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TRANSURANIC SOLID WASTE MANAGEMENT

RESEARCH PROGRAMS

PROGRESS REPORT FOR JANUARY THROUGH JUNE 1975

ABSTRACT

Progress is reported for the transuranic solid waste management programs funded at the Los Alamos Scientific Laboratory by the Energy Research and Development Administration's Division of Nuclear Fuel Cycle and Production.

Under the Transuranic Waste Research and Development Program, tests continued to evaluate less costly fiber drums as alternate storage containers for low-level wastes. Tests completed to date indicated that the factory-applied fire retardants were not satisfactory; however, investigations of more promising coatings have been undertaken. The fiber drums were more satisfactory in other aspects. Expanded laboratory and field radiolysis experiments were performed. These were accompanied by investigations of H_2 diffusion through common waste packaging materials and through Los Alamos soil. Radiolysis studies were also initiated on wastes typical of Mound Laboratory. All results to date show that while H_2 is being slowly generated, the quantities are not excessive and should diffuse rapidly away.

Construction of the TDF facility began and was 14% complete at the end of this reporting period. The incinerator was received, installed and checked out, and is operational. Additional specifications were developed and equipment procurement continued.

Progress is reported on development of a system for evaluating radioactively contaminated solid waste burial sites. Source term data are summarized for some Los Alamos areas along with waste composition and configuration considerations. Physical and biotic transport pathways are discussed and development of modeling methods for projecting the environmental fate of transuranic materials is detailed.

I. TRANSURANIC WASTE RESEARCH AND DEVELOPMENT PROGRAM (G. Maestas, R. Nance, A. Zerwekh)

A. Corrosion Studies

Studies to determine corrosion rates for various materials to be considered for waste storage containers continued with the testing of mild steel drum coupons coated with various corrosion-resistant materials in air containing 50 and 100%

relative humidity at ambient temperature. The coatings under study include Rustoleum Industrial Coatings, white and black enamels, hot-dipped zinc galvanize, and two bituminous coal-tar and petroleum-based coatings. Although some of these coatings may prove to be satisfactory anticorrosive agents, the high dollar cost and increasing difficulty in procuring mild steel containers and 2.29-mm polyethylene liners make it

mandatory to consider substitutes. In addition, various resins reported to be chemical, corrosion, and fire resistant are being investigated for coating metallic or nonmetallic waste containers, inside and/or outside, with or without fiberglass added to the resin. The first of these resins, Synres, a thixotropic polystyrene, has been applied to both mild steel and fiber drums in preparation for testing. The second, Synolite Gel Coat, a mixture of isophthalic and orthophthalic resins, is on hand and the third, Continental Chemical Tuffhyde, is expected soon.

B. Fire Propagation Investigations

Continued field testing in the investigation of fire causes and propagation involved attempts to induce combustion inside mild steel and fiber containers. Contents simulated alpha waste and included paper, rags, plastics, and rubber. A heat source consisting of a nichrome wire coil was placed among the contents and energized with 115 V ac from a portable generator. Surface temperature of the coil was about 900°C and heat dissipation was at a rate of about 650 J/s. Test drums were placed in an array simulating actual storage conditions.

Results indicate that combustion inside waste containers is unlikely, but strict controls should be enforced to exclude pyrophoric materials. Combustion was not internally induced in any of the tests in spite of the extremely high temperature of the heat source. Posttest inspection of contents showed charring only near the heater element. Materials outside about a 7-cm radius from the heat source appeared intact.

Evidently the available oxygen initially in the container is insufficient to support combustion in the enclosure configuration tested. The free air in a 115-l container has enough oxygen to burn stoichiometrically only about 5 g of PVC under ideal conditions, i.e., air/fuel mixing, high temperature, and sufficient time. Mass spectrograph analysis of gases liberated

during the charring revealed that oxygen content decreases and the CO₂ content increases, reducing the possibility of further combustion. In addition, a positive pressure exists inside the container until most of the added heat is transferred to the surrounding atmosphere. The positive pressure would inhibit outside air from entering the container and enhancing combustion. However, fiber drum rupture which occurred with an explosive material in the contents did result in autoignition and the ensuing fire spread to other containers in the array.

The explosive used to simulate pyrophoric material was a nitric acid (HNO₃) soaked piece of cheesecloth (dry weight 55 g). The cheesecloth was soaked for 10 to 20 min, allowed to dry, and then placed among the test drum contents. Rags soaked in 16 M HNO₃ caused fiber drum rupture, but a rag soaked in 10 M HNO₃ did not explode. A test with a 210-l mild steel drum which contained a rag soaked in 16 M HNO₃ burned but did not explode. Previous laboratory tests have demonstrated, however, that an explosion caused by a cheesecloth soaked in 16 M HNO₃ will blow the lid off a stainless steel drum of 18-l capacity. It is therefore probable that the 210- or 115-l mild steel drum would also rupture. Prohibition of all pyrophoric materials is recommended.

Although both fiber and molded steel drums are likely to break if a 16 M HNO₃-soaked rag explodes, propagation of fire is probable only with fiber drums. Tests disclosed that the fire retardant paint applied by the drum manufacturer was ineffective, and fire which occurred after rupture spread quickly to adjoining containers. Replacement of mild steel containers by fiber ones for retrievable storage of combustibles would obviously require a more effective fire retardant. Efforts are presently under way to find a suitable product.

Present efforts also include investigation of fiber drums for sludge disposal. Fiber containers filled with water have shown no leaks after two months. The feasibility of using rectangular waste containers made of this fiber material also is being considered. These small boxes would subsequently be enclosed in fiberglass-coated plywood boxes.

Table I outlines the results of the tests performed during this reporting period. They indicate a high incidence of fiber drum wall breakdown due to the heater element. It should be noted that the element surface temperature of 850 to 900°C is much higher than would be expected in ^{239}Pu waste storage.

No attempt has been made to define the upper limit of fiber resistance to burn-through. Clearly the limit is considerably lower than for mild steel.

TABLE I
TEST RESULTS FOR FIRE RESISTANCE
IN WASTE CONTAINERS

Test No.	Container	Results
1	115- $\frac{1}{2}$ fiber	16 M HNO_3 -soaked rag exploded 6 min after heat generation began. Lid deformed, preventing pressure build-up, but drum did not rupture. Heater element burned through bottom of drum after 67 min. Oxygen content went from 21% before heat to 20% after 1 min and 16% after 5 min.
2	210- $\frac{1}{2}$ mild steel	16 M HNO_3 -soaked rag did not explode. Internal temperature and pressure stabilized after 55 min and test was terminated. Rag partially charred.
3	115- $\frac{1}{2}$ fiber	16 M HNO_3 -soaked rag exploded 13 min after test began, rupturing drum wall. Test drum ignition followed rupture and entire array was on fire within 5 min.
4	115- $\frac{1}{2}$ fiber	Heater element in direct contact with drum wall; burned through in 3 min. Test terminated.
5	115- $\frac{1}{2}$ fiber	10 M HNO_3 -soaked rag did not explode. Heater element eventually burned through drum wall 57 min after test began.

C. Radiolysis Studies

Studies of the radiolysis effects caused by $^{238}\text{PuO}_2$ on various waste matrices were continued using type 304 stainless steel cylinders each containing 52.5 g of waste. Each cylinder had a volume of 300 cm^3 and was fitted with a pressure gauge and a miniature brass shut-off valve (see Fig. 1). One cylinder, containing 52.5 g of mixed cellulose strongly contaminated with 62 mg of ^{238}Pu , generated a maximum gauge gas pressure of 689.5 kPa (100 psi)/gauge in 285 days. As would be expected, the rate of pressure increase was not constant but diminished with time. The remaining gas pressure was 558.5 kPa after the initial sample. A second sample was taken 85 days later when the pressure had again reached 689.5 kPa, reducing the pressure to 572 kPa. It took 84 days for the pressure to climb back to 689.5 kPa a third time. Table II shows the composition of these gas samples.

After withdrawing the third mass spectrographic sample, enough of this gas mixture was back-filled into an evacuated 500- cm^3 Pyrex flask to bring it to atmospheric pressure. A radio frequency arc was repeatedly discharged through the gas mixture with no discernible reaction. The literature describes the explosive limits of hydrogen in air as 4 to 75%, but information concerning the explosive properties of hydrogen in other gaseous mixtures could not be found. It is planned to repeat this same test using a gas sample from a drum containing ^{238}Pu -contaminated hydrogenous waste in retrievable storage at LASL. When last sampled, the gas mixture in this drum contained 13% H_2 and 5.3% C_2 .

Monitoring of four ^{238}Pu -contaminated waste drums in interim storage continues, and it is planned to instrument two additional drums which will be placed in storage soon. Table III is a compilation of the data collected from the instrumented waste drums to date. There has been no gas pressure build-up, although there is a significant concentration of combustible gases.

Fig. 1. Experimental container for radiolysis studies.

Fortunately, there is a decrease in percentage of oxygen. Hopefully, the above described arcing experiment will be the first step in determining whether there is an actual explosion hazard in the storage drums. Hydrogen has been found to diffuse rapidly through some packaging materials and through Los Alamos disposal-area soil. This diffusion, and the fact that these drums are not sealed gas-tight, makes it unlikely that there will be any pressurization of waste drums.

Matrices typical of Mound Laboratory wastes were individually contaminated with plutonium, mixed together, and placed in experimental cylinders (see Table IV).

After 60 days at ambient temperature (20°C) they have not begun to pressurize.

Another cylinder containing a strongly contaminated mixed cellulose matrix (62 mg $^{238}\text{PuO}_2$ on 52.5 g waste), plus water equal in weight to the matrix, showed erratic gas pressure behavior. Although a leak was not detected, all hardware was tightened. There was an immediate and significant gas pressure rate increase, and the average daily increase in pressure has subsequently been 5.52 kPa. For a duplicate cylinder containing no added water, the daily pressure increase over the same time span has averaged 2.79 kPa. A sample was drawn from this cylinder after 60 days

TABLE II
COMPOSITION OF GAS SAMPLES FROM $^{239}\text{PuO}_2$
CONTAMINATED CELLULOSES

Sample No.	Time to Reach 689.5 kPa (Days)	Gas Composition (mol %)					
		H_2	CH_4	O_2	CO	CO_2	N_2
1	285	50	0.8	<0.1	10	32	8
2	85	51	0.9	<0.1	10	32	6
3	84	50	1.0	<0.1	7	35	6

TABLE III
DATA FROM ^{238}Pu -CONTAMINATED WASTE IN COVERED-TRENCH STORAGE

Drum Number	^{238}Pu Content, g	Waste Content, kg	Days in Storage	Temperature, °C				Sample Withdrawn From	Gas Composition (Mol %)					
				Inside Drum	Outside Drum	Ambient	Soil Under Cask		H ₂	CH ₄	O ₂	CO ₂	CO	N ₂
223	14.9	17.5	41	12.5	11.5	2.0	7.0	DRUM	0.8	0.1	16.0	6.3	2.0	74.0
			94	12.0	12.0	5.0	7.0	DRUM CASK	0.9 <0.1	0.1 0.1	15.0 20.0	5.4 0.1	0.9 0.3	77.0 79.0
			176	14.5	14.5	24.5	6.0	DRUM CASK	1.0 0.1	0.1 <0.1	15.0 20.0	5.6 <0.1	1.3 0.4	76.0 79.0
224	22.1	14.5	41	18.0	12.5	2.0	7.0	DRUM	0.2	<0.1	19.0	1.4	0.7	77.0
			94	16.5	12.0	5.0	7.0	DRUM CASK	0.2 0.1	<0.1 <0.1	19.0 20.0	1.2 <0.1	0.3 0.1	78.0 79.0
			176	19.0	13.5	24.5	6.0	DRUM CASK	0.2 <0.1	<0.1 <0.1	20.0 20.0	1.2 <0.1	0.4 0.2	78.0 79.0
232	29.4	10.2	41	20.5	13.0	2.0	7.0	DRUM	6.7	0.4	11.0	12.0	3.0	66.0
			94	20.0	12.5	5.0	7.0	DRUM CASK	10.0 0.5	0.4 <0.1	7.7 20.0	14.0 0.1	4.8 0.5	62.0 78.0
			176	23.5	20.0	24.5	6.0	DRUM CASK	13.0 0.6	0.6 <0.1	5.3 20.0	18.0 <0.1	7.0 0.6	56.0 78.0
233	17.0	14.5	41	19.0	12.5	2.0	7.0	DRUM	<0.1	<0.1	20.0	0.6	0.7	78.0
			94	17.5	11.0	5.0	7.0	DRUM CASK	0.1 <0.1	<0.1 <0.1	20.0 20.0	0.6 0.1	<0.1 <0.1	79.0 79.0
			176	20.0	13.5	24.5	6.0	DRUM CASK	<0.1 0.1	<0.1 0.1	20.0 20.0	0.6 0.1	<0.1 0.1	78.0 78.0

of radiolytic attack. The analysis was as follows: H₂, 85%; CH₄, 0.9%; O₂, < 0.1%; CO, 3.9%; CO₂, 7.1%; N₂, 3.9%. This gas mixture, compared to that from the cellulose matrix with no added water, indicates that there is significant radiolytic decomposition of the water.

Two experimental cylinders, containing 35 g of sorbed Duoseal vacuum pump oil contaminated with finely divided ^{238}Pu oxide,

also appeared to be producing anomalous time-pressure data. When the hardware was retightened, there was an immediate positive pressure response for cylinder 33. Table V shows the average daily pressure increase by weeks. (Note that cylinder 33 apparently developed a leak during the third week.) At the end of the seventh week, cylinder 34 reached 103.4 kPa, and its gaseous contents were analyzed by mass

TABLE IV
CONTAMINATION LEVELS OF SIMULATED MOUND LABORATORY WASTE

Matrices	Contamination Levels, nCi/g		
	Strong	Medium	Weak
PLASTICS	15 x 10 ⁶	7.5 x 10 ⁶	2 x 10 ⁶
Polyethylene			
Polypropylene			
Polyvinylchloride			
GLOVES, DRYBOX	4 x 10 ⁶	2 x 10 ⁶	4 x 10 ⁶
Neoprene/Hypalon/Lead			
CELLULOSES	2 x 10 ⁶	1.5 x 10 ⁶	1 x 10 ⁶
Rags			
Paper			

TABLE V
AVERAGE DAILY PRESSURE INCREASE (kPa) BY WEEKS
(35 g DUOSEAL ON 17.5 g VERMICULITE)

Cylinder No.	Contamination (mg $^{238}\text{PuO}_2$)	Weeks ^a								
		1	2	3	4	5	6	7	8	9
33	62	2.71	2.71	0.97	0.49	Neg	Neg	3.69	3.94	2.96
34	31	0.76	2.69	2.83	3.59	2.40	2.48	1.97	3.69	2.22

^aHardware tightened on cylinders between weeks 5 and 6.

spectrograph. Cylinder 33 took 62 days to reach 103.4 kPa, undoubtedly because it leaked an unknown volume of gas between the third and sixth weeks. Both cylinders contained the typical gas mixture for contaminated homogeneous waste matrices. The percentages are shown in Table VI.

D. Handling of Waste from Plutonium Processing Areas

1. Nonretrievable Waste

Assay of Room Waste

The MEGAS (Multi-Energy Gamma Assay System) has been in use for evaluating room-generated waste in 60-l cardboard boxes for approximately 1 yr. In December 1974, it was modified by incorporation of a minicomputer to perform calculations and give an answer directly in units of nCi/g. The operation of the MEGAS has generally been very satisfactory. Occasionally, small quantities of fission products are found. Sometimes they have been incorrectly identified as ^{238}Pu . Procedures for the correct identification of these fission products will be incorporated in the computer's operation of the MEGAS.

A summary of room waste boxes from the plutonium processing facility is presented in Table VII.

Dumpster Lock-Up Program

All of the Dempster Dumpsters inside the inner exclusion fence of TA-21, and two plutonium dumpsters at TA-35, have been equipped with padlocks. Keys were restricted to selected personnel and all site employees were made aware of operating restrictions. The primary objectives of these actions were

- Exclude potentially radioactive waste from the "cold" Dumpsters.
- Exclude Pu-contaminated room waste which should be placed in normal room trash boxes for assay.
- Prevent plutonium waste from being placed in uranium waste Dumpsters.
- Improve monitoring of large waste items in order to exclude items exceeding 10 nCi/g of waste.
- Promote packaging or bundling of waste in order to prevent its uncontrolled dispersal by wind at the burial site.

To date the program is operating successfully.

Reduction of Waste Volumes

In order to reduce the volume of waste materials, laboratory, construction, and maintenance personnel have been instructed to remove all unnecessary packing materials

TABLE VI
GAS SAMPLES FROM RADIOLYTIC ATTACK OF DUOSEAL ON VERMICULITE

Cylinder No.	Gas Composition (mol %)						
	H ₂	CH ₄	O ₂	CO	CO ₂	N ₂	Organics
33	84	1.7	<0.1	0.4	0.6	13	Traces
34	62	1.2	<0.1	0.6	0.6	35	Traces

TABLE VII
ROOM WASTE BOXES FOR JANUARY - JUNE 1975

	Jan. ^a		Feb.		Mar.		Apr.		May		June	
	No. of	%	No. of	%	No. of	%	No. of	%	No. of	%	No. of	%
	Boxes		Boxes		Boxes		Boxes		Boxes		Boxes	
Boxes less than 1 nCi/g	107	80	111	85	122	86	155	90	152	91	162	87
From 1 to 10 nCi/g	12	9	15	12	9	6	7	4	9	5	21	11
10 to 100 nCi/g	8	6	4	2	6	4	5	3	1	1	2	1
100 to 5000 nCi/g	7	5	1	1	6	4	5	3	5	3	11	1
Totals	134		131		143		172		167		196	

Summary for this 6-month period.

	Number of Boxes	Percent of Total
Boxes less than 1 nCi/g	809	85.8
From 1 to 10 nCi/g	73	7.7
10 to 100 nCi/g	26	2.8
100 to 5000 nCi/g	35	3.7
Total	943	

^aJanuary numbers are estimates due to installation of the MEGAS minicomputer during the period December 10-30, 1974. This required counting many December boxes in January.

before moving the equipment into plutonium processing areas. The Materials Receiving Room was constructed in 1974 and is now being used for this purpose by Laboratory personnel.

2. Retrievable Waste

A summary of retrievable waste for the period of January through June 1975 is presented in Table VIII.

E. Loss of Hydrogen from Storage Containers and Simulated Burial

In order to simulate conditions that would be encountered in 20-yr retrievable burial at Los Alamos, a 1.4-m-high by 0.3-m-diam test pit was excavated and covered with 1 m of loose earth (tuff) fill. The sides of the pit were typical porous tuff. Hydrogen was injected into the pit and its concentration was measured as a function of time to determine the diffusion rate. A precise, nondestructive assay device for H₂ is not commercially available; therefore, an MSA H₂ safety alarm system, employing a catalytic head, was modified for this purpose. Experimental results are

listed in Table IX in terms of percent of original H₂.

Hydrogen diffusion through typical waste containers was also measured. In comparison with the results given in Table IX, H₂ losses were much slower for both 2.3-mm (90-mil) 200- μ polyethylene drum liners and heat- and tape-sealed 0.33-m (12-mil) PVC bag-outs. H₂ losses varied with the taping technique and the kinds of tape used in the tape-seals, but were always greater for tape-sealed bags than heat-sealed bag-outs. It was determined that H₂ consumption by the catalytic head may have caused spurious results. Future work will use a non-destructive assay method.

F. Assay Instrumentation (MEGAS)

The minicomputer-controlled box counter, MEGAS, has been in operation at the LASL Plutonium Processing Facility for six months. All of the low-level waste from this facility is measured to determine if it is above or below 10 nCi/g. The counter through-put is between 150 - 300 boxes per month. About 7% of these are found to

TABLE VIII

DRUMS OF ^{239}Pu WASTE SENT TO 20-YR RETRIEVABLE STORAGE

	Miscellaneous						Incinerator Ash Process Residues					
	Jan	Feb	Mar	Apr	May	June	Jan	Feb	Mar	Apr	May	June
No. of 115-l and 210-l drums	32	10	20	11	28	23	3	--	4	1	2	2
Total ^{239}Pu , g	131	39	53	51	121	95	177	--	322	89	208	217
Total wt, kg	621	245	532	258	618	628	111	--	160	32	77	67
g ^{239}Pu /kg residues	0.21	0.16	0.10	0.20	0.20	0.15	1.59	--	2.01	2.78	2.70	3.24

DRUMS OF ^{238}Pu WASTE SENT TO 20-YR RETRIEVABLE STORAGE

No. of 115-l and 210-l drums	40
Total ^{238}Pu , g	298.9
Total Wt., kg	1103.3
g ^{238}Pu /kg residues	0.27

contain contamination above 10 nCi/g.

A number (less than 2% of through-put) of the boxes were found to contain low levels of high-energy gamma emitters such as ^{137}Cs , ^{22}Na , and ^{60}Co . The present analysis code would incorrectly interpret the Compton background from these as plutonium. The system has been calibrated to

measure these isotopes manually. The operating procedures have been changed so that the operator can correctly identify these emitters.

Measurements were made to examine the feasibility of replacing the present NaI detector with a high-resolution GeLi or intrinsic Ge detector. A comparison was

TABLE IX

 H_2 LOSS FROM AN EARTH COVERED PIT FOLLOWING A SUDDEN INJECTION OF HYDROGEN

Run No.	H_2 Starting Conc., vol% ^a	H_2 , Minutes After Injection, % of Original Concentration					
		5 min.	10	30	100	400	1000
1	2	74	64	50	25	6	---
3	2	78	68	52	32	6	---
7	2	70	64	48	28	---	---
2	4	85	76	58	33	10	---
6	4	85	77	60	35	9	---
8	4	78	70	53	28	7	---
4	8 ^b	--	--	47	25	8	2
5	8 ^b	--	--	--	31	8	4
9	8 ^c	85	77	58	34	---	---

^a 4 vol% H_2 = 100% LEL (lower explosive limit).

^b Based on H_2 flow for 2x, the time necessary for 4 vol% (100% of the LEL); this is the full span of the recorder.

^c Performed with a modified recorder to allow >4 vol% readings.

made between the MEGAS NaI detector and a medium-size GeLi (7.5% relative efficiency at 1332 keV). The GeLi detector did not have a thin window so gamma rays below ~100 keV were severely attenuated by the Ge dead layer and the stainless steel snout. The data from this comparison are summarized in Table X.

TABLE X
COMPARISON OF MEGAS AND GeLi SENSITIVITY
Sensitivity for 300-s Count^a

Isotope	Energy	MEGAS	GeLi ^b
241Am	60 keV	12 nCi	18.9 nCi
57Co	122	2.2	1.9
137Cs	662	5.6	3.5
60Co	1173	6.0	4.4

^bSensitivity is defined here as that activity which will produce a signal equal to or greater than three times the standard deviation of the background.

^aThis is not a thin window detector. Transmission of detector dead layer and cryostat snout is only ~0.3 at 60 keV.

These data show that the sensitivity of a GeLi system would be comparable to that of the present MEGAS if a thin window GeLi is used. In addition, this detector has a sensitivity at 129 keV (²³⁹Pu) of about 3.5×10^4 nCi or just under 10 nCi/g for a 5000-g box. This line cannot be resolved by the present NaI system. It would be very advantageous to be able to measure this higher energy because of its much higher penetrability. Table XI below shows the mass attenuation coefficient and mean free path in cellulose.

The advantages of the high-resolution detector are many. A thin window Ge detector will be ordered soon to verify these measurements and be part of an upgraded box counter.

TABLE XI
GAMMA-RAY ABSORPTION IN CELLULOSE

Energy	Mass Attenuation Coefficient	Mean Free Path ^a
15 keV	1.2 cm ² /g	8 cm
60 keV	.19 cm ² /g	53 cm
129 keV	.14 cm ² /g	71 cm

^aWaste density ~0.1 g/cm³

II. TRANSURANIC-CONTAMINATED SOLID WASTE TREATMENT DEVELOPMENT PROGRAM (L. Borduin, W. Draper, R. Koenig, C. Warner, W. Whitty)

Progress within this program realized during the past six months emphasized three major activity areas: construction of the new treatment development facility (TDF), final design and procurement of the initial waste reduction process, and installation of pre-facility study equipment. Reference is made to LA-6100-PR for a more detailed discussion of all facets of the SWTD program. The final draft of the Preliminary Safety Analysis Report was formally submitted on January 31, 1975, to the Albuquerque Operations Branch of ERDA.

A. Facility

The new facility for housing the solid waste development studies is currently in the Title III phase. Construction was 14.3% complete as of June 30, 1975. The construction contract was awarded on March 21, 1975; completion is scheduled for March 20, 1976.

Title II design and cost estimates received final approval on February 10, 1975. Facility bid opening was held on March 13, 1975, with the successful bidder being the Richard A. Peck Company of Santa Fe. Following receipt of a favorable base bid, two alternates were accepted--paving the parking lot and upgrading the roofing material from asphalt to coal tar. Final contract amount totaled \$778k, approximately \$64k less than the Government estimate.

A re-design of the facility acid waste collection system has been submitted to the architect/engineer for final design, drafting, and cost estimating. This design incorporates double-contained plastic (PVC) pipe, with pipe trenches and access pits, in lieu of direct burial of single runs of "duriron" pipe. This modification will provide positive leak detection and containment along with ready access for removal for repair or modification.

The proposed changes are currently being reviewed by the project contractor. Cost estimates from both the contractor and the architect/engineer are scheduled to be submitted by the week of July 6th. Approval and release for construction will be expedited to preclude delays in the facility construction schedule.

B. Process Design

The design for the initial TDF process, shown schematically in Fig. 2, has essentially been completed although results of pre-facility studies (see Section D) will continue to influence system design. The addition of a condenser to reduce off-gas volume to the filters and induced draft fans is the only significant conceptual change since January 1975.

Purchase orders have been issued for major off-gas system components including the quench chamber, venturi scrubber, packed-column scrubber, heat exchanger, and scrub solution pumps. Equipment proposals for the scrub solution receiver tanks and exhaust blowers are currently being evaluated. A purchase order was also issued for the feed preparation glovebox train. Inadequate response received for the exhaust blowers will likely require further specification revision and reissue of bid requests. Development studies to determine actual system differential pressure requirements are being considered to reduce pressure requirements for the fans.

Specifications for the off-gas condenser, off-gas heater, and scrub solution filters are in preparation. Adequate dimensional information has now been obtained from the suppliers of purchased equipment to permit the preparation of detailed layout drawings, which are requisite to determining piping needs. Instrumentation needs are being reviewed; specifications will be prepared for components not already on hand. A significant part of the required instrumentation supply will be met by components obtained as surplus equipment.

Extensive use of surplus equipment has been dictated by the need to remain within the project cost envelope of \$1.65 million. Surplus equipment receipts are currently 82% complete. A major item delivered during this period was the auxiliary generator set to be used primarily as a stand-by power supply when the process is in operation. Several pieces of laboratory equipment and a fork lift were also received.

Equipment vendor response to requests for bids has been a continuing problem in the procurement of system components. Lack of interest and/or misinterpretation of process needs has required revision and resubmittal of specifications. This has caused delays relative to the project schedule, however, procurement is expected to be completed on schedule due to better-than-anticipated delivery times.

C. Evaluation Basis

Efforts directed toward formulation of a valid process evaluation basis (Figure of Merit) continued during this period.

The objective of the study is to develop a valid evaluation basis of alternative transuranic waste treatment processes. Most of the effort to date has been in library research building toward a tentative approach for determining a Figure of Merit based on decision theory. Essentially, the procedure is a scoring method for evaluating the most important complex attributes of a process. The scores of each attribute are weighted and combined to determine the overall score or Figure of Merit. The Figure of Merit derived from the scoring procedure will not specify the absolute worth of any process under consideration, but rather will be used for purposes of comparative evaluation.

D. Pre-Facility Studies

Selected segments of the initial process to be installed in the TDF are being assembled and operated in existing LASL buildings for the purpose of expediting development studies. Experience gained from these studies will provide valuable

Installation of the incinerator system, which included a ram feeder and a 12.2-m stack, required approximately three weeks of crafts' time. Costs incurred, including utility connections, heavy equipment time, labor, and miscellaneous

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Following cool-down, the vacuum equipment was used to remove ash from the lower chamber (no visible amount was observed in the upper chamber). The collected ash weighed 12.3 kg, resulting in approximately 91% weight reduction for this first run. Samples of the ash and feed stock were submitted for analysis to determine total carbon and noncombustible species for completion of combustion efficiency calculations.

Concurrent with incinerator start-up activities, discussions were held with the manufacturer's field engineer regarding refractory integrity, instrumentation design, control philosophy, and recommended operating procedures. Close inspection of the refractory liner, which contained cracks and was generally nonuniform in appearance, was judged basically sound by the field engineer. Cracks in the liner--tending to close when heated to operating temperatures and reopen on cooling--are unavoidable with plastic refractory. Subsequent discussions with refractory manufacturers indicate that the position of the cracks can be controlled somewhat by the intentional introduction of expansion cracks in the liner (similar to concrete sidewalk construction). This procedure should be specified in the purchase of future refractory-lined equipment.

Plywood mockups of the feed preparation gloveboxes are being assembled for testing various shredders, compactors, etc., under simulated operating conditions. Planned tests will determine the suitability of each component for its intended use as well as maintenance requirements for those components judged suitable for the operation.

A barometric damper is currently being installed to offset internal pressure fluctuations caused by the high-velocity winds normally experienced at LASL. This assembly will be installed downstream of the quench chamber when the complete process is assembled in the TDF. Oxygen

introduced into the high-temperature combustion gases could be expected to shift equilibrium adversely toward higher chlorine production.

Upon completion of these modifications, incinerator operations will be resumed with selected wastes, both to gain operating experience and to determine satisfactory operating conditions for all components of the design waste matrix.

III. EVALUATION OF TRANSURANIC-CONTAMINATED RADIOACTIVE WASTE DISPOSAL AREAS

(M. L. Wheeler, A. F. Gallegos, W. J. Smith, W. J. Whitty, L. J. Johnson)

Progress is reported on the development of a system for evaluating the potential short- and long-term environmental impacts of existing radioactively contaminated, shallow earth, burial areas in the United States. Development of this system emphasizes the Los Alamos burial areas, with the generalized development to be applicable at any location.

The types of information required for such an evaluation include: (a) source term data for each burial area; (b) identification of potential contaminant release mechanisms, both acute and chronic, together with associated probabilities or rates; (c) establishment of physical transport and dispersion vehicles from the burial location (primarily atmospheric and hydrologic); (d) identification and quantification of movement along abiotic and biotic pathways; and (e) estimation of the dose to the various ecosystem components, particularly man.

A. Source Term: Composition and Configuration of Waste

Previous reports^{1,2,3,4} have described the composition of waste in burial pits in the presently active LASL disposal area (Area G), and the estimated radionuclide inventory of the burial sites at LASL. The last progress report⁵ discussed the

mechanisms by which contaminants might enter the biosphere (Fig. 3), primarily involving the action of water. Radionuclide uptake by plants with subsequent deposition on the land surface and erosion of the waste cover material to expose the waste is certain to occur if the burial pits are left undisturbed indefinitely. Other mechanisms which might expose the waste, such as earthquakes and meteorite impacts, are of a probabilistic nature.

It is essential, in evaluating the significance of the various release mechanisms, to know the composition and concentration of the waste in the various burial sites and the geometry of its placement. In general, the waste and fill materials at the LASL burial sites are intimately intermingled so that the entire contents of a burial pit must be considered initially contaminated except for the final cover material. Vertical upward transport by water or plants could result in contamination in this zone as well.

The presently disposed waste is in various forms, from small easily breached containers to large bulky objects such as contaminated vehicles. However, as the exposure process is sufficiently slow, nearly all materials will corrode or decay as they are exposed at the surface, making the radioactive contamination available for erosional transport. Similarly, plant roots growing in the waste have an equal likelihood of contacting any of the contamination present. Thus, it is reasonable to calculate an average concentration of the various radionuclides in the burial pits. Tables XII and XIII summarize the available information for all of the burial sites at LASL; note however, that some of the values are estimates or approximate values, due to a lack of detailed records.

Shafts drilled into the tuff have been used for disposal of special types of solid radioactive waste since 1960, including material contaminated with fission products or activation products, radioactively

Fig. 3. Release mechanisms.

TABLE XII. GEOMETRY OF RADIOACTIVE WASTE PLACEMENT IN LASL BURIAL PITS
(Completed as of 1974)

Disposal Area	Pit No.	Volume (m ³)	Minimum thickness of cover material (m)	Pit Depth (m)	Distance to closest canyon rim (m)
A	1	3.7×10^3	1	8	25
	2	2.8×10^4	1	8	25
	3	2.8×10^4	Open	8	25
B	1-5 ^a	4×10^4	1	4	10
C	1	1.4×10^4	1	8	45
	2	1.4×10^4	1	8	45
	3	1.4×10^4	1	8	45
	4	1.4×10^4	1	8	45
	5	1.4×10^4	1	8	45
	6	1.4×10^4	1	8	45
E	1-6	1×10^3 ^b	1	2	50
G	1 ^c	3.4×10^4	4	8	23
	2	3.4×10^4	1.5	8	50
	3	3.4×10^4	4	8	30
	4	3.4×10^4	2	8	60
	5	3.4×10^4	2	8	30
	6	3.4×10^4	2	8	30
	7	2×10^4	1.5	8	50
	8	7×10^3	2	8	50
	16	7×10^3	2	8	50
	17	1.7×10^4	1.5	8	30
	21	2.8×10^4	1.5	8	100
T	1	3×10^2	2	1.5	50
	2	3×10^2	2	1.5	50
	3	3×10^2	2	1.5	30
	4	3×10^2	2	1.5	30
U	1-2	3×10^2 ^b	.5	1	10
V	1-3	1.3×10^3	1.5	1	8

^a Exact pit dimensions and number uncertain. Volume is estimated total for all pits.

^b Total volume of all pits.

^c Missing pit numbers are those of unfilled or unconstructed pits.

TABLE XIII. ESTIMATE OF RADIONUCLIDE CONTENT OF PRINCIPLE RADIOACTIVE WASTE BURIAL PITS
(through 1974)

Disposal Area	Pit No.	⁹⁰ Sr		Uranium		²³⁸ Pu		^{239,240} Pu		²⁴¹ Am	
		conc		conc		conc		conc		conc	
		Ci	nCi/gm	Ci	nCi/gm	Ci	nCi/gm	Ci	nCi/gm	Ci	nCi/gm
A	1-3							Trace (a)			
B	1-5							Trace			
C	1							1	.05	Trace	
	2							1	.05	Trace	
	3							1	.05	Trace	
	4			2	.1			2	.1	Trace	
	5			3	.2			5	.3	Trace	
	6			20	1.8			16	.8	150	6
E	1-6			Trace							
G	1	3000	55	6	.1			74	1	650	11
	2			12	.2			124	2	352	6
	3			10	.2			64	1	586	10
	4			6	.1			60	1	219	4
	5			10	.2			86	2	315	6
	6			6	.1	Trace		26	.5	Trace	
	7							3	.1	Trace	
	8					Trace		2	.2	Trace	
	16			2	.2					Trace	
	17							6	.2	Trace	
	21			2					.05	Trace	
T	1							4 (b)	8	Trace	
	2							2.5	5	Trace	
	3							3	6	Trace	
	4							2.5	5		
V	1-3							Trace (<.1)		Trace	

^aBased on limited quantity of plutonium discarded during pit use.

^bEstimate of relative amounts to each bed.

contaminated animal tissue, and tritium-contaminated waste. When the shafts are filled to within about 1 m of the ground surface, a final layer of uncontaminated concrete is poured into the shaft. This concrete cap is mounded above the ground surface. Shafts have also been used for disposal of sludges from the liquid treatment plant at the principle plutonium-handling facility (TA-21). These sludges are mixed with cement and placed in disposal shafts, and the upper meter of each shaft is filled with uncontaminated concrete. The total radionuclide content of the various disposal shafts at LASL was reported previously.¹

The use history of the various disposal areas has been previously detailed.¹ All of the burial sites are located on the tops of mesas (see Fig. 4), in the surface of the Bandelier Tuff. Although the factors controlling erosion, such as rock and soil erodibility, precipitation, wind speeds, exposure, etc., vary somewhat from point to point, the variation is likely no greater than the error of estimate of erosion rates at Area G discussed in the Jul.-Dec. 1974 progress report. Hence, all burial sites can be treated as being subject to similar exposure processes.

Estimating the radionuclide content of the disposal areas at LASL has been a major effort. The compilation in Table XIII shows the total activity and activity concentration estimates for the disposal pits at the principal disposal sites.

B. Atmospheric Transport

Considerable time has been devoted to developing atmospheric transport models for application to the Los Alamos release site and study area. Past progress reports have discussed various states of development for an advanced atmospheric model. This model was felt to be justified in light of the complex terrain and wind fields of the area. However, numerous difficulties in making this model usable on the

Fig. 4. LASL waste burial sites.

area and time scales needed, and in providing the necessary atmospheric data have resulted in a delay of this approach. Current efforts have been directed toward simple representations, which are more appropriate for the quality of available atmospheric data. The quality of available meteorological data indicates this simplified approach will yield results that are adequate for this application. Two separate models are under development; one for short-term or acute releases, the other for long-term or chronic releases.

The preliminary form of the acute release model ignores the presence of northern New Mexico's irregular terrain. It selects a direction of movement from a modified local surface wind rose for Los Alamos. This direction is assumed to be invariant with distance downwind from the source, and constant over the time period of one day. Downwind concentration is presently determined by a uniform mixing model, using the concentration at the center of a study region as representative of the

region as a whole. The downwind distance is calculated as that from the center of the Los Alamos region to the center of the region of interest. Cloud concentrations are based on a 2000-m inversion layer, and dispersion parameters for stability classes as presented in Turner.⁶ These parameters have been grossly misused by extrapolation from 4 km to 150 km. Further, no account is taken of the losses due to deposition, and also, the single midplume value is used for the concentration over an entire region. These all contribute to the model greatly overestimating air concentrations. The highly artificial nature of the model is apparent, yet it will provide input with which to load and test other modules in this simulation project. Further, it will allow a sensitivity analysis of the importance of the atmospheric compartment to the simulation as a whole. Based on such information, more detailed and realistic representations may be made, as determined to be necessary.

Fig. 5. Estimated Average Annual X/Q Patterns.

Chronic releases have been treated in a separate model. Release and transport over an extended time suggest that the study area would be overlaid by isopleths of long term concentration. Figure 5 represents a characteristic annual average normalized concentration isopleth pattern from a source located near Los Alamos. A considerable amount of subjective judgment was exercised in arriving at the pattern, reflecting an attempt to incorporate knowledge of the terrain and upper wind patterns. A tendency is indicated for channeling and reduced diffusion along valleys, and enhanced turbulent dilution of material crossing mountain ranges. Figure 5 does not consider losses due to deposition, but, as with the short-term formulation, it may be used to derive deposition estimates.

C. Abiotic and Biotic Transport of Transuranics

Present progress in the study of the biological transport of plutonium and other transuranics (TRU) is evidenced by the development of abiotic plant and herbivore modules and efforts toward their integration (see Fig. 6). It is increasingly apparent that the use of biomass as a vector for tracing a contaminant will be applicable to other environments, radionuclides, and man-made contaminants.

1. Abiotic Module

This module provides a mechanism for applying the analysis model to other study areas, given site specific information. It includes driving variables supporting plant growth and TRU uptake from both soil and atmospheric origins.

These relationships were initially developed in the forage module.⁵ Efforts are now in progress to isolate them as a separate entity and to expand them to include the abiotic statistical information and soils data required to simulate the growth of agricultural crops and livestock.

The agricultural data for modeling the growth of farm crops have been acquired with

Fig. 6. Status of module development for regional assessment model.

the necessary livestock information expected in FY 76. Refinement of this module and new data base descriptions will include the elements of a "switching circuit" required for management of interregional transports within the study area.

2. Plant Module

Efforts involved in the biotic transport of TRU materials through the study area have been concentrated on simulating the growth of plants as a primary vector for these radionuclides to animals and man. The plant module has been divided into the following submodules for simplification.

The Forage Submodule, which was described and documented in the last semi-annual report,⁵ has been updated, refined, and extended throughout this reporting period. One improvement lies in determining the deposition velocity of particulates on different plant canopies using a modified leaf area index (LAI)⁷ calculation as a predictor rather than the estimates derived previously.⁵ This development permits daily adjustment for changing deposition velocities as a function of growth dynamics. Also, the calculation of plant cover estimates utilizing yearly production estimates for forage may eliminate the need for estimating this parameter from more complicated densitometric techniques. Present efforts show good agreement between observed and calculated ground covers based on annual production figures for conifers, as described further on in this discussion.

Limited fine tuning of the module has resulted in the optimization of several driving variables. The study area used for tuning purposes is the Pawnee Grassland Site near Ft. Collins, Colorado, which has been studied and modeled by IBP investigators.⁸

The forage submodule has been extended to simulate the growth and TRU uptake by annual grasses, although perennial grasses are assumed to be dominant throughout the study area.⁵ The TRU uptake mechanism for roots is being refined by tuning the model

to give better estimates of dynamic root biomass.

Agricultural Crops growth and TRU accumulation modeling has been based on previous experiences with forage modules. To date this submodule includes growth and TRU accumulation for alfalfa and corn. The module will be extended to include annual as well as perennial forage, other annual vegetable composites including chili, tomatoes, beans, squash, and fruit trees growing within the study area. Documented characteristics for given crop types included:

- 1) planting-harvesting schedules;
- 2) irrigation schedules and volume applied;
- 3) crop yields; and
- 4) fraction of crop consumed within the region of growth, in adjacent regions and within the study area.

The first two characteristics have been incorporated into the abiotic module, and crop yields have been used to tune the module. The fourth characteristic is to be used for determining transport of contaminated crops to livestock, and ultimately to man, as part of the abiotic module.

Corn growth was simulated as a warm-season annual and alfalfa as a cool-season perennial. The alfalfa biomass estimates are 94% of the yields reported for this crop in the study area.⁹ The differences in water utilization efficiency between plants are under investigation for modeling purposes in terms of the wide variations among the same kind of plant and between different kinds of plants for this factor in diverse environments.¹⁰ A dynamic relationship to replace the use of a "tunable" constant for estimating this parameter is necessary because, in terms of sensitivity, the latter has proved to be very important in regulating plant growth.

Transuranic uptake by agricultural crops has been modeled similar to forage, although the rate of uptake by root systems

differs as the relative size of root biomass to the above-ground component varies by plant type.¹¹ A means to determine the active metabolic mass responsible for the uptake phenomenon is being developed. At present the model is using the entire root biomass (corn, alfalfa) for this determination. Efforts, in varying stages of development, are now directed toward refining the TRU uptake mechanism for other crops, for inclusion into this module.

Development of The Conifer Module is of considerable interest because of the prevalence of conifers in the study area.⁵ The possibility that these plants can transport buried TRU materials to above-ground parts via root uptake, annual pollen release, and the ever-present danger of fires makes them significant from a risk analysis point of view. The simulation of growth and stand development assumes importance in terms of the relatively long life span (300+yr) of conifers, their use as building materials and firewood, and their recreational aspects under forest management. Finally, their ability to remove air particulate due to their large LAI affects the air deposition pattern and effective deposition velocity of any given region.

The growth strategies for trees, in comparison with herbaceous plants, are quite complex, as can be witnessed by comparing IBP efforts in this regard^{8,12} and by descriptions of the physiology of forest trees.¹³ The present model has been developed with a plan similar to the forage module, but is not of the complexity of the current IBP Coniferous Forest Model,¹² which is too comprehensive for our use, but is dynamic enough to allow observation of yearly differences in growth in response to the climatic trend simulation in the abiotic module.

An example of this effect is observable in the simulation growth of a ponderosa pine, which was conducted assuming soil characteristics of the Los Alamos area and

an annual precipitation of 25 in. for a 300-yr period (Fig. 7). The simulation was conducted using an iterative step of 1 day. A leveling of herbage density for pine needles (260 g/m^2 dry wt) at about 30 yr into the simulation is noted although woody tissue density continues to increase throughout most of the 300-yr period. This effect has also been noted in comparisons between young and old Douglas fir in the Cascade Mountains of Oregon and Washington where an equilibrium herbage density reached a value of about 900 g/m^2 and remained constant despite the differences in age of the stands (450 yr vs 42 yr).¹⁴ Analysis shows this phenomenon to be due to the annual production of the forest in any given year, which is used to limit foliage production in the forthcoming year. Another check on model predictability has been made by analysis of tree stand data for the Beaver Creek watershed near Flagstaff, Arizona.¹⁵ The precipitation pattern and soils characteristics (both volcanic in origin) are similar enough to use the data as a tuning device for this module. The height of the trees of the simulated forest stand at 100 yr (site index) was calculated using a regression equation of Larson,¹⁶ and found to equal 62 ft, compared with a site index of 60 ft for the Beaver Creek site.¹⁵ Also, the volume of the simulated stand at the approximate age of the Beaver Creek site (65 yr) was determined to be in close agreement with the reported value (1763 lbs/ft^3 to 1775 lbs/ft^3). Percent of ground cover for the forest stand (approx. 37%) was calculated using water needs of the forest compared to available moisture. This value compares favorably with observed cover estimates in that area for ponderosa pine, and also for the Los Alamos area in this range of annual precipitation.

Spruce-fir, Douglas fir, and piñon-juniper are also under model development for the study area using the growth strategies employed in the growth simulation of

Fig. 7. Growth of ponderosa pine, region 49, Los Alamos
(precipitation = 25 in./yr).

ponderosa pine. Distinct temperature optimums for growth of spruce-fir and piñon-juniper have been employed, based on temperature-dependent relationships used in the growth simulation of warm and cool season grasses, and modified to account for photosynthesis at reduced temperatures.¹⁷

A major difference among conifers is their relative sapwood thickness related to water storage and utilization.¹⁸ As such, this sapwood compartment adds to the maintenance requirements of these trees and acts to reduce net productivity. Our modeling efforts have taken into account sapwood cross-sectional areas for ponderosa pine, Douglas fir, and Noble fir at DBH to foliage biomass, and the relationship of Larson¹⁶ between foliage biomass and DBH. Our own studies have produced a "tuned" relationship between DBH and total tree biomass density for ponderosa pine,

$$DBH = 0.003 \times TBM$$

(1)

where

DBH = diameter at breast height, cm

TBM = tree biomass, g/m² for total stand.

A relationship for obtaining sapwood cross-sectional areas of piñon and juniper at base diameter from limited data base information^{18,19,20} has also been derived for use in this module. Work is in progress to incorporate other relationships^{16,20} for timber management and to develop DBH height relationships to obtain tree-stand size distributions required for maintaining TRU inventory in response to forest fires or timber management practices within the study area. These studies have been based on the Beaver Creek Watershed data for ponderosa pine, juniper, and scrub oak stands,¹⁵ although only ponderosa pine has been studied to date. Studies in progress indicate that size distributions follow a modified log-normal distribution²¹ based on the total

volume of the stand:

$$f(M) = \frac{1}{\sqrt{2\pi} \ln \sigma} \exp \left\{ - \frac{\left[\ln \frac{(M-M_0)}{(M_\infty-M)\bar{M}} \right]^2}{\sqrt{2} \ln \sigma} \right\} \quad (2)$$

where M = DBH of tree category,

M_0 = minimum DBH observable,

M_∞ = maximum DBH observable,

$\bar{M}$ = geometric mean of tree-stand class analysis, and

σ = geometric standard deviation of tree stand by class analysis.

Class analysis was performed by setting up the DBH distributions of the stand in 2-in. increments, i.e., $M_0 = 0-2, 2-4, 4-6 \dots M_\infty-1 - M_\infty$. A geometric mean and variance was obtained from this distribution to obtain the required unknown constants in Eq. (2). Comparison of tree-stand analysis to Beaver Creek watershed data shows good agreement. The first class was obtained by extrapolation of the succeeding two class intervals, as the equation does not respond well in this interval for reasons probably related to regeneration-mortality characteristics which are accentuated in this DBH category. The number of trees was derived from Eq. (2) by calculating the volume of each class:

$$f(m)_{ij} \cdot V_{ij} \quad i = m_0-2, 2-4, 4-6, m_\infty-1, m_\infty \quad (3)$$

$$j = 1, 2, 3, 4, \dots, 20$$

where $f(m)$ = Eq. (2) and

V_{ij} = volume of subinterval within each class of DBH.

Class volume is thus determined by the ratio:

$$V_i(m) = \frac{\sum_{j=1}^{20} f(m)_{ij} \cdot V_{ij}}{\sum_{i=1}^{20} f(m)_{ij}} / V_T \quad (4)$$

where $V_i(m)$ = volume of stand within the class interval and

V_T = total volume of stand.

Total volume of stand was determined as previously described; V_{ij} was calculated by tuning the model to determine the volume of an individual ponderosa pine tree at any

given DBH by utilizing a truncated cone relationship:

$$V_{DBH} = H/3 (r_1^2 + r_1 r_2 + r_2^2) \pi$$

where V_{DBH} = volume of tree of given DBH,

H = height of tree calculated as in Larson,

r_1 = radius of tree, DBH/2, and

r_2 = radius of tree at upper limit of stem adjusted to include total biomass of tree.

Tuning of the model resulted in an estimate for r_2 of

$$r_2 = 0.41 \times R_1. \quad (5)$$

This relationship may make it possible to specify tree stands in a dynamic sense and allow for selected cutting or forest fires as part of the model because it permits predicting tree-stand characteristics from a biomass estimate of the forest.

The movement of plutonium and other transuranics through coniferous forests is simulated with root dynamics and surface deposition characteristics analogous to forage. The effective absorbing biomass of roots for TRU is estimated to be about 50% of the total root biomass density until the foliage density reaches an equilibrium, after which it also remains rather constant. However, the estimate for pre-equilibrium foliage density needs further evaluation. Finally, TRU are traced through compartments analogous to those found in the forage module;⁵ however, above-ground parts are divided into foliage and supporting structures (stem and branches). Litter is formed from dead-above-ground parts while dead root matter is treated similarly for TRU transport out of the forest system back to soil for recycling.

3. Herbivore Module

The herbivore module simulates the growth and TRU uptake of a ruminant herd of beef and dairy cattle, sheep, deer, and elk. The module has not been extended to include nonruminant herbivores. The modeling of beef and sheep growth is based on cow-calf and sheep herd operations within the study area as best determined from a

variety of sources. The data for deer have been obtained from the New Mexico Department of Game and Fish.²²

Animal growth is based on a population structure of a given type. The population structure for whitefaced cattle, for example, simulates the growth of the herd by moving cattle from one age group to the next and allows for marketing of yearlings and animals culled from the herd in maintaining the same population structure from year to year.

The module is highly interactive with the plant module. Natural and cultivated forage simulated by these systems is utilized by the herbivore module for simulating herd growth. The ingestion rate for any weight category within the herd population is determined simulating rumen activity.^{23,24} Briefly, the model determines weight gain for a given cow within the herd based on the availability of food and its nitrogen content and digestibility.

TRU materials are transferred to beef cattle through three processes: 1) ingestion of food and water, 2) ingestion of soil with food, and 3) inhalation of air particulates. The first process has been described. Ingestion of soil has been modeled after Martin,²⁵ modified to include the effects of ground cover and herbage density. The third process has been modeled from the use of ICRP²⁶ transport coefficients for standard man, applied to cattle and making allowance for different minute volumes of these animals related to their metabolic weight. The concentration available for human consumption is simulated on the basis of marketing practices for the total herd. These practices tend to lower the effective concentration as is shown by comparison of concentration factors with respect to soil with 1- and 8-yr-old cows (Fig. 8); the simulation indicates that the concentration in muscle tissue may vary by a factor of

Fig. 8. Concentration factor in heef for 1-8 yr old cattle compared to marketed beef. (20-yr simulation)

about 20 depending on the age of the animal harvested.

D. Inter- and Intraregional Transport

Interregional interphasing (Fig. 6) of biotic and abiotic components, and coding into the analysis model, are almost complete for those modules described here. Intra-regional interfacing for TRU in these systems primarily consists of allocating for consumption of foodstuff grown or grazed in a given region to: 1) the same region, 2) adjacent regions, and 3) the study area.

The grazing schedules⁹ will be coded, for beef cattle, and sheep, on an intra-regional basis, as well as the total number grazing at any given time. This scheme will permit more realistic TRU uptake process for animals which are being "switched" from one region to another for grazing purposes. The amount of regionally produced winter feed will also be incorporated for cattle and sheep which are retained during the winter season on a given pasture. Other information to be included within this development will be the available area within a region which is actually grazed and whether the operation is a yearly operation or a cow-calf operation in the case of cattle.

E. Dose to Man

The fundamental concepts for determining the radiation dose to man from intake of transuranic elements were discussed in a previous progress report.⁵ Current progress in developing the overall structure of the regional simulation model, and in determining the functional details of other modules has resulted in some changes in the mathematical formulation of the dose concepts.

Radionuclide intake by inhalation has been simplified to remove explicit dependence on a particle size description of the airborne material. A form of the simple lung deposition model proposed in 1959 by the ICRP Committee II is now used.²⁷ Lung clearance is being modeled as proposed by the ICRP Task Group on Lung Dynamics (1966);²⁶ and updated by the ICRP Publication 19 (1972).²⁸ Ingestion of radionuclides in water and food, and in material cleared from the respiratory system, is modeled according to Eve's revision²⁹ of the model of the ICRP Committee II.²⁷ These models are all standard tools in radiation dose assessment. Although more sophisticated versions of the models have been developed, data and simulation constraints indicate that the simple versions are more appropriate in our effort.

In order to best fit the daily iteration of the simulation, simple difference equations have been substituted for the more commonly used integral forms of the dose calculations. A running total of organ Ci-days is maintained for each organ and at the end of a specified time period (nominally 1 yr) the organ doses are calculated. This approach makes it quite easy to treat irregularly varying daily inputs of radionuclides from air, water, and food. The current program is designed to handle 16 organs: lung, lymph, four GI segments, bone, liver, spleen, kidney, muscle, total body, and up to four others of the user's specification. Presently only "standard man" doses are calculated; further development will result in the calculation of dose for age groups within a population, and the accumulation of dose for a group as it ages.

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