proposed FY 97 budget. Several states voiced concerns about the identification of activities in the FY 97 budgets for their DOE sites. In many cases, states felt environmental restoration activities involving actual cleanup had been misidentified as "studies" and thereby obtained a lower priority from DOE-HQ when considered for funding.

A major concern of the states relating to the DOE budget that was not addressed by DOE-EM is the issue of expenditures among the its Assistant Secretary level offices. In particular, states did not believe that the EM Office should suffer budget cuts disproportionate to the other DOE Offices, in particular, Defense Programs. This is an issue that should be addressed at the Secretarial level within DOE. Further, states were not convinced of the rationality and need for large allocations of funds for "mortgage" expenses.

Generally, the states did not believe that DOE-EM had presented good budget information in this area and that additional work was necessary to obtain a better understanding of these costs.

DOE-EM's "Criteria for Decisionmaking—FY 1997 Budget Formulation" dated March 17, 1995 was used by sites and regulators to look at risks in the budget/prioritization process. This document provided a starting point for incorporating risk into the process as these criteria focused on funding the highest risks first and were used in the IRB for allocating funding "at the margins." Most involved in the budget/prioritization process tacitly agreed that risk provides an appropriate basis upon which activities can be prioritized and will be the key driver for waste management and clean-up budgets in the future.

The June 1995 Draft Risk Report to Congress prepared by DOE entitled "Risks and the Risk Debate: Searching for Common Ground, 'The First Step'" addresses how EM has evaluated risk throughout the weapons complex and provides a link between budget, compliance agreements and risk activities. This Draft Report links the risks associated with DOE's environmental management activities in a qualitative fashion to compliance and budget issues and provides an approach to establishing priorities for activities at DOE facilities. Many states have devised their own risk-based prioritization systems. The report *Risk in Environmental Decisionmaking: A State Perspective* (National Governor's Association 1994), lays out several choices that may be appropriate to the task confronting DOE and its host states in prioritizing budget expenditures. DOE's Draft Risk Report should be improved with input from states and tribes so that useful policy guidance can be provided in establishing priorities in developing the DOE-EM budget. DOE and the states need to work together to quantify risks, and develop budgets that give priority to activities at sites based on those risks.

Additional work also needs to be done on how budget cuts should or will be shared equitably on a "fair share" basis across sites. DOE needs to consider how it can formalize a process where good performance, cost reductions and specific public concerns can be part of the formula for allocation of funding to a site. Exceptions could be made for programmatic

priorities and where a site could show an adverse impact on a locally significant activity. Cleanup activities that reduce the EM mortgage could be given preference. Further, an incentive system to sites for "productivity savings" could be part of the guidance—for example, a percentage in "savings" could be returned to priority projects at those sites that follow headquarters' guidelines for reducing the EM mortgage or obtaining future savings.

In its "State Taskforce Report Environmental Obligations at Federal Facilities and an Analysis of the Environmental Management Program of the Department of Energy" dated June 2, 1995, states provided their perspectives on improving DOE-EM's program and addressed a number of budget issues. In particular, the states point out that while they are willing to continue to work with DOE in its budget formulation process to address shortfalls, states also want DOE to increase its efficiency by reducing the infrastructure costs of maintaining former weapons complex facilities, contract reform, and better oversight of contractors. The states point to the huge cost of simply maintaining the status quo at DOE facilities and the problem that current budgets do not allow for significant progress in bringing these costs down (e.g., \$1.6 billion for nuclear material and facilities stabilization "does nothing to reduce risk—it simply keeps the plants operating and from becoming more dangerous").

Further, the overriding concern voiced nationally by governors and attorneys general has been with regard to states' authority to continue to regulate environmental compliance at DOE facilities, even in the face of funding shortfalls. In attempting to retain and expand their regulatory authority over DOE facilities, the states point out that they acted reasonably and cooperatively with DOE-EM in the FY 97 budget process to accommodate funding problems and missed compliance agreement milestones. They also point to their willingness to renegotiate agreements with the department to address funding limitations and technical constraints (e.g., Hanford and Rocky Flats cleanup agreements). Thus, although states clearly are not willing to relinquish any legal oversight authority over DOE, they are willing to accommodate budget shortfalls.

In fact, over the course of the budget discussions with DOE, many state regulators gained a better understanding of the rigidity created by long-term milestones in compliance and cleanup agreements. Most states have become willing to adopt enforceable rolling milestones for short-term (two to three year) commitments. However, states continue to insist that long-term enforceable milestones, "end points" or written plans which establish how DOE will fulfill its environmental restoration and waste management obligations at each site are necessary to "drive" action by DOE. The enforceability of these commitments remains an issue, but re-focusing the discussion away from hard and fast long-term "milestones" to the flexibility of "plans" is a step in the right direction.

A switch in focus in this regard may require a process with the states, tribes and local stakeholders that addresses comprehensively the priorities at each site and EM program priorities nationwide. The acceptability of any such process will depend on a "bottoms up" approach that is based on the needs and perceptions at each site. These site priorities, however, should be tested against criteria developed by DOE-HQ that take into account risk and national program needs. DOE, states, tribes and stakeholders should collaborate in refining DOE's Draft Risk Report, so criteria is formulated that it can be understood and accepted by the sites, regulators and local stakeholders.

Such a planning process could be built into and around DOE's ongoing budget process to assist in priority setting and to resolve problems created by long-term milestones in compliance agreements. Long range vision/mission statements could be developed for each site that would assess a complete range of options for future missions among all DOE programs at the site based upon local input. Future land use recommendations and life-cycle impacts would provide the basis for vision/mission statements by addressing site development and comprehensive planning, environmental remediation and waste management decisionmaking, and reuse of surplus land and facilities. More specific site plans that would respect sites' vision/mission statements could be developed that would guide site priorities and schedules. Budget projections for activities at sites would establish the parameters of these plans, but they also could incorporate long-term or end points for DOE activities.

Compliance agreements with enforceable two to three year rolling milestones would provide the mechanism for implementation of site plans.

DEVELOPMENT OF FUTURE BUDGETS

The consensus among state and departmental officials is that the budget review and prioritization process should be continued to deal with upcoming actions on the current budget (FY 96) and the next budget cycle (FY 98). Improvements to the process would include earlier involvement of field personnel and stakeholders in priority setting and the development of initial site level requests. It also would be appropriate to address the mechanics of how issues shaping the FY 98 request will be tracked by DOE-HQ. In refining the process, DOE will need to focus on key activities for sites and headquarters, including: increasing visibility into base budgets; promoting standardization of methodology so numbers can be compared across sites and programs (e.g., risk); using land use as a means of guiding priorities for cleanup; and providing key oversight and policy functions. For example, in the FY 97 budget most "productivity" savings were realized simply by cutting base budgets. Greater visibility into and consistency in evaluating base budgets could increase savings and make them more acceptable.

A consensus exists for DOE-EM to build on the process developed for the FY 97 budget and continue it as an ongoing process of planning and prioritization with an effective flow of information among DOE and its regulators and stakeholders about priorities and funding. Meetings should occur at the site level for local input regularly, particularly to coincide with the sites' development of integrated priority lists and draft budgets. Information about cuts and activities targeted for elimination or support should be conveyed.

DOE could look across several fiscal years and apply this process to a three year budget cycle—the current fiscal year and the next two (FY+1 and FY+2)—at three important time periods in the budget process. Meetings among representatives of DOE sites and headquarters, states, tribes and stakeholders could be held in October/November to review performance during the completed fiscal year and to review DOE's submittal to OMB

for the the FY+1 budget, in February/March to review the President's submittal to Congress for the the FY+1 budget and to begin obtaining information to formulate the FY+2 budget, and in May/June to review the results of the IRB meeting on the budget for FY+2.

CONCLUSION

The budget/prioritization process implemented by DOE-EM in 1995 for the FY 97 budget worked well. As DOE's budgets become tighter, it has no choice but to work even more closely with states who have environmental regulatory enforcement authority over DOE's facilities. In fact, the process implemented this year gave states more of a sense of "ownership" in their DOE sites and resulted in many good suggestions by states and stakeholders.

Collaboration among DOE, states and stakeholders to further refine priority setting models and planning processes for EM activities at DOE sites is necessary. Valid and cooperative implementation of priorities tied to funding can continue into the future if done in a "bottoms up" manner beginning at the site level. However, states are likely to insist on "end points" or deadlines by which DOE is to initiate or complete certain activities. This process should continue to feed into a larger national group of DOE, state and stakeholder representatives on a periodic basis so common and interrelated issues can be discussed and resolved.

**THE CONGRESSIONAL VIEWPOINT: DEFICIT REDUCTION
AND RISK LEGISLATION**

**H. Elliot Chakoff
Senate/House Staff Member**

ABSTRACT

This presentation will provide a current congressional status of legislation related to low-level waste and DOE cleanup. Key legislation discussed will include S. 755 for Privatization of the Uranium Enrichment Corporation and the markup of H.R., 1020, the Nuclear Waste Legislation. In addition, the session will include a discussion of legislation related to the approval of the Texas compact.

RISK-BASED DECISIONMAKING IN THE DOE: CHALLENGES AND STATUS

Carol J. Henry, Ph.D., Justine Alchowiak, Marina Moses, Ph.D.,
Mark Gilbertson, and Michael Godin
U.S. Department of Energy
Office of Environmental Management, Office of Integrated Risk Management
1000 Independence Ave., S.W.
Washington, DC 20585
(202) 586-7150

ABSTRACT

The primary mission of the Environmental Management Program is to protect human health and the environment, the first goal of which must be, to address urgent risks and threats. Another is to provide for a safe workplace. Without credible risk assessments and good risk management practices, the central environmental goals cannot be met. Principles for risk analysis which include principles for risk assessment, management, communication, and priority setting were adopted. As recommended, Environmental Management is using risk-based decision making in its budget process and in the implementation of its program. The challenges presented in using a risk-based Decision making process are to integrate risk assessment methods and cultural and social values so as to produce meaningful priorities. The different laws and regulations governing the Department define risk differently in implementing activities to protect human health and the environment, therefore, assumptions and judgements in risk analysis vary. Currently, the Environmental Management Program is developing and improving a framework to incorporate risk into the budget process and to link the budget, compliance requirements and risk reduction/pollution prevention activities.

INTRODUCTION

In the United States, the nuclear arms race resulted in the development of a vast research, production, and testing network that became known as the "nuclear weapons complex." The complex consisted of 2.3 million acres of land and 120 million square feet of buildings and ranged in diversity from a vast tract of land in the deserts of Nevada to warehouses in downtown New York City that once stored uranium.

The Environmental Management program bears the responsibility for stabilizing, treating, and cleaning up hazardous and radioactive wastes and materials left from more than 50 years of research, development, testing, production of nuclear weapons, and other defense

and non-defense activities. The program also manages wastes currently being produced during nuclear energy research and development, basic science research, and ongoing missions.

The decisions involved in managing these problems include long-term environmental and public safety concerns, national security issues such as nuclear proliferation, and federal budget limitations. To address these risk management issues, the Environmental Management program developed the following strategic goals:

- Address truly urgent risks
- Assure worker safety
- Assume managerial and financial control
- Become outcome oriented
- Focus technology development
- Become more customer/stakeholder oriented.

The future course of the Environmental Management program will depend on a number of fundamental technical and policy choices, many of which have not yet been made. The Department is facing a number of difficult questions regarding the management of risks including:

- How can special nuclear materials be managed safely?
- Where will the waste generated in the cleanup process be disposed?
- How will land and facilities be used in the future?
- To what extent can access to Environmental Management facilities and residual contamination be controlled, and how should this factor be considered in determining appropriate levels of cleanup?
- How can workers be protected during the cleanup of sites and facilities?
- How can sensitive ecosystems be protected during remediation?
- How can valuable water resources be protected from further degradation?

Since its formation six years ago, the Environmental Management Program has been beset by public and Congressional concerns over priorities and the pace of cleanup versus total program costs. The Department of Energy's Office of Environmental Management's overall budget grew from approximately \$2.3 billion in 1990 to approximately \$6.5 billion in 1994. Concerned about this rapid budget increase, yet sensitive to the public concerns about the risks posed by the department's sites, the Congress urged the Department to begin to develop a risk-based approach for sequencing or prioritizing its activities. Specifically, the Conference Report of the Energy and Water Development Appropriations Subcommittee for Fiscal Year 1994, indicated that the Department ". . .needs to develop a mechanism for establishing priorities among competing cleanup requirements." Further the Department was directed to "submit by June 30, 1995 a report. . .evaluating the risk to public health and safety posed by the conditions at weapons complex facilities that are addressed by compliance agreement requirements." The committee emphasized that it did "not intend [for] the Department to perform an exhaustive formal risk assessment, as that term is frequently used, of the thousands of cleanup activities required by compliance agreements. Instead, the Department [was] directed to estimate the risk addressed by cleanup requirements on the basis of the basis of the best scientific evidence available."

In response to the Congressional request, the Department initiated a major effort to define its risks in a site-by-site basis are in a systemic way. In re-evaluating the Environmental Management program in 1994, the Department announced its intent to establish more credible and consistent methods of conducting risk assessments at its sites and facilities. The Department of Energy favors the use of sound science in the conduct of risk assessment, and the use of risk assessments and cost benefit analysis as tools for decision making and in establishing priorities or sequencing work. This paper will provide a status of risk-based decision making within DOE and its future challenges.

SETTING THE STAGE FOR RISK MANAGEMENT

Reduction of major risks to the public and workers is a top priority of the Environmental Management program. Given current and future budget realities, the

Department cannot attempt to address all risks simultaneously, nor to address certain relatively lower risk activities as rapidly as some would like. What is clearly needed is an integrated risk assessment and management process that meets the current and future needs of the Department, as well as stakeholders. Yet there have been many questions raised regarding risk assessment: not able to define what the risks are on a site-by-site basis and in a systematic way; in addition, "who" performs the risk assessment matters; there are many methodology questions about identifying and assessing risks as well as uncertainty, data gaps, and concern over the quality of information.

Knowing these controversies surrounding risk and the use a risk-based approach for environmental management, two years ago the Department requested the National Academy of Sciences-National Research Council to determine whether and how risk and risk-based decisions could be incorporated into the Environmental Management program. The National Research Council study resulted in the January 1994 report *Building Consensus through Risk Assessment and Management of the Department of Energy's Environmental Remediation Program*. In the report, the Council identified the major obstacles, issues and barriers to implementing a risk-based management approach. The report concluded that the use of risk-based approach could help compare outcomes, build consensus, and gain early public involvement to include cultural, socioeconomic, historical, and religious values, if its purposes and limitations are well-defined.

The Committee also noted that to be effective and useful, the procedures and institutions adopted for risk assessment satisfy several objectives:

- They must be credible to stakeholders and the general public.
- They must operate expeditiously without threatening scientific validity.
- They should consider the full range of risks of concern to the stakeholders in the light of social, religious, historical, political land use, and cultural values and needs.
- They should be efficient and cost effective and produce results that contribute to identification of remedies and priorities that are themselves efficient and cost effective.

Based on the findings of the National Academy of Sciences, that risk-based decision-making was both feasible and desirable for the Environmental Management program, the Department of Energy has adopted a set of principles for using risk analysis developed by an interagency working group. The principles are designed to be a first cut at defining risk analysis, its purposes, and the principles to be followed by the Department of Energy if it is to be done well and credibly.

These principles include four major categories:

- Risk Assessment. Use the best available information from all sources; all judgements and assumptions should be explicitly stated.
- Risk Management. Analyze the distribution of risk and costs/benefit of potential risk management strategies, using the best available tools and techniques.
- Risk Communication. State risk management goals, assumptions, uncertainties and comparisons clearly, accurately, and meaningfully; provide public access in a timely manner.
- Priority-Setting. Compare risks by grouping them into broad categories of concern (e.g., high, medium, low) and identifying the population at risk; include as broad a range of views as possible, ideally with consensus.

CURRENT APPROACH TO RISK MANAGEMENT AND RISK-BASED DECISION MAKING

The Environmental Management program is committed to environmental restoration and waste management, as well as, keeping nuclear materials or stabilizing its facilities, and promoting the nonproliferation of nuclear weapons. The Department is also working to return land and facilities to productive use. It is investing in technological solutions where there were none before and to do things cheaper, faster, and better. Risk assessment is one of several elements Environmental Management must consider in its decision-making process. Other important elements include public policy decisions and the regulatory and legal context in which they must function, public concern and how the public participates in decision-making and finally how all of these elements are integrated into risk management.

These elements must be iteratively integrated to develop cost effective, acceptable, and credible solutions.

Currently, risk assessment information that is available at the facility or site level has not been available for decision making or when establishing priorities for budget allocations. Many of the risk-related reports are completed based on requirements specific to a regulation or a compliance agreement and do not provide an integrated complex-wide analysis of risk. A primary objective of the report entitled *Risks and the Risk Debate: Searching for Common Ground "The First Step"* (hereafter referred to as the Draft Risk Report), recently submitted to Congress, was developing a process that provides an integrated approach to evaluating the risks to human health, worker safety, and the environment posed by conditions at the Department's sites and facilities.

An integrated risk approach should include the following elements:

- Consider the anticipated future land use options
- Identify and quantify or describe the hazard
- Identify and quantify or describe the individuals, populations, or segments of the environment that might be at risk from the hazard
- Quantify or describe the degree of risk posed by the hazard to individuals, populations, or segments of the environment that might be at risk from the hazard
- Estimate the costs, both direct and indirect, of eliminating or reducing the risks to reasonable limits by undertaking an environmental management activity
- Quantify or describe the benefits of the environmental management activity, compare these with the benefits of alternative methods of risk reduction activity and compare them with the estimated costs
- Employ the best scientific and economic information
- Explain the assumptions, uncertainties, and methods of data development used in the analysis

- Consider the potential increased risk to human health, safety or the environment of the environmental management activity or any risk reduction alternative.

An integrated qualitative risk evaluation process was developed by the Office of Integrated Risk Management within the Environmental Management program for the Draft Risk Report. The intent of the qualitative approach is to develop a consistent, Environmental Management-wide framework for capturing and communicating the information from the various site-developed prioritization approaches. The process is not designed to replace existing approaches, but rather to use risk information from them and aggregate it to a higher level to make it more relevant to senior managers thereby increasing the understanding of risk activities particularly as related to compliance requirements and budget allocations across the EM programs. Department of Energy field program managers with expertise about these activities at their site categorized the activities. This approach allowed Environmental Management to capture the spectrum of risks (public, health, worker, and environment) associated with all currently planned environmental management activities and links the risks in a qualitative fashion to compliance and budget.

The information provided a baseline from which both DOE and its stakeholders can use to engage in dialogue about the risks and costs associated with the various Environmental Management activities at the site, the assumptions used to categorize the risks, and types of information that is available or that needs improvements both risk communication and risk prioritization. This baseline information was used in the FY 1997 internal budget review process as one tool in the decision making process to determine where Environmental Management should allocate its funding and establishing priorities or sequencing work.

FUTURE CHALLENGES

Additional effort is needed to provide a common understanding and consistent framework for comparing risks and hazards throughout the complex. Improvements are needed in the qualitative evaluation process to link risk prioritization, the budget, and

compliance activities. To assist in this effort, external review and advice was sought. The Environmental Management Advisory Board, an advisory group chartered under the Federal Advisory Committee Act, was requested to review the Draft Risk Report and the qualitative evaluation process used to develop information linking risk, compliance, and budget for all Environmental Management activities. The Environmental Management Advisory Board recognized the process used to develop the Draft Risk Report as an important first step in linking both compliance and budget information. The Board endorsed the use of the process and endorsed the recommendations made to improve the data quality and assure consistent application and interpretation of those data. The recommendations were:

- The categorization of activities needs to be consistent across sites, clear , recognizable and meaningful.
- A “tiered approach” should be implemented by the Department to further improve the risk assessment/risk management process at the site level, across the sites, and at the Departmental level. The tiers would consist of experts (internal and external to the Department of Energy), stakeholders, and regulators. This method would ensure cross-site input, thereby reducing bias, promoting consistency, and building credibility for the process.
- Future land use and land use assumptions are critical components of the process.
- The entire process should be fully integrated with the budget, long-term cost projections, future land use planning, and stakeholder involvement.

As Environmental Management goes forward to use this process/framework in the FY 1998 budget and planning process, these recommendations are being incorporated. However, the process is iterative as policy decisions such as land use options are determined for each site, or as new requirements such as new regulations or compliance agreements are implemented, and as risk information improves and more data are available to reduce uncertainties and to increase the confidence level of the data. The Department believes that to have this framework fully developed and implemented will take more than one year but that the lessons learned each year will be incorporated into the framework and that the Department will continue to work on enhancements for risk evaluations throughout the year.

The Department must continue to make progress in its clean up activities and in reducing risks at its sites. Since the budget planning cycle is yearly, the Department must use the tools it has available each year in making the budget decisions. The qualitative risk evaluation process has indicated data gaps and uncertainties and the Department will continue to improve its data collection process. However, the process must be evolutionary to take into account data on individual risk assessments and other data sources to enable managers to use a risk based decision making process and to set priorities for allocation of resources across the complex.

The Department recognizes that stakeholder involvement is important to both the quality of information and the credibility and validity of the decision making process. A variety of approaches are needed to meaningfully engage stakeholders in the risk and budget issues so that stakeholders have access to accurate, understandable, and timely information; sufficient time to be able to assimilate the information; and an opportunity to be heard during the decision making process. For example, the Department assisted stakeholders in participating in the 1997 budget process by preparing a guide entitled *Public Participation in the Fiscal Year 1997 Office of Environmental Management Budget*. This document laid out the decisions to be made, key documents that provide the decision-makers with information upon which to base their decision, and identification of opportunities for stakeholder involvement. As we go forward, the Department needs to improve its communications tools for both risk and budget issues so that stakeholders can continue to participate in the process in a meaningful way and contribute to effective, cost-efficient, risk reduction measures.

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RISK-BASED DECISIONMAKING IN THE NRC: CHALLENGES AND STATUS

Andrew C. Campbell
Nuclear Regulatory Commission
(301) 415-7285

No paper available

RISK-BASED DECISIONMAKING: CURRENT RESEARCH TOPICS RESEARCHER

Fritz A. Seiler
IT Corporation
(505) 262-8908

No paper available

RISK-BASED DECISIONMAKING: CHALLENGES IN APPLICATIONS

Harold S. Blackman
Idaho National Engineering Laboratory
(208) 526-0245

No paper available

ASSESSING DOE'S SUCCESS IN IMPLEMENTING THE FFC Act:
A FEDERAL AND STATE PARTNERSHIP TO DEVELOP TREATMENT PLANS

Martin J. Letourneau
DOE, EM-332
(301) 903-7656

Patrice M. Bubar, Director
Office of Planning and Analysis (EM-35)
Environmental Management
U. S. Department of Energy
19901 Germantown Road
Germantown, MD 20874-12909
(301)903-7130

ABSTRACT

Implementation of the Federal Facility Compliance Act (FFCA) required total cooperation among the Department of Energy (DOE), the involved States and interested stakeholders. Although the effort was time consuming, tedious and (at times) trying, the results obtained [Site Treatment Plans (STP)] were an unprecedented success. Through long-range planning, attention to details and organization of effort, a coordinated, cohesive, focused team was developed that included the DOE Headquarters, the Environmental Protection Agency (EPA), 40 DOE sites, 20 states and multiple interested stakeholders. The efforts of the FFCA team resulted in the preparation of 37 STPs which outline the methods, locations and schedules for the treatment and disposal of DOE's mixed wastes. The Plans provided a strong foundation upon which consent orders were prepared and approved. The FFCA approach also resulted in the development of working relationships that will prove not only useful but vital to the planning and implementation necessary to the successful clean-up and disposal DOE's mixed wastes.

INTRODUCTION

For more than 40 years, the United States has produced materials for nuclear weapons and conducted research with nuclear materials. These activities generated mixed wastes that contain both radioactive and hazardous constituents. The DOE is responsible for managing these mixed wastes. At present, there is insufficient capacity, and in some cases, a lack of available technology to treat these wastes.

The Resource Conservation and Recovery Act (RCRA) as amended by the FFCAct of 1992 requires the Secretary of Energy to prepare Site Treatment Plans (STP) describing the development of treatment technologies as well as treatment capacities for treating mixed wastes so the wastes can be safely treated and land disposed in accordance with RCRA regulations. Plans are required for all facilities at which DOE has previously or presently does generate or store mixed waste, and must be submitted to appropriate states or the EPA for approval.

STP IMPLEMENTATION STRATEGY

The DOE followed a two-year iterative process in developing the STP. This process eventually resulted in three versions of each Plan, with each version becoming more refined, focused and decision specific. DOE also worked closely with state regulatory agencies and EPA at both the state and national levels throughout the process.

Implementation of the FFCAct plan was almost entirely dependent upon the several teams organized and assigned responsibility for specific portions of the effort. Team members included DOE Headquarters and DOE Field personnel, regulatory entities, political entities, stakeholders and contractor support personnel.

The entire FFCAct program was melded into a cohesive, manageable unit effort by forming several support teams; assigning each team responsibility for a significant portion of the overall effort; assuring continuous team interface and communication; and, maintaining management oversight and involvement throughout.

The FFCAct implementation effort and subsequent team activities were benefited significantly by applying basic project management principles of delegating responsibility and authority; outlining specific assignments; providing necessary resources; clearly defining expected products; establishing schedules having clear, frequent and defined milestones; assuring continuous management availability and involvement; and, requiring clear, concise progress reports.

The key teams and organizations involved in the FFCAct effort included the following:

- FFCAct Policy Coordination Group: participate in development of guidance; implement policy; interact and coordinate among DOE sites; interact with the states and EPA; and assure FFCAct compliance.
- FFCAct Task Force: develop policy and guidance; interact with the National Governors' Association (NGA), the EPA and the DOE Headquarters; and assure DOE management approval.
- Options Analysis Team: evaluate and analyze waste streams, treatment systems and treatment facilities; perform trade-off studies; and recommend stream groupings, common treatment methods, and new treatment facilities.
- EPA.
- NGA.
- Western Governors' Association.
- Stakeholders.

FFCACT TEAM PRODUCTS

The crux of the entire STP effort was knowledge. Specifically, knowledge of the DOE's present and future mixed wastes streams by type, volume, location, content and condition. Additional information needs included waste treatment methods, facilities, schedules and costs. Essential supplemental information important to waste treatment and disposal planning included proposed budgets, anticipated funding, estimated costs, schedules, existing and pending regulatory agreements or compliance orders, and known as well as potential barriers.

Some of the major issues identified, addressed and resolved by the FFCAct teams and organizations included:

- Establish an acceptable STP content; develop a common Conceptual Site Treatment Plan, Draft Site Treatment Plan and Proposed Site Treatment Plan format; preparing and issuing document preparation, review and approval schedules; and, obtaining agreement upon the manner and mechanism for accepting and resolving comments and conflicts.
- Preparing a master waste stream inventory data base including waste types, volumes, and locations; treatment facilities and locations; treatment schedules; and treatment costs.
- Identifying and resolving (negotiating) waste equity issues; performing trade-off studies upon which decisions could be based; and recognizing and resolving political influences.
- Identifying processes for disposal of mixed waste treatment residuals.
- Assuring total conformance with regulatory and compliance issues, regulations and laws.
- Identifying and selecting treatment methods and facilities; reviewing and obtaining agreement on treatment schedules; and, assuring preparation of treatment cost estimates.
- Preparing and agreeing upon common compliance order content and language.
- Identifying and resolving budget and funding issues.

The overall product of the FFCAct effort was the preparation of 37 STPs covering 40 sites in 20 states. The scope of the wastes encompassed by the FFCAct include approximately 2,200 separate waste streams having a total volume of 652,355 cubic meters

(471,012 cubic meters of High Level Waste, 128,664 cubic meters of Mixed Low Level Waste, and 52,679 cubic meters of Mixed Transuranic Waste).

COORDINATION AND COOPERATION

To demonstrate a good-faith effort to increase regulatory and stakeholder involvement, provide early opportunity for and consideration of reviewer input, and avoid last-minute misunderstandings or identification of unexpected issues, the DOE (as published in the April 1993 Federal Register notice) scheduled three interim versions of the Plans: an October 1993 conceptual version, an August 1994 draft version and a February 1995 proposed version. In each case, the Plans were issued to regulatory agencies and stakeholders for review and comment. Comments received on each document were considered and where appropriate addressed in the succedent document. In addition, each document built upon its predecessor document, thus leading to and implementing a continuous improvement process.

In an effort to accommodate regulator's needs, improve document useability and understanding, and assure user-friendly documents, each STP was organized into two volumes: a Background volume and a Compliance Plan volume. The Background volume includes information on mixed waste streams and treatability groups, a preferred treatment option for each mixed waste stream and other pertinent background information. The Compliance Plan volume contains the schedules required by the FFCAct (based on currently available or projected funding), identifies the uncertainties and assumptions upon which the plan is based, and provides DOE's proposals for implementing the approved STP's. This approach reflected earlier discussions with and input from regulatory agencies and participating stakeholders and was well received. The approach also led to improved working relationships, accelerated document review times, decreased review comments and a shortened review comment resolution cycle.

An especially important aspect of the FFCAct effort was an intentional effort to coordinate the STP text with preparation of the draft compliance orders. Further, this coordination was accomplished with the full knowledge and participation of key regulators.

By approaching the compliance order issue in this manner, significant advantages were gained by a) assuring early and complete involvement of all participants, b) provide a uniform baseline order language upon which later orders could be based; c) obtain at least tentative regulator agreements upon the content of the orders; and d) avoid later lengthy negotiations concerning order content and language. The importance of this particular aspect of the FFCAct effort cannot be overstated, because once compliance orders are drafted and submitted to the regulatory authority the regulators have three options: approve, approve with changes or disapprove. Once approved by the appropriate regulatory authority an order becomes an enforceable document that carries not only the weight of law but also the possibility of monetary enforcement action. Thus, compliance orders have the potential to become extremely powerful documents that could unless carefully planned, coordinated, worded and implemented be used against the DOE. Thus the need to ensure complete involvement of both the regulators and interested stakeholders throughout the process.

ANCILLARY BENEFITS

A somewhat unanticipated (but welcome) benefit of preparing the FFCAct data base was the availability of the data base for use in preparing the mixed waste portions of the Baseline Environmental Management Report (BEMR). If desired, each site have the opportunity to use the FFCAct mixed waste streams inventories in BEMR, thus avoiding expending additional resources and time in generating the same information. Using a common data base also avoids a site having two sets of common but conflicting information, and the associated lengthy searches for causes, explanations and resolutions.

Preparing the STPs in a three-step process provided an opportunity to implement a continuous improvement process. Each iteration of the document permitted improvements in the document narrative as well as the specific waste stream data. The process also provided an opportunity to perform three separate reviews of each STP and thus assure a complete understanding, a thorough evaluation, and a satisfactory resolution of review comments.

RESULTS

By approaching the FFCAct program in a deliberate, planned and coordinated manner, the results proved to be both rewarding and exciting. Plans were prepared, actions taken, data bases prepared, decisions made, equity issues resolved, consensus reached, schedules met and draft consent orders prepared.

The DOE expects that the sites that participated in the STP process will have a final order requiring compliance with an approved STP in place by December 1995 or shortly thereafter. The orders are expected to include consent orders, unilateral orders, and other types of enforceable agreements issued under state law, as well as compliance orders issued by the EPA under Federal RCRA enforcement provisions.

Through the application of systems engineering methods, the FFCAct Task Force achieved significant positive budget/cost impacts including reductions in the total number of individual waste streams, reductions in the number and type of waste treatment systems and significant reductions in the number of new waste treatment facilities anticipated. For example, at the Idaho National Engineering Laboratory, the \$614 M Idaho Waste Processing Facility and the \$3,490 M Waste Immobilization Facility were replaced by the \$1,930 M Idaho Chemical Processing Plant-Remote Handled Immobilization Facility and the \$416 M Advanced Mixed Waste Treatment Facility; at Hanford the \$601 M Waste Receiving and Processing Facility was deleted in favor of commercial treatment; at Oak Ridge the \$930 M Mixed Waste Treatment Facility was deleted; and, at the Nevada Test Site the \$30 M Liquid Waste Treatment System was deleted.

As a secondary result, the comprehensive information data base previously mentioned is now available to enable and assist the DOE management in making informed, knowledgeable, defensible decisions concerning budget requests, budget needs and funding allocations. The data base will also prove useful in determining equity issues, performing trade-off studies and completing "what if" scenarios.

CONCLUSIONS

The FFCAct "coordinated approach" resulted in the preparation and issuance of 37 STPs on schedule, with each document displaying a common format, common text and focused on the unified goal of treating DOE's mixed wastes in an effective, timely and cost efficient manner.

The FFCAct program truly resulted in a win-win situation for the States, the EPA and the DOE. The effort also demonstrated that with a concentrated, dedicated effort goals can be established and met, institutions having differing opinions can work towards and agree upon important issues, and participants having diverse backgrounds and differing opinions and objectives can work as a team and accomplish important, timely results.

**UPDATE ON THE FFC Act: DISPOSAL WORKGROUP DISPOSAL SITE
EVALUATION PROCESS—WHAT HAS WORKED AND WHAT HAS NOT**

Joel T. Case
DOE, Idaho Operations Office
(208) 526-6795

Martin J. Letourneau
DOE, EM-33, Trevion II

ABSTRACT

Although not required under the Federal Facility Compliance Act of 1992 (FFC Act), the states working with the Department of Energy (DOE) in complying with the FFC Act requested that DOE address the disposal of the residues from the treatment of mixed wastes covered by the FFC Act. DOE has established a process separate from but integrated with their FFC Act process to address the disposal issue. The resulting disposal evaluation process will ultimately lay the groundwork for the future of both mixed and low-level waste disposal across the DOE complex. The DOE disposal workgroup process, developed in conjunction with the affected states, evaluates the performance capabilities of a set of sites to determine which sites are suitable for DOE's future waste disposal operations. This paper lays out the disposal site evaluation process, the current status of the effort, and highlights the specific key sections of the process. The primary highlight of this paper will be a description of the Site Performance Evaluation Assessment methodology and an interpretation of the results of the application of the Site Performance Evaluation Assessment to a number of DOE sites.

FFC Act: A SITE PERSPECTIVE

Keith Kristofferson
Idaho National Engineering Laboratory
PO Box 1625
Idaho Falls ID 83415
(208) 526-9363

No paper available

OFFSITE SHIPMENTS AND EQUITY

Martin J. Letourneau
DOE, EM-332
(301) 903-7656

No paper available

HOW CITIZEN ADVISORY BOARDS PROVIDE INPUT INTO MAJOR WASTE POLICY DECISIONS

Erin Rogers, Linda Murakami, and Lisa Hanson
Rocky Flats Citizens Advisory Board
9035 Wadsworth Parkway, Suite 2250
Westminster, CO 80021
(303) 420-7855

ABSTRACT

Volunteer citizen boards, such as Site Specific Advisory Boards, can be a very important key to success for the Department of Energy's (DOE's) Waste Management program. These boards can provide informed, independent recommendations reflecting the diversity of the community and its values. A successful volunteer process requires collaboration among regulators, DOE and other Boards; knowing how and when to interface with the broader public; understanding the diversity and representational issues of a citizens group; knowing the "ins and outs" of working with volunteers; education and training and most importantly, planning. Volunteers on a citizens board were created to tackle the big picture, policy decisions. The chair of the Rocky Flats Citizens Advisory Board will describe her Board's successes, including the challenges in reaching consensus agreements, as well as the need for integration with other boards and the sites' on-going public involvement programs to provide the input the department is seeking. Finally, one of the greatest challenges for the boards is interfacing with the greater public-at-large, seeing how the CAB has overcome this challenge and integrating broader public input into its decisions.

BACKGROUND

The Rocky Flats Citizens Advisory Board held its first meeting in November 1993, but the origins of the group date back to February 1993 and a report entitled "Recommendations for Improving the Federal Facilities Environmental Restoration Decision-Making and Priority Setting Processes." This report was authored by the Federal Facilities Environmental Restoration Dialogue Committee (FFERDC), also known as the "Keystone" Committee. The Environmental Protection Agency (EPA) established this group to develop consensus policy recommendations to improve the cleanup decision-making process at federal facilities. The FFERDC was comprised of representatives of federal agencies; tribal and state governments and associations; local and national environmental, community, and labor organizations.

One of the primary recommendations of this group's report was to develop site-specific advisory boards (SSABs) for each of the U.S. Department of Energy's (DOE) nuclear sites to provide a structure for including the public in the cleanup decision-making process. In June of 1993, Colorado Governor Roy Romer and Congressman David Skaggs followed up on those recommendations and sent a letter to the Colorado Department of Public Health and Environment (CDPHE) and the Region VIII EPA requesting that the two agencies work jointly to support the development of an SSAB for Rocky Flats. The Rocky Flats Citizens Advisory Board was formed as one of the first SSAB's in the nation's nuclear weapons complex.

Today the Board is comprised of 21 members. It includes representatives of academic institutions, the business community, environmental organizations, labor groups, local government, the health industry, Rocky Flats employees, and public interest groups. The diversity of the members of the Board provides a sense of credibility that does not exist with a DOE-selected group. When you have a wide spectrum of interests represented, you are more likely to gain the trust of the broad community. It is important to preserve the diversity and not allow a group to become too heavily dominated by any one interest.

The Board's first consensus decision was their mission statement approved in January of 1994:

The Rocky Flats Citizens Advisory Board, a nonpartisan, broadly representative, independent advisory board with concerns related to Rocky Flats activities, is dedicated to providing informed recommendations and advice to the agencies (Department of Energy, Colorado Department of Public Health and Environment and the Environmental Protection Agency), government entities and other interested parties on policy and technical issues and decisions related to cleanup, waste management and associated activities. The Board is dedicated to public involvement, awareness and education on Rocky Flats issues.

The Board hired independent staff and set up an office, off-site and independent of DOE and the contractor. This has been an important part of the success that the Board has

achieved. As an all-volunteer Board, we rely very heavily on our staff to provide us with the most current and accurate information available. The Board has four staff members: an administrative/office manager person, two project staff and a project administrator, who leads the office.

CAB WORK PLAN

Once organizational development was complete, the Board focused on developing a work plan. Its first work plan was approved in late 1994. The work plan identified short-term goals and objectives for Board activities. One of the purposes of this Board is to allow the public to participate in identifying the problems and solutions in the cleanup of Rocky Flats. This Board has the opportunity to work directly with the decision-makers to come up with realistic solutions to the site's problems.

Board members sent several messages to its staff and other members while the plan was being developed. They wanted to be more proactive than reactive; to hear from outside, independent sources; to be educated on Rocky Flats issues; and felt they needed to understand DOE's plans regarding cleanup, waste management and plutonium disposition.

The work plan was divided into two phases. Phase I outlined goals, milestones and educational presentations. This phase involved learning about and then analyzing DOE's priorities and plans for cleanup and risk reduction activities at Rocky Flats. These activities were then categorized by the CAB on a "what decisions need to be made first" basis. With this information, CAB could then develop a list of specific activities to be addressed in Phase II.

The Board identified many questions. Is on-site waste disposal acceptable at Rocky Flats? If yes, what types of waste are acceptable and in what locations? If the government does not have the money or the technology to return the site back to green fields, what are acceptable cleanup levels? If the plutonium stays on-site for the next 10-50 years, should it

be stored in one building or in several buildings? Should the plutonium be shipped off-site for disposal?

The Board came to an agreement that the broad policy, or "big picture" decisions must be made first. These are the fundamental choices that need to be made about handling plutonium, waste and cleanup which will in turn drive the decisions on specific projects and other activities. The Board identified four "big picture" areas for which it would provide recommendations to DOE:

- Develop recommendations on radioactive waste storage and disposal
- Develop cleanup criteria for the site
- Endorse/modify the Future Site Use Working Group recommendations
- Develop a position on interim storage and long-term disposition of plutonium.

Each of these four focus areas or priorities were assigned to a committee. The committees are responsible for in-depth study of issues and making recommendations to the full Board, sometimes in the form of values, criteria or a list of prioritized options. Members of the general public are encouraged to participate in the committees. The Board has four issue committees: the Plutonium and Special Nuclear Materials Committee, the Site Wide Issues Committee, the Environmental/Waste Management Committee and the Alternative Use Planning Committee. The Board also has a Community Outreach Committee that meets quarterly and an Executive Committee, made up of the Board's officers, which deals with administrative and policy issues. The most pressing decision for Rocky Flats, and the subject of the rest of this paper, is the process through which the Board addressed the issue of waste disposal. Cleanup cannot begin until Rocky Flats and the affected stakeholders agree on what to do with the waste generated from cleanup. The waste generated from cleanup can be 10 times the amount of the current wastes generated from past production.

PUBLIC OUTREACH

The Board is committed to being a conduit for broad public involvement and access to information on Rocky Flats. Members feel a responsibility to "report back" to the community. An outreach plan has been developed to ensure that this goal is achieved. All meetings are advertised in local papers and the public is encouraged to attend. The Board produces a quarterly newsletter, *The Advisor*, that is distributed to about 5,000 residents in the affected communities and greater Denver area.

REACHING CONSENSUS

The Board operates via consensus. They based this decision on the belief that its recommendations would be more useful and credible if they reflected the opinions of the entirety of its diverse membership, rather than only those of the majority. However, there is a process to move to a vote if unanimity is not attainable. The Board is committed to first trying to reach consensus and has yet, to date, never moved to a super-majority vote for issues other than administrative.

Consensus process has mutual agreement as its goal. Mutual agreement cannot be reached until all parties understand the issues. To reach a high level of shared understanding, care is taken to see that all viewpoints on a given issue are expressed clearly. This brings differences out into the open. Once differences are acknowledged, they then can be taken up and resolved whether by seeing that the differences are insignificant or that the proposal before the group must be rejected or modified to reflect the differences. The important of this approach is that no individual or minority is run over by a dominating majority. Rather, the viewpoint of everyone is taken seriously and each individual is treated with respect.

LeRoy Moore

Board Member

DEVELOPING A FOUNDATION

The Board developed a "foundation" of core values or principals for the waste management issue before addressing more specific and technical issues. Once again, this means that the broad policy questions must be asked and answered first before any technical issues are addressed.

For example, DOE will "dig a hole" in the ground and then asks the public how it should cover it or fill it—what they did not do was ask the important question "do we need a hole in the first place?"

Last year DOE asked the Board to address the design of a closure cap of a hazardous waste landfill. The Board had not yet discussed, let alone had a unanimous agreement on, whether to dispose of hazardous waste permanently at Rocky Flats. It was a classic example of putting the cart before the horse.

During the first few months, the Board primarily "reacted" to DOE regulator issues. By doing this, the Board reacted to the smaller and often very technical issues without first addressing the larger policy issues that guide the other issues. It was very important for the Board to reach a balance between being proactive, creating its own agenda and addressing what it feels are the most important decisions, as well as being reactive to the needs of DOE and the agencies. When the Board reacts to decisions or proposals, it wants to give DOE informed advice. If they have a predetermined set of criteria or core values already in place, these can be used as a tool to provide a better recommendation.

It's also necessary to mention that if new information becomes available, the Board's principles or values can be refined by consensus of the Board. The purpose of getting something on paper and agreed upon early in the process gives the Board and DOE direction around which they can create policy and decide the more specific activities or issues. This is what we would term "early" public involvement.

In addition, the development of values and principles are usually non-technical in nature. This allows non-technical people—which is most of the Board and the general public—to participate in the discussions.

The committee developing the waste management recommendation listened to the views, questions and concerns of not only the Board members, but members of the public who participate in the different committees and attend Board meetings, the regulators and DOE. The committee developed a foundation consisting of general "principles" to be used as guidelines and a set of "recommendations." (SEE BELOW)

DEVELOPING A RECOMMENDATION

There are several ways in which the Board could address the waste disposal issue. One is to obtain the information to address all the questions and concerns raised by the Board. Many of the questions fall into major categories of transportation, disposal and storage, contamination, waste treatment, health and environmental risks, and regulatory and legal issues. The problem is, some of the information is not readily available. And the information that is available is not always viewed as credible to stakeholders. For example, all of the transportation risk assessments have been developed by DOE or its contractors. Because of the lack of trust due to the Cold War era, many stakeholders still do not trust DOE information and it takes a lot of time and resources to commission additional independent risk assessments. Instead, the committee incorporated the questions and concerns into "value" statements.

To avoid confusion, the Board also developed definitions for "storage" and "disposal" for the purposes of interpreting the recommendation and values. The purpose of this recommendation was to give DOE, its contractors and the regulators a sense of where CAB is on the issues of waste storage and disposal. Timing was crucial because the contractor was circulating a proposal for an on-site, underground waste disposal cell. The public comment period was scheduled a couple of months after the recommendation was sent to

DOE. At this time, the contractor and DOE are revisiting their proposal and new plans or proposals have not yet been announced.

This recommendation will really impact what DOE/Kaiser-Hill will or will not be able to do at Rocky Flats regarding waste storage and disposal. For example, the Kaiser-Hill disposal cell proposal currently on the table clearly goes against the Rocky Flats-CAB waste disposal recommendation outlined below.

RECOMMENDATION: Waste Management: Storage and Disposal at Rocky Flats
Definitions

Disposal: The placement of wastes, either permanent or interim, in any facility that makes it physically and financially unrealistic to retrieve and monitor.

Long-term Storage: The conditions whereby wastes remain at Rocky Flats in the event that plans for shipment off-site fail to take place or do not transpire within the planned and desired time frame set out by the Department and the stakeholders. Thereby ensuring the safest possible storage of wastes for as long as the wastes remain at Rocky Flats.

Guiding Principles

The Guiding Principles should be viewed as general guidelines.

- 1. Different categories of waste will remain at Rocky Flats for some period of time.*
- 2. Waste at Rocky Flats shall be stored in the safest possible manner.*
- 3. Waste shall be stored in such a manner that it cannot escape into the surrounding environment during the time that it remains a potential hazard.*

4. *Waste shall be stored in such a manner that it is fully monitorable and retrievable. In addition, there shall be institutionalized review systems in place ensuring inspection on a regular basis.*
5. *It is not acceptable for Rocky Flats to send waste to a facility that would not meet CAB criteria for storage at Rocky Flats. (NOTE: Broad criteria for storage at Rocky Flats are outlined below. These criteria may need more development by the Board before inclusion into the guiding principles.)*
6. *Any waste storage or "disposal" facility must be selected through an objective, scientific process and include public participation.*
7. *The concept of "disposal" of radioactive waste is misleading due to the toxic and long lived nature of the wastes. Because wastes are out of sight, does not mean that the problem is solved.*

Recommendations

CAB understands there are financial and budgetary constraints. However, constraints should not prohibit achievement of waste management plans envisioned in the following recommendations:

1. *Because it is unlikely that a waste "disposal" facility can be guaranteed to contain the contaminants for the life of the waste, CAB opposes the development of such a facility at Rocky Flats.*
2. *DOE shall develop plans for long-term storage of all wastes currently at Rocky Flats.*
3. *Any waste facility must be fully monitorable, with regular inspections, and the waste must be fully and easily retrievable.*
4. *To ensure the safest possible storage, any waste storage facility must be able to be upgraded; and if the facility cannot be upgraded the facility must be replaced.*
5. *No waste from other facilities shall be accepted at Rocky Flats for treatment or storage.*

6. *Because radioactive waste is a national issue, and because there is no guarantee that proposed "solutions" will proceed, a national dialogue must be convened that addresses the issue of waste storage and "disposal." CAB agrees to support and participate in such discussions.*
 - *Near term activities include a national stakeholder meeting between now and December 22 to discuss the Waste Management Programmatic Environmental Impact Statement and a Site Specific Advisory Board roundtable in February at the Waste Management 1996 conference. Tom Marshall, Linda Murakami and Lisa Hanson have been asked to participate on both planning committees.*
7. *DOE shall vigorously pursue a research program aimed at developing technologies to make radioactive waste benign (not a potential hazard).*
8. *The Rocky Flats Citizens Advisory Board and other external stakeholders (including regulators) shall be involved in the development and approval of all waste management plans and activities.*

In addition to the recommendation, the Board identified specific information needs the committee will use to research and address more specific waste management issues, such as treatment and storage. Necessary information includes: more detailed cost information for the proposed low-level waste cell, description of wastes to be included in the waste cell, cost information for all alternatives to the underground waste cell, and contingency plans for storage of transuranic waste in the event that the Waste Isolation Pilot Plant facility does not open.

This recommendation will also be used by the Board and other committees when addressing more specific issues like designing low-level waste storage facilities and caps for closures.

POLICY IMPACTS

When generating the broad policy that drives the cleanup program, DOE must now take the Board's input into consideration. The Board is able to provide the framework which DOE must operate. For example, the Board's requirement that storage be physically and economically retrievable would limit the options the Department has for on-site storage of waste. It would not meet the Board's requirement if DOE simply put a closure cap on a waste cell.

CONCLUSION

Individually, the boards have the power to influence projects; together they are truly a force that will shape national policy. As the boards band together, they will have the national dialogue necessary to begin to come to agreement on national issues. The weapons complex that was purposely created to be fragmented and geographically isolated is now coming together through these citizen advisory boards. No longer will decisions be made in a vacuum or without taking into consideration the breadth of impact of those decisions.

PUBLIC EDUCATION: LEARNING TO SAY WHAT WE WANT TO SAY

Joe E. Heimlich
Karen M. Manel
Audeen Fentiman
Brian Hajek
Rich Christiansen
The Ohio State University

ABSTRACT

Most people involved in the public arena know that people often react with fear and concern to the word "radiation." It is also known that many of these same people readily admit they have little knowledge of the topic. As publics are facing the demands of decision making related to low level radioactive waste, discussions of high level waste challenges, and confusing information regarding what are sound data, the difficulty in conveying good, science based information to the public is increased.

In examining the various groups involved in the low level radioactive waste (LLRW) discussions, it is some of the environmental activist groups with an anti-nuclear goal whose messages are *heard* by the general public. Why do these groups succeed and others not?

This paper will provide a cursory examination of issues surrounding how people hear the radiation science message, what people want and need to know versus what the scientific literature contains and provide examples of how information is presented from the LLRW Education Program at Ohio State University.

WHAT PEOPLE KNOW. . .

Any public information program must start with the present knowledge of the public concerning the central issues of the program. What people know, or believe or think they know, is irrefutable. Although radioactive materials occur naturally, and the release of energy called radiation is constantly occurring, society has become aware of radioactivity primarily within the last half-century and many of the advances in this field have been made by government agencies working under a shroud of secrecy (Rhodes, 1988).

When something is observed, but defies existing empirical understanding, an individual will try to find meaning in the event or mythologize the incident (Feinstein and

Krippner, 1988). Entire cultural practices have grown from attempts to describe something external, but that must be made meaningful (Carlsen, 1988). Radioactivity, and the resultant ways in which the public "knows" about radioactivity, became embedded in its own mythology spurred on by several dominant cultural factors. Five major factors appear pivotal to the discussion. Perhaps the cornerstone of these influences was society's making the term "nuclear" synonymous with radioactivity and environmental destruction (Litton, 1993).

A second of the metacultural events was that of the "cold war" in which the threat of enemy strikes overrode the probable reality of such attacks (Zinberg, 1982). Another factor is that the waste from nuclear activities is also viewed with suspicion because it is generated through activities which much of the public associates with disaster (Greenwood, 1982). A fourth factor is the very real problems of radioactive waste management at early defense and low-level radioactive waste sites which served to further the fear of dread and reduced public perception of good risk (Slovic, 1987).

A fifth meta-cultural event involves the media portrayal of radioactivity as causing mutation of cells, thus leading to nuclear activity and all associated activities being perceived as one of the public's greatest fears (Slovic et al, 1979). Zinberg (1982) notes that even when mishaps are minor, the news industry, sensitive to the public's ambivalence about nuclear power, rushes in with elaborate and often unscientifically based or inaccurate coverage. Much has been explored about the media's role in shaping current public perceptions, but little has been offered in terms of ways to deal with the resultant views of radiation, nuclear sciences, and LLRW.

What people believe they know is what they know. As scientists, most of us use as our basis of determination the validity of scientific study and technological analysis. Yet, even scientists do not always agree on what is "good" or "better" science; even well constructed research may have radically opposed outcomes. The current knowledge, attitudes, beliefs, and misconceptions of the public must be the grounding for any educational or informational project (Mancl et al, 1994). It is the independent knowledge of the

fundamentals of an issue which provides individuals with the basis for evaluating "experts' pronouncements" (Morgan et al, 1992). Only when the information is driven from the perspective of the attitudes and beliefs of the targeted public, and is not driven by the expediency of government or the knowledge base of the experts, can a program truly address the core understanding of the public (Heimlich and Winkle, 1993).

WHAT PEOPLE WANT TO KNOW...

Often, public information campaigns approach public awareness through the belief that by presenting "facts," peoples' knowledge base will change and this, in turn, will change their attitudes. The reality which continually confronts us is that teaching for facts and concept learning is different; there is a relationship between the person and society, or "attitude-cognition" that must first be addressed (Bowman, 1979). Consider the scientific understanding of the shape of the Earth: in 1490, the best "fact" suggested that the planet was flat; by 1900 the best "fact" suggested that the planet was round; by 1995, the best "fact" suggests the planet is ellipsoidal. Did the planet's shape change, or was the change constructed by better means of empirical data and a shift in the social conventions that support such beliefs?

The goal, then, is to construct educational or informational programs with an understanding of what the public knows, and designing a program that will not be dismissed, misinterpreted, or allowed to coexist with misconceptions held by the targeted audience (Morgan et al, 1992). These programs work when individuals feel the information they are receiving works to help relate the individual to the rest of the world in a satisfying and intelligent way (Raths et al, 1966).

All of us fear being told we are wrong, even more than we fear being wrong. This fear grows from the many lessons we each had as children in which we were told our empirical knowledge was incorrect (Bloom, 1976). As an example, how many of us as children, or as parents, went through the scenario in which the parent tells the child, "no, you don't want that piece of candy." Actually, the child *does* want the candy, it is the parent

who does not want the child to have the candy. And of course, this process of correction of sensory based learning continues through the formal educational system, until each of us as adults has a fear of losing the basic sensation of oneself as a conscious being when our perceptions of the world are challenged (Watts, 1972).

Once people have an attitude about something, this attitude can affect perception and interpretation of social situations, objects, and data very markedly (Lovell, 1987). Before an "expert" can be heard by a group, people want their existing beliefs and experiences to be validated (Heimlich and Winkle, 1993). Only then are people prepared to open their minds to new or more complex information (Hill, 1981).

AN ALTERNATIVE APPROACH TO PUBLIC EDUCATION...

Asking people what they need to know about a subject is meaningless (DeMarchi, 1990). What is important is how people organize information. This central concept became the basis for the Low Level Radioactive Waste Education Program at The Ohio State University. As opposed to constructing a public information campaign based on what the public perceived it needed, the program was designed to help individuals gain substantive knowledge of what LLRW is, and how it "works" (Bostrom et al, 1992).

To understand the conceptual approach to this project, the following is offered as a "flow" of consciousness on the parts of the individuals involved. Each of the consideration points is then briefly explained including an abbreviated description of program activities and outcomes.

What do people know, feel and believe about LLRW?

|

What is the knowledge gap between | what people know/feel/think
and the best scientific information?

|

What questions do people have about LLRW that would narrow the gap?

|

How can we present the answers to the questions without confronting individual's beliefs and values?

Is it possible to operationalize our convictions that our purpose is to empower individuals for participation-- regardless of their position?

What do people know, feel, and believe about LLRW?

To discover the foundation upon which the project would be structured, a telephone survey of randomly selected Ohio households was conducted to collect information on knowledge of and attitudes toward low level radioactive waste and radiation science. The knowledge gained from this survey provided information on who people trust regarding LLRW, what people think they know, and general reactions toward LLRW. Thus, the program was able to frame itself upon where people are, and not unwittingly confront their beliefs.

What is the knowledge gap between what people know/feel/think
and the best scientific information?

The data from the survey were analyzed and compared to other studies, expert opinion, and scientific, empirical data. This process, tedious and frustrating, provided the program team with a scientific "gap analysis" from which we were then able to construct a series of inquiries that would begin to narrow the gap between what people think/feel, and the scientific information. This stage of the process involved the project team in discussions and brainstorming following individual team members' analysis of data from the survey.

What questions do people have about LLRW that would narrow the gap?

The project materials were initiated by constructing lists of questions people have and ask about LLRW. These questions became the basis for a series of fact sheets with each fact sheet answering one question, and a series of displays. The idea is that it is not possible to

make someone understand everything, nor is it appropriate to try. To enable individuals to gain information, it is vital that it be done at their individual rate.

How can we present the answers to the questions without confronting
individual's beliefs and values?

None of us woke up one morning and knew everything we know now. It took time, study, and inquiry. To honor the individuals who comprise "the public," the project team elected to maintain a position of presenting the best scientific information available in an understandable manner. This means we never drew conclusions for the public such as "it is safe" or "the risk is negligible." As a team, we also recognize that to honor peoples' fears, we had to include the risks of radiation and present health effects, past historical problems, and other similar concerns. These were presented in the same manner as the rest of the information--straightforward, no nonsense information without interpretation. To ensure our being on track, the review process for all materials was a complex, multi-leveled effort. This review included local and national experts, from the judicial system, environmental groups, medicine, user groups and radiation experts. All comments were taken, reviewed, considered and where appropriate, included.

Is it possible to operationalize our convictions that our purpose is to
empower individuals for participation--regardless of their position?

Perhaps the most important component of the development of this project was in one of the philosophic considerations that have been prominent in all project activities: LLRW exists and a need for managing it exists. This management function involves public decision making and, therefore, the more informed the citizenry, the better the public decision. Operationalizing this belief would suggest that *what* an individual believes is less important to the project team than what the individual *knows*. Such an idealistic position is, has been, and will be a significant challenge. Yet, by constructing a team comprised of individuals with strong and differing opinions, we have been able to challenge our individual and collective assumptions. By seeking individuals for input with opinions differing from ours or more

extreme toward any pole than project team members, we have been able to avoid much of the value laden language and approaches that have marked most informational and educational materials on LLRW from any position.

The bottom line for all of us is to be explicit to ourselves on what the message is we are wanting to convey. By stepping back and addressing LLRW from the position of the public, we are better equipped to handle the concerns, fears, and interest of the public in the topic. By initiating an educational message from this affective position, individuals are empowered to *hear* what is said. The approach of many of the environmental activist groups opposed to nuclear power on LLRW management is to use emotion, one affective channel, to get their message across. By observing these groups, we can improve public education effectiveness by also approaching the public through affective learning channels. We can raise the level of informed discussion and decision making by moving through affect to cognition with the very real intent of sharing good science.

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OPENNESS INITIATIVE

S. Scott Duncan
Los Alamos National Laboratory
(800) 422-5265

ABSTRACT

Although antinuclear campaigns seem to be effective, public communication and education efforts on low-level radioactive waste have mixed results. Attempts at public information programs on low-level radioactive waste still focus on influencing public opinion. A question then is: "Is it preferable to have a program focus on public education that will *empower* individuals to make informed decisions rather than trying to *influence* them in their decisions?" To address this question, a case study with both quantitative and qualitative data will be used. The Ohio Low-Level Radioactive Waste Education Program has a goal to provide people with information they want/need to make their own decisions. The program initiated its efforts by conducting a statewide survey to determine information needed by people and where they turned for that information. This presentation reports data from the survey and then explores the program development process in which programs were designed and presented using the information. Pre and post data from the programs reveal attitude and knowledge shifts.

PULP FICTION*--THE VOLUNTEER CONCEPT
(OR HOW NOT TO SITE ADDITIONAL LLRW DISPOSAL CAPACITY)

Diane Aurelia Burton
Heartland Operation to Protect the Environment, Inc.
1903 'N' Street
Suite "E"
Auburn, Nebraska 68305
(402) 274-5242

ABSTRACT

Experiences of compacts and of individual states throughout the nation indicate that low-level radioactive waste disposal siting processes, based from the beginning upon the volunteer concept are fraught with problems. Most apparent among these problems is that the volunteer concept does not lead to scientifically and technically based siting endeavors. Ten years have passed since the Amendments Act of 1985, and no compact or state has been successful in providing for new LLRW disposal capacity. That failure can be traced in part to the reliance upon the volunteer concept in siting attempts. If success is to be achieved, the future direction for LLRW management must focus on three areas: first, a comprehensive evaluation of all LLRW management options, including reduction of waste generated and on-site storage; secondly, a comprehensive evaluation of the current as well as projected waste stream, to determine the amount of disposal capacity actually needed; and, finally, sound scientifically and technically based siting processes.

INTRODUCTION

The Federal Low-Level Radioactive Waste Policy Act (the Act) was originally enacted in 1980. That legislation was a scant three pages. It mandated that states were responsible for providing disposal capacity for commercially generated low-level radioactive waste (LLRW) and encouraged states to form compacts to fulfill that responsibility by permitting compacts to prohibit the importation of LLRW from outside of the compact region.

a. Pulp: a soft, moist, formless mass that sticks together; the soft, Juicy part of a fruit; the soft, spongy pith inside the stem of a plant; a mixture of ground-up, moistened cellulose material; (slang) a magazine printed on rough, inferior paper stock made from wood pulp containing sensational stories. Fiction: a making up of imaginary happenings; feigning; anything made up or imagined, as a statement, story, etc.; fable; fantasy; fabrication.

The U.S. Nuclear Regulatory Commission (NRC) codified regulations for the development and operation of commercial LLRW disposal sites in December, 1982, and numerous regulatory guidance documents were published as early as 1982.¹ The NRC regulations were used as a template by Agreement States^b to develop their own LLRW disposal requirements.

During the five years following the passage of the Act, seven compacts were formed by 35 states, however, no compacts had yet been consented to by Congress. In 1985 Congress undertook a major rewriting of the Act, providing a timeline for the development of additional LLRW disposal capacity with specific incentives and penalties. States or compacts were to have additional disposal capacity available by 1993, or at the very latest by 1996.

The timetable set forth in the 1985 amendments to the Act proved unrealistic. In early 1990, Senator John Glenn requested that the U.S. General Accounting Office (GAO) review states' efforts to implement the Act. The GAO found that, "Although most states and compacts have made some progress in developing their disposal facilities, only one compact [Southwest Compact-California] expects to complete a new facility by 1993 and only two compacts [Central Midwest Compact-Illinois & Central Compact-Nebraska] expect to complete their facilities by 1996. The slow pace of facility development results from the numerous and complex legislative and administrative tasks, such as selecting potential sites, that must be accomplished. These tasks have often been performed in the face of public opposition, legal challenges, and uncertainty over issues such as liability protection for new disposal facilities."²

Now, 15 years after the initial legislation and 10 years after the rewrite, there are 9 established compacts representing a total of 41 states (and one other compact of 3 states pending before Congress). There, however, has yet to be established any additional LLRW

b. An Agreement State is a state that has entered an agreement with the NRC to assume regulatory authority over certain sources of radiation under the provisions of 42 USC 2021.

disposal capacity under the compact system. Indeed, the only additional disposal capacity has been developed outside, and apparently in spite of, the compact system.^c

The mid-eighties found compact commissions across the country beginning to form, and to set about the task of developing siting processes. Some compacts designated a host states in legislation enacting the compact agreement (i.e. Central Midwest); some compacts undertook screening studies of their entire region (i.e. Central Interstate Compact) to find a host state. The legislatures in member states of some compacts enacted legislation specific to the siting and licensing of LLRW disposal sites (i.e. California, Illinois, Michigan).

THE VOLUNTEER CONCEPT

An interesting notion radiated from all this activity -- the Volunteer Concept (The Concept). The Concept could be applied at the compact, as well as at the local level. "Selecting a host state to serve as the site of the region's low-level radioactive waste facility is a complex and politically sensitive activity. The selection process can be strengthened if one of the Compact member states freely accepts the leadership position and responsibilities of a host state....A similar approach can be used on a statewide basis once a host state is selected...."³ The Concept basically consisted of the fantasy that if a locality would volunteer to have a LLRW disposal site, then siting would flow smoothly thereafter.

The Concept implies public involvement; nonetheless, early and significant public involvement was routinely neglected in developing siting processes. There are few, if any, examples of meaningful involvement of the effected public in siting processes across the country.

c. In 1991 EnviroCare received a license from the State of Utah, an NRC Agreement State, to accept certain low-level radioactive waste materials. In April, 1995, the Northwest Compact, of which Utah is a member state, passed a resolution allowing EnviroCare to receive waste from outside that Compact region, provided there was approval from the Compact of origin of such waste.

Illinois

Illinois^d incorporated The Concept into its Low-Level Radioactive Waste Management Act (Management Act), which provided for a local approval mechanism. The Illinois Department of Nuclear Safety (IDNS) was designated as the siting authority; it began to implement its site identification plan in early 1987. Potential siting areas were to be a minimum of four square miles and an interstate highway was not to lie within that four square mile area. Counties were not to be considered as potential sites without evidence of interest from the county officials. By August, 1987, of Illinois's 102 counties only 21 had expressed any level of interest.

As the siting process progressed (or more specifically, failed to progress as envisioned), the Management Act was amended in November, 1987; a veto power was given to county officials, however, a county's veto would not apply to a site within 1½ miles of a municipality that supported the site. Following that amendment, counties voted to drop from consideration at an alarming rate. With the number of "interested" areas dwindling, IDNS supplemented the list of favorable sites by adding areas of less than four square miles within 1½ miles of the city of Martinsville (located in Clark County).

The early efforts to involve the public in the Illinois siting process consisted of letters, formal meetings, informal meetings, and telephone calls with county officials. The IDNS took state and local officials on trips to Barnwell, South Carolina, and to France to tour LLRW disposal sites. As the siting process homed in on potential sites, citizen groups formed to support and oppose the LLRW project. Once Martinsville was isolated from the pack as the site, the LLRW project became a very divisive issue for the community. Charges that the IDNS and its contractors had changed the rules in the middle of the game and had ignored or changed data became common place.

d. Illinois and Kentucky make up the Central Midwest Compact, Illinois is the designated as host state in the Compact statute.

The end result of Illinois's \$80 million plus venture into a voluntary siting process was the legislative creation of the Low-Level Radioactive Waste Disposal Facility Siting Commission (the Siting Commission) which was charged with reviewing the siting process and with ensuring the safety and suitability of the Martinsville site. The Central Midwest Compact Commission made one of the most meaningful efforts to date in providing for public participation. "In an unprecedented attempt to earn the confidence of the public, the Central Midwest Compact Commission agreed to fund the participation of public interest groups [in Siting Commission proceedings] by paying the cost of their technical experts and legal counsel."⁴ But, was it too little and too late to save the Martinsville site?

The answer is "Yes." Following 72 days of testimony and arguments, the Siting Commission voted unanimously to reject the Martinsville site. The Honorable Seymore Simon, Chairman of the Siting Commission, observed, "Rather than working within the guidelines that it established looking elsewhere to find a technically acceptable site with local approval, IDNS simply changed the rules in the middle of the game abandoning the technical criteria that it had used for months.... Thus, to me, it was politics, not science, that was the primary consideration for the selection process.... I would reject in part the explanation put forth by IDNS and Chem-Nuclear that a careful scientific analysis settled upon a site that was also politically acceptable. Instead, I am satisfied that political acceptability was a cornerstone of the selection process for the MAS [Martinsville site]. Science was called in after the fact in an attempt to justify the politically selected and clearly the only site that was available."⁵

Nebraska

Nebraska's then Governor Kay Orr, in December, 1987, issued 10 conditions for Nebraska^e to act as host state, including The Concept among those conditions, calling its "community consent" -- no disposal site was to be located where "community consent" was not evident. No statute was adopted in Nebraska defining what "community consent" was, much less allowing for a local vote on the issue. Further, all efforts to define "community" or "consent" in statute were adamantly opposed by lobbyist for the developer US Ecology (USE), the Central Compact Commission, and the nuclear utilities of the region.

The Central Compact Commission adopted Nebraska's conditions as generic conditions for any host state, and a week later its contractor USE recommended that Nebraska be host state. USE announced that it was "undertaking a public participation program with the dual purpose of public education and direct public input into site selection decisions."⁶ A Citizens Advisory Committee (CAC) was established through a grant from USE to the Nebraska League of Women Voters, purportedly to assist USE in selecting the actual candidate sites. The CAC received information under the sole direction of USE.

The siting process in Nebraska^f followed a path similar to that in Illinois. Only counties that expressed interest in the LLRW project were to be considered. Promises were made that counties could withdraw from consideration at any time in the process. Of Nebraska's 93 counties only 20 expressed interest in the project. Seven months following its creation, at the final planned meeting of the CAC, "Rich Paton [USE vice-president] said.... US Ecology has identified 111 areas that meet or exceed the licensing requirement. Data presented was from the 27 areas considered best suited. Paton said each of the areas may

e. Nebraska, Arkansas, Kansas, Louisiana, and Oklahoma make up the Central Interstate Compact. There is no statutory provision setting out a process for the Compact to name a host state. The statute provides that if no state volunteers, the compact selects a developer to select a host state.

f. For a review of the Nebraska siting process see: Diane Aurelia Burton, "Site Selection -- The Nebraska Experience: Could It Have Been Successful?" 15th Annual DOE Low-Level Radioactive Waste Conference, Phoenix, Arizona, December 1-3, 1993.

hold several 300 acre parcels of land which are equally suitable. The CAC was asked to help narrow the 27 to 5-10 candidate areas."⁷

At that final meeting, the CAC was directed through an exercise, based upon information provided by USE, to rank the 27 areas that USE presented as the most favorable. Two months later USE identified three candidate sites, one each in Boyd, Nemaha, and Nuckolls counties. The candidate sites in Nemaha and Nuckolls counties were not located within any of the 27 purportedly best suited areas presented to the CAC by USE. The Boyd County site was among those areas, but was not among the "top" areas as ranked by the CAC.

Only Nemaha and Nuckolls counties remained on record as supporting further involvement in the LLRW project at the time the candidate sites were announced. To this point in the process, USE had relied on the county as the entity whose support was necessary. However, given the lack of support by the Boyd County officials, USE simply decided that the support of the Village of Butte was adequate to demonstrate community consent.

Following approximately nine months of onsite characterization work, on December 29, 1989, USE designated the Boyd County site as its preferred site. USE submitted its license application in July, 1990, for the 320 acre site in Boyd County. Following a January, 1993, announcement by Nebraska regulators of an intent to deny a license because over 40 acres of certified wetlands existed on the site, USE attempted to reconfigured its site, carving out a 110 acre portion of the 320 acre site that hopefully would be without wetlands. USE's final revision of its license application material was submitted in June, 1995. Today that material is under review by Nebraska's Departments of Health and Environmental Quality. It is of note that the U.S. Army Corps of Engineers has determined that wetlands are contained on the 110 acre site --USE continues to dispute that fact.

The Boyd County Board voted to withdraw Boyd County from consideration as a LLRW disposal site prior to the designation of the three candidate sites, and that body

maintains that position to this day. Needless to say, there is extensive community disruption in Boyd County. Unlike the Illinois project, the Nebraska project has not failed yet. A preliminary decision by Nebraska's regulatory agencies is expected before the end of 1996. This scrivener believes the chances of the Body County site receiving a license to be slim to none.

POLITICAL CRITERIA AS A SCIENTIFIC FOIL

The preceding outlines of The Concept in action in Illinois and Nebraska demonstrate that when one starts with the political criteria of only examining areas where county officials express an interest in a LLRW project, attempts to represent the siting process as scientifically based are foiled. The perception is that political criteria drive the process, regardless of protestations to the contrary. Once embarked down The Concept road, there's little if anything that can be done to convince people that something highly scientific and technical is going on.

Both in Illinois and Nebraska the rhetoric used by representatives of the state, the compact, and the contractors emphasized the highly technical, scientific nature of the process. They touted comprehensive, detailed studies of all available data, including geology, hydrology, biological resources, cultural resources, transportation, land use, and engineering considerations to identify suitable candidate sites. They were striving for technical excellence -- a worthy goal. However, when push came to shove, some expression of interest from county officials and the availability of land appeared to be the selection criteria.

The blade of the political criteria sliced through the heart of the later applied scientific criteria. Sites were selected that had documented technical problems (i.e. certified wetlands, limestone as a groundwater source, irregular soil settling patterns) and characterization efforts were less than adequate.

The Siting Commission was anything but complimentary in its evaluation of the Illinois site characterization efforts.⁸ All three commission members admonished the IDNS and its contractors for haphazard work and shoddy quality assurance. The Siting Commission noted conflict among the groups of scientist working on the project as well as "a revolving door" that spun between IDNS and its contractor. The political criteria -- county officials' expression of interest in the project -- in place from the beginning left the IDNS in a most un-scientific mode, attempting to develop technical justification for the only site it had.

Chairman Simon assessed the "technical excellence" of the Illinois site characterization: "I'd like to talk about whether there was technical excellence in the study.... In September, 1988, IDNS circulated the first issue of a newsletter which was entitled 'The Illinois Approach.' The director wrote the feature article. It was entitled, quote, 'Technical Excellence - Political Acceptability - Public Participation.' The title referred to three self-proclaimed key elements to the low-level waste program.... That IDNS appeared to retreat from technical excellence in order to sponsor the MAS gives me reason for pause.... Although the siting process failed to meet its promised goals, broken promises alone, I suppose, are not sufficient to reject this site.... careless science, however, is another matter. ... Scientific efforts in several cases were fraught with errors, sloppiness, and carelessness."⁹

The GAO in conducting a review of the Nebraska siting program, concluded, "On the basis of our comparison of geologic and geographic data for the three sites to technical criteria established by the NRC and Nebraska's Department of Environmental Control, we agreed that the Boyd site is technically preferable to the other sites. However, we had several questions about local geologic and groundwater and surface water conditions that were not addressed in the US Ecology data and reports we reviewed or in the license application material submitted to the state during the time of our review."¹⁰

That GAO report further noted that the complex geologic conditions present at the Nebraska sites could have been discovered by a review of available literature and data prior

to their selection. "Our review of certain geologic literature and data for those counties indicated that these geologic conditions were known to others for many years before the site - selection process."¹¹ Further, the GAO found that the storage of the geologic cores collected during characterization, "did not appear to represent good storage practices." It should be noted that the GAO reviewed only data gathered by US Ecology and its license application material, assuming the information was accurate.

MOVING TO A RATIONAL CONCEPT

Public participation is a most worthy endeavor, the laws and regulations governing LLRW disposal require it, during the licensing process. Allowing a community to "volunteer" to be host to a LLRW disposal site is not a bad thought. Unfortunately, the processes undertaken to develop that thought have not been successful, mainly because too much effort was exerted to find a volunteer and not enough effort was placed upon meaningful public participation and technical siting requirements.

Michigan has recently completed a report to its legislature on the state's management options and a new siting process that uses a volunteer host community program plan.¹² This year, Ohio finally enacted legislation to allow for a siting process to begin in that state and it intends to utilize a volunteer host community plan (Ohio has been host state for the Midwest Compact since July, 1991). Pennsylvania is also just now undertaking a volunteer siting process.

As those states embark on their volunteer siting processes, they should be mindful of a number of facts: the process will cost a lot of money; the process will take a long time; the backdrop before which they operate is 15 years of failure; one of the main criticisms too many sites planned given the volume of waste to be economically viable of the current LLRW management plan gains weight rapidly. Further, it is imperative that when terms like "volunteer," "community," and "consent" are used in statutes and regulations, that those terms be defined with specificity. To allow those terms to become "elastic concepts"¹³ is to undermine the process in the beginning.

Public participation must be early and indepth. Those in charge of a LLRW project must acknowledge the risks and uncertainties inherent in nuclear technology. The decisions maker would be wise to heed Clark Bullard's perceptive assessment of the situation: "In a democratic society the burden is on government to earn public confidence rather than assume it. When people act through their legislature to authorize an executive agency to take an action such as developing LLRW disposal, that delegation of authority involves an element of trust....Uncertainties about the effects of a complex technology are handled through this mechanism of trust. The uncertainties are first reduced to the extent possible through technical competence, and any residual doubts are handled through the trustee's responsibility to give the benefit of the remaining scientific doubt to the client. The case of radioactive waste presents a special challenge because of the magnitude of the scientific uncertainties involved, and because the nuclear institutions that must be the object of such trust are encumbered with the failures of the past."¹⁴

Public education programs need to emphasize not just the need for the LLRW disposal capacity, but also the problems associated with it. Although Organizations United, Energy Awareness Council, and others tell you the hot button to push to get public support is medical treatment and research, we all know that medical treatment and research are not the major source of LLRW -nuclear power reactors are. Tell the people that up front; It's easier to tell the truth than to later explain why you did not.

Independent experts and representatives from state and national organizations opposed to the development of LLRW disposal sites must necessarily be included in any public education program. This last statement might sound ludicrous to those of you planning a siting process, but these folks mentioned -- opponents and critics -- will be involved eventually. if developing public confidence, credibility, and avoiding community disruption are among the goals of a siting process, you will be taking a step in the direction of achieving those goals by acknowledging and involving representatives from groups opposing or critical of the project from the beginning.

Let's back up now. Public education is very important, but first there needs to be institutional education -- education for those in charge of the LLRW project.

"'Human beings have gotten pretty good at looking into deep space,' says a thoughtful consultant at DOE, 'but we are really no good at looking into deep time.' Thus the time may have come to abandon the cool, measured language of technical reports -- all that talk of 'perturbations' and 'surprises' and 'unanticipated events' -- and simply blurt out: 'Holy shit! Ten thousand years! That's incredible!'"¹⁵ That quote may appear to be a bit sensationalistic. It refers to the DOE's Yucca Mountain high-level waste project. However, while the regulatory time period for isolation of LLRW is only five hundred years, some radionuclides present in LLRW have half-lives that are measured in tens of thousands of years.

These are timeframes that are very difficult for people to grasp, and they evoke much uncertainty in LLRW disposal projects. The fact that there are uncertainties is what makes it critical that a comprehensive base of knowledge is available upon which to base decisions. There needs to be an evaluation of the waste stream -- the current waste stream, projected waste stream, amount of waste within those waste streams that can be stored for decay. All alternatives need to be studied in depth: development of additional disposal capacity; on-site waste management for major generators; waste reduction, both source and volume; assessment of available disposal options. Further, there needs to be an evaluation of the costs of all options.

It is unfortunate that, "There are no good, current data on the economic and environmental effects of states' plans for disposal facilities nationwide. ... there is limited information currently available throughout the nation on quantities of waste now in storage, waste generator's storage capabilities, and the extent to which generators are using alternative waste management techniques. And, neither NRC nor DOE currently have plan to collect such information."¹⁶ Unless and until decision makers have comprehensive information upon which to base their decision, any process undertaken will be flawed -- it will take more time, it will cost more money, and it will be more likely to fail.

While the compact system may have theoretically been a good idea, in practice the concept has not been playing out as intended. Studies and reports too numerous to mention note that under the present compact system, many more disposal sites are planned than the volume of waste would necessitate. The inauspicious position -- that no alternatives should be examined lest such efforts undermine support for the compact system¹⁷-- taken by supporters of the status quo is rather ostrich-like. That position will not aid in solving the problem.

The lack of information regarding LLRW Issues, after 15 years of time consumed and hundreds of millions of dollars expended, is astounding. Before sound scientific, technical based siting criteria can be applied successfully, the abyss of knowledge must be filled. More information might indicate that the compact system, in spite of the lack of progress thus far, is the best approach; or it might indicate that some other approach would better serve the citizens of our nation. The problem is we do not know; we lack information.

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**DOE ORGANIZATION AND MANAGEMENT APPROACH IN RESPONDING
TO RECOMMENDATION 94-2—THE IMPLEMENTATION PLAN**

**Derek Widmayer
Science Applications International Corporation
(301) 601-5605**

ABSTRACT

In March, the Department of Energy (DOE) submitted the Implementation Plan in response to the Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 94-2, "Conformance with Safety Standards at Department of Energy Low-Level Nuclear Waste and Disposal Sites." This paper discusses the management organization and interactions established to accomplish the tasks developed to respond to the DNFSB Recommendation. The organization of the tasks into six technical areas and the interfaces and connections between the tasks are briefly described. A summary of how each significant part of the DNFSB Recommendation is being addressed is presented. This paper provides a brief introduction to the remaining presentations in this session.

**COMPLEX-WIDE REVIEW OF DOE'S MANAGEMENT OF LOW-LEVEL
RADIOACTIVE WASTE - PROGRESS TO DATE**

**Martin J. Letourneau
DOE, EM-33, Trevion II**

ABSTRACT

The Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 94-2 includes a recommendation that the Department of Energy (DOE) conduct a comprehensive, complex-wide review of the low-level waste issue to establish the dimensions of the low-level waste problem and to identify necessary corrective actions to address the safe disposition of past, present, and future volumes. DOE's Implementation Plan calls for the conduct of a complex-wide review of low-level radioactive waste treatment, storage, and disposal sites to identify environmental, safety, and health vulnerabilities. The complex-wide review focuses on low-level waste disposal facilities through a site evaluation survey, reviews of existing documentation, and onsite observations. Low-level waste treatment and storage facilities will be assessed for their ability to meet waste acceptance criteria for disposal. Results from the complex-wide review will be used to form the basis for an integrated and planned set of actions to correct the identified vulnerabilities and to prompt development of new requirements for managing low-level waste.

LOW-LEVEL WASTE DISPOSAL PERFORMANCE ASSESSMENTS—
TOTAL SOURCE-TERM ANALYSIS

Elmer L. Wilhite
Westinghouse Savannah River Company
(803) 725-5800

ABSTRACT

Disposal of low-level radioactive waste at Department of Energy (DOE) facilities is regulated by DOE. DOE Order 5820.2A establishes policies, guidelines, and minimum requirements for managing radioactive waste. Requirements for disposal of low-level waste emplaced after September 1988 include providing reasonable assurance of meeting stated performance objectives by completing a radiological performance assessment. Recently, the Defense Nuclear Facilities Safety Board issued Recommendation 94-2, "Conformance with Safety Standards at Department of Energy Low-Level Nuclear Waste and Disposal Sites." One of the elements of the recommendation is that low-level waste performance assessments do not include the entire source term because low-level waste emplaced prior to September 1988, as well as other DOE sources of radioactivity in the ground, are excluded. DOE has developed and issued guidance for preliminary assessments of the impact of including the total source term in performance assessments. This paper will present issues resulting from the inclusion of all DOE sources of radioactivity in performance assessments of low-level waste disposal facilities.

**IMPROVEMENTS TO THE DOE LOW-LEVEL WASTE REGULATORY STRUCTURE
AND PROCESS UNDER RECOMMENDATION 94-2—PROGRESS TO DATE**

Edward Regnier
DOE-HQ, EH-232
(202) 586-5027

ABSTRACT

Among the concerns expressed by the Defense Nuclear Facility Safety Board (DNFSB) in its Recommendation 94-2 was the lack of a clearly defined and effective internal Department of Energy (DOE) regulatory oversight and enforcement process for ensuring that low-level radioactive waste management health, safety, and environmental requirements are met. Therefore, part of the response to the DNFSB concern is a task to clarify and strengthen the low-level waste management regulatory structure. This task is being conducted in two steps. First, consistent with the requirements of the current DOE waste management order and within the framework of the current organizational structure, interim clarification of a review process and the associated organizational responsibilities has been issued. Second, in coordination with the revision of the waste management order and consistent with the organizational responsibilities resulting from the strategic alignment of DOE, a rigorous, more independent regulatory oversight structure will be developed.

UPDATE OF TECHNICAL COORDINATING COMMITTEE ACTIVITIES

Ruben A. Alvarado
Texas Low-Level Radioactive Waste Disposal Authority
(512) 451-5292

ABSTRACT

The Technical Coordinating Committee has its origins in the earliest days of implementing the Low-Level Radioactive Waste Policy Act. Between 1982 and 1985, individuals in several of the states felt that coordination among the states would be beneficial to all by affording states a cost-effective method for sharing ideas, discussing alternatives, and presenting solutions to common problems. At the current time, the committee comprises members from each of the sited states. Various compacts, federal agencies, and industry groups participate in committee activities. The Low-Level Management Program provides support for the committee through the provision of logistical support and limited manpower allocation. Activities of the committee have recently focused on waste treatment and minimization technologies. The committee also has worked diligently to see the review of the 3RSTAT computer code completed. The committee has taken a position on various regulatory proposals the past year. The committee expects to continue its work until new sites are brought online.

**STATES AND COMPACTS: ISSUES AND EVENTS AFFECTING FACILITY
DEVELOPMENT EFFORTS, INCLUDING THE BARNWELL REOPENING**

Gregg S. Larson
Midwest Interstate Low-Level Waste Commission
(612) 293-0126

ABSTRACT

Ten years have passed since the first regional low-level radioactive waste compacts received Congressional consent and initiated their efforts to develop new disposal capacity. During these 10 years, both significant achievements and serious setbacks have marked our efforts and affect our current outlook. Recent events in the waste marketplace, particularly in the operating status of the Barnwell disposal facility, have now raised legitimate questions about the continued rationale for the regional framework that grew out of the original legislation enacted by Congress in 1980. At the same time, licensing activities for new regional disposal facilities are under way in three states, and a fourth awaits the final go-ahead to begin construction. Uncertainty over the meaning and reliability of the marketplace events makes it difficult to gauge long-term implications. In addition, differences in the status of individual state and compact facility development efforts lead to varying assessments of the influence these events will, or should, have on such efforts.

STATUS ON DISPOSAL OF GREATER-THAN-CLASS C

Terry L. Plummer
DOE-Headquarters, EM-32
(301) 903-7176

ABSTRACT

The Department of Energy (DOE) has developed a plan for the management and disposal of commercially generated greater-than-Class C (GTCC) low-level radioactive waste. The Low-Level Radioactive Waste Policy Amendments Act of 1985 made DOE responsible for disposal of GTCC waste. The act requires that GTCC waste be disposed in a Nuclear Regulatory Commission (NRC)-licensed facility. The NRC has amended 10 CFR 61 to express a preference for geologic disposal of GTCC waste. Based on reassessment studies, legislative guidance, and stakeholder involvement, a revised plan has been formulated to provide for total management of GTCC waste. The plan has four major thrusts: (1) plan for GTCC waste storage at the generator site until disposal is available, (2) establish storage for GTCC sealed sources posing health and safety risk to the public, (3) facilitate storage for other GTCC waste posing health and safety risk to the public, and (4) plan for co-disposal of GTCC waste in a geologic disposal site with similar waste types. The revised plan focuses on applying available resources to near- and long-term needs.

AUTHORITY OF COMPACT COMMISSION TO CONTROL IMPORT/EXPORT FOR
DISPOSAL AND OTHER PURPOSES

Robert D. Poling
Congressional Research Service
Library of Congress
(202) 707-6006

ABSTRACT

As operational capabilities for radioactive waste disposal expand and as approaching dates for waste exclusion near, the legal question of the authority of compact commissions to control the import and export of low-level radioactive nuclear waste is a legal issue of significance to many regions. This presentation will review the provisions of various compacts and the federal compact approval legislation, consider the interpretation of the Commerce Clause of the U.S. Constitution, and discuss possible interpretive perspectives relating to the authority of compact commissions. The discussion will focus on whether waste exclusion authority is confined in application to imported waste for permanent disposal or extends to transported and imported waste for processing, treatment, or other purposes.

