**This technical report has been made
electronically available on
the World Wide Web
through a contribution from**

Larry W. Brown

Member, Defense Nuclear Facilities Safety Board

Office of Scientific and Technical Information
Office of Science
U.S. Department of Energy
November 2010

U.S. DEPARTMENT OF
ENERGY

*Office of
Science*

MASTER

MANAGEMENT OF RADIOACTIVE WASTES*

J. O. Blomeke
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

For presentation at seminar at
School of Nuclear Engineering, Texas A & M University,
College Station, Texas, November 5-9, 1979

By acceptance of this article, the
publisher or recipient acknowledges
the U.S. Government's right to
retain a nonexclusive, royalty-free
license in and to any copyright
covering the article.

DISCLAIMER

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

* Research sponsored by the Office of Nuclear Waste Management, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

DISCLAIMER

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

MANAGEMENT OF RADIOACTIVE WASTES*

J. O. Blomeke
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

1. INTRODUCTION

If nuclear fission is to provide a major share of the world's energy requirements, we must provide technically, socially, and politically acceptable methods for handling the radioactive wastes that arise in a multiplicity of chemical and physical forms at every stage of the nuclear fuel cycle. Some of the radioisotopes in these wastes are so long-lived that they must be isolated from the environment for hundreds of thousands of years. They appear principally in the high-level liquid wastes from reprocessing spent fuels and in a wide assortment of solid refuse, contaminated with plutonium and other transuranium elements, that is generated in fuel reprocessing and mixed-oxide fuel fabrication.

Much work has been done over the past 20 years to develop suitable techniques for coping with these wastes; however, plant and field demonstrations are needed before much of the more recently developed technology can be reduced to practice.

Today, I would like to review the nature and characteristics of the wastes, the status of the work that has been done, the options that are available in waste management, and our plans and expectations for the near future.

* Research sponsored by the Office of Nuclear Waste Management, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

2. LWR FUEL CYCLE

- (1) DWG 68-12735R2 - Schematic of LWR Fuel Cycle. Wastes are generated at each step which require conditioning, packaging, and shipment to disposal sites. High-level wastes from processing spent fuel are a principal problem.

3. PROJECTIONS OF FUTURE WASTES

- (2) DWG 78-529 - Physical Characteristics of LWR Fuel Assemblies. PWR assemblies have more fuel pins and contain more than twice as much UO_2 as BWR assemblies.
- (3) DWG 78-530 - Irradiation Parameters of LWR Fuels. Considering 32% thermal efficiency, about 117 million kW-hr of electricity are generated from each PWR assembly, and 39 million kW-hr are obtained from a BWR assembly.
- (4) DWG 78-458 - Spent Fuel Decay Characteristics. The heat generation rate from radioactive decay of the fission products declines by more than a factor of 10 between 1 and 10 years after discharge.
- (5) DWG 77-319 - Forecast of U.S. Nuclear Capacity. This 1976 projection is now clearly optimistic, but still serves for ensuing discussion. Present projections range from 148 to 380 GW of installed nuclear capacity in the year 2000. There will probably be no commercial LMFBR or HTGR before 2000 A.D.
- (6) DWG 78-636 - Fuel Cycle Wastes Projected for the Year 2000. Reprocessing spent fuels greatly increases all types of wastes shown here except, of course, the uranium ore tailings.

- (7) DWG 78-634 - Fuel Cycle Wastes from 1000 MW-Years of Electricity.

Based on recycling plutonium, which increases the volume of low-level TRU wastes but greatly reduces ore requirements and tailings wastes.

4. CHARACTERISTICS OF HIGH-LEVEL WASTE

High-level wastes (HLW) are emphasized because they pose the greatest problem. These wastes consist of fission products and actinide elements.

- (8) DWG 73-3963R1 - Activity of Fission Products in Accumulated HLW.

Composed of over 400 isotopes of about 40 elements; little radioactivity remains after 1000 years.

- (9) DWG 73-3964R1 - Activity of Actinide Elements in Accumulated HLW.

"Actinides" consist of about 20 isotopes of about 6 heavy elements plus their decay daughters.

- (10) DWG 73-3965R1 - Thermal Power in HLW. Fission products predominate for several centuries. After 1000 years the heat generation rate is very low.

- (11) DWG 73-3966R1 - Ingestion Toxicity of HLW. Fission products dominate for first 1000 years, then actinides.

- (12) DWG 73-3967R1 - Inhalation Toxicity of HLW. The actinides dominate at all ages. This and the preceding slides suggest that an advantage might be gained by separating actinides from fission products and reduce isolation time required.

5. HLW MANAGEMENT

- (13) DWG 72-10392A - Options for Management of HLW. Three principal paths for management through permanent disposal: chemical separations and actinide transmutation in power reactors; solidification, interim storage, geologic disposal; direct disposal of wastes as liquids.

- 4
- (14) DWG 72-11707 - Potential Gain in Hazard Reduction from Partitioning Actinides from HLW. With partitioning, hazard index falls after 1000 years well within the range of naturally-occurring radioactive materials.
- (15) DWG 75-5339 - Requirements for Acceptable Actinide Partitioning Concept. Are currently attempting a cost-risk-benefit analysis of this concept.
- (16) DWG 74-6122 - Drawing of Sealed Storage Cask Concept. For long-term surface storage. Can be used for either spent fuel or HLW.
- (17) DWG 74-6124 - Surface Storage Concept. Casks spaced on 25-ft centers, would require 1000-1200 acres of land in 2000.
- (18) DWG 74-6121 - Alternate Surface Storage Concept Using Air Cooling.
- (19) DWG 74-6123 - Surface Storage Concept Using Water Cooling.
- (20) DWG 74-12661 - Possibilities for Long-Term Storage and Disposal.
"Storage" implies simple retrievability and requirement for surveillance. Seabed, transmutation, and space require advanced technology; polar ice caps not generally accepted. Storage/disposal in crystalline rocks, shales, and salt formations seen as best near-term bet.
- (21) DWG 61939R1 - Advantages of Salt Formations. Disadvantages that have been cited are its solubility in water and its usual proximity to mineral deposits. Most don't consider these to be serious defects, however. Salt has been extensively studied in U.S. and Germany. More recently studies of shale and crystalline formations have begun.
- (22) DWG 70-5361 - Salt Deposits in U.S.
- (23) DWG 74-1641 - Argillaceous (Shale) Formations in U.S.
- (24) DWG 74-1639 - Crystalline Formations in U.S. Granite is being studied in Canada and Sweden.

5

(25) DWG 73-924 - Drawing of Salt Mine Repository Designed for Disposal of HLW. Extensive work has been done in SE New Mexico for possible location of a repository for low-level TRU wastes and some spent fuel.

6. PRESENT PLANS

"Present plans," which are subject to frequent revision, include the establishment of three or four surface storage (Away From Reactor) facilities for spent fuel by 1985. A pilot plant repository for defense wastes may be established in salt in New Mexico by the mid 1980s, and repositories for commercial wastes may be operative in the 1990 time frame. Retrievability of all wastes will be maintained until necessary confirmatory data concerning safety are obtained.

Technology is available to prepare wastes in a variety of solid forms suitable for isolation by a variety of methods. However, plant and field demonstrations of much of this technology are required before it can be put into practice.

NUCLEAR FUEL CYCLE FOR LIGHT WATER REACTORS

**PHYSICAL CHARACTERISTICS OF TYPICAL
UNIRRADIATED LWR FUEL ASSEMBLIES**

	BWR	PWR
OVERALL ASSEMBLY LENGTH, M	4.47	4.06
CROSS SECTION, CM	13.9 X 13.9	21.4 X 21.4
ACTIVE FUEL HEIGHT, M	3.76	3.66
FUEL PIN O.D., CM	1.25	0.95
FUEL PIN ARRAY	8 X 8	17 X 17
ASSEMBLY TOTAL WEIGHT, KG	276	658
URANIUM/ASSEMBLY, KG	183	461
ZIRCALOY/ASSEMBLY, KG	57 ^a	108 ^b
HARDWARE/ASSEMBLY, KG	9.8 ^c	26 ^d
TOTAL METAL/ASSEMBLY, KG	68	135

^aINCLUDES ZIRCALOY FUEL-ELEMENT SPACERS

^bINCLUDES ZIRCALOY CONTROL-ROD GUIDE THIMBLES

^cINCLUDES STAINLESS STEEL TIE-PLATES AND INCONEL SPRINGS

^dINCLUDES STAINLESS STEEL NOZZLES AND INCONEL-718 GRIDS

ornl

8/28/78

TYPICAL IRRADIATION PARAMETERS OF LWR FUELS

PARAMETER	BWR	PWR
URANIUM/ASSEMBLY, KG		
INITIAL	183	461
DISCHARGE	176	440
ENRICHMENT, WT % ^{235}U		
INITIAL	2.75	3.20
DISCHARGE	0.69	0.84
PLUTONIUM/ASSEMBLY AT DISCHARGE, KG	1.57	4.32
AVERAGE POWER, MW/ASSEMBLY	4.75	17.3
AVERAGE SPECIFIC POWER, KW/KG INITIAL URANIUM	25.9	37.5
AVERAGE DISCHARGE BURNUP, MWD/METRIC TON INITIAL URANIUM	27,500	33,000
IRRADIATION TIME, FULL-POWER DAYS	1062	880

ORNL DWG 78-458

FORECAST OF U.S. NUCLEAR INSTALLED CAPACITY, GWe (NET)
(MID CASE, AUGUST 1976)

CALENDAR YEAR ENDING	LWR	HTGR	LMFBR	TOTAL
1975	32	0	0	32
1980	68	0.3	0	68
1985	146	0.3	0.4	147
1990	250	0.3	1.3	252
1995	367	1.3	2.3	371
2000	468	10	32	510

FUEL CYCLE WASTES PROJECTED FOR THE YEAR 2000

CATEGORY OF WASTE	ANNUAL GENERATION		TOTAL ACCUMULATED		
	VOLUME (10 ³ m ³)	ACTIVITY (Mci)	VOLUME (10 ³ m ³)	ACTIVITY (Mci)	POWER (MW)
SPENT FUEL ASSEMBLIES	3.4	40,800	40.1	86,400	340
TRANSURANIUM WASTES					
HIGH-LEVEL SOLIDIFIED	0.67	40,500	8.0	85,400	336
CLADDING HULLS	0.56	280	6.7	980	4.1
INT.-LEVEL SOLID	2.9	2.8	28	12.4	0.05
LOW-LEVEL SOLID	17	11	142	77	0.10
NON-TRU WASTES					
NOBLE GASES	0.02	59	0.22	470	0.7
IODINE	0.009	0.0002	0.1	0.003	1.6 x 10 ⁻⁶
CARBON-14	-	0.004	-	0.05	-
LWR TRITIUM	53	0.3	660	2.1	7.0 x 10 ⁻⁵
FP TRITIUM	0.07	3.5	0.8	29	1.0 x 10 ⁻³
LOW-LEVEL SOLID	390	0.8	5500	5.7	-
ORE TAILINGS	15,000	0.18	224,000	2.5	0.06

FUEL CYCLE WASTES FROM THE PRODUCTION OF 1000 MW-YEARS OF ELECTRICITY^a

CATEGORY OF WASTE	VOLUME (m ³)	ACTIVITY ^b (Mci)	POWER ^b (kW)	NUMBER SHIPMENTS
SPENT FUEL ASSEMBLIES	14	172	970	11
TRANSURANIUM WASTES				
HIGH-LEVEL SOLIDIFIED	3.1	170	960	2
CLADDING HULLS	2.7	2.0	10	2
INT.-LEVEL SOLID	140	0.012	0.057	66
LOW-LEVEL SOLID	480	0.05	0.04	17
NON-TRU WASTES				
NOBLE GASES	0.1	0.25	0.37	0.4
IODINE	0.05	1×10^{-6}	-	0.2
CARBON-14	-	2×10^{-5}	-	-
LWR TRITIUM	140	6×10^{-4}	-	9
FP TRITIUM	0.35	0.02	7×10^{-4}	1
LOW-LEVEL SOLID	2400	0.002	0.007	180
ORE TAILINGS	42,000	5×10^{-4}	0.011	-

^aMIXED (U-Pu) OXIDE-FUELED LWRs.^bACTIVITY AND THERMAL POWER AT TIME OF WASTE GENERATION.

MEGACURIES OF FISSION PRODUCTS TO BE ACCUMULATED IN
HIGH-LEVEL WASTES THROUGH THE YEAR 2000^A

	YEAR 2000	TIME FOLLOWING 2000 (YEARS)		
		1,000	100,000	1,000,000
TOTAL FISSION PRODUCTS	77,000	2.4	1.7	0.35
⁹⁰ Sr	6,600 ^{B,C}	—	—	—
⁹³ Zr	0.20	0.20	0.19	0.12 ^{B,C}
⁹⁹ Tc	1.6	1.6 ^{B,C}	1.2 ^{B,C}	0.06
¹³⁷ Cs	10,000	—	—	—

^AINSTALLED NUCLEAR CAPACITIES ARE 70, 285, AND 625 GW IN CALENDAR YEARS 1980, 1990, AND 2000. WASTE VOLUME IN THE YEAR 2000 WILL BE ABOUT 20 MILLION GAL OF LIQUID, OR 380,000 FT³ IF SOLIDIFIED.

^BCONTROLLING INHALATION HAZARD AT INDICATED TIME.

^CCONTROLLING INGESTION HAZARD AT INDICATED TIME.

MEGACURIES OF ACTINIDES TO BE ACCUMULATED IN
HIGH-LEVEL WASTES THROUGH THE YEAR 2000^A

	YEAR 2000	TIME FOLLOWING 2000 (YEARS)		
		1,000	100,000	1,000,000
TOTAL ACTINIDES	1,260	29	0.55	0.55
²²⁶ RA	—	—	0.0058 ^C	0.0012
²²⁹ TH	—	—	0.02	0.05 ^{B,C}
²³⁹ PU	0.24	0.39	0.17 ^B	—
²⁴⁰ PU	1.0	2.9	0.0001	—
²⁴¹ AM	64	14 ^{B,C}	—	—
²⁴³ AM	6.0	5.5	0.0007	—
²⁴⁴ CM	820 ^{B,C}	—	—	—

^AASSUMES LOSS TO WASTE OF 0.5% OF PU, U, AND TH IN FUELS, AND
ALL OF THE OTHER ACTINIDE ELEMENTS FORMED DURING IRRADIATION.

^BCONTROLLING INHALATION HAZARD AT INDICATED TIME.

^CCONTROLLING INGESTION HAZARD AT INDICATED TIME.

ORNL DWG 73-3965R1

KILOWATTS OF THERMAL POWER IN HIGH-LEVEL WASTES TO BE
ACCUMULATED THROUGH THE YEAR 2000

	YEAR 2000	<u>TIME FOLLOWING 2000 (YEARS)</u>		
		1,000	100,000	1,000,000
FISSION PRODUCTS	330,000	2.7	1.6'	0.096
ACTINIDES	41,000	780	14	13
TOTAL	371,000	780	16	13

ORNL DWG 73-3966R1

INGESTION TOXICITY OF HIGH-LEVEL WASTES TO BE
ACCUMULATED THROUGH THE YEAR 2000^A

	YEAR 2000	TIME FOLLOWING 2000 (YEARS)		
		1,000	100,000	1,000,000
FISSION PRODUCTS	2.5×10^{16}	9.4×10^9	7.0×10^9	1.2×10^9
ACTINIDES	1.5×10^{14}	5.6×10^{12}	4.2×10^{11}	3.1×10^{11}
TOTAL	2.5×10^{16}	5.6×10^{12}	4.3×10^{11}	3.1×10^{11}

^ACUBIC METERS OF WATER REQUIRED FOR DILUTION TO RCG (COLUMN 2 OF TABLE II,
10CFR20),

ORNL DWG 73-3967R1

INHALATION TOXICITY OF HIGH-LEVEL WASTES TO BE
ACCUMULATED THROUGH THE YEAR 2000^A

	YEAR 2000	TIME FOLLOWING 2000 (YEARS)		
		1,000	100,000	1,000,000
FISSION PRODUCTS	3.4×10^{20}	9.4×10^{14}	6.9×10^{14}	1.0×10^{14}
ACTINIDES	3.5×10^{21}	1.6×10^{20}	4.7×10^{18}	3.0×10^{18}
TOTAL	3.8×10^{21}	1.6×10^{20}	4.7×10^{18}	3.0×10^{18}

^ACUBIC METERS OF AIR REQUIRED FOR DILUTION TO RCG (COLUMN 1 OF TABLE II,
10CFR20).

ORNL-DWG 72-10392A

Options for Management of High-Level Wastes.

EFFECT OF AGE AND METHOD OF TREATMENT ON THE HAZARD INDEX OF HIGH-LEVEL WASTES FROM LWR'S

REQUIREMENTS FOR ACCEPTABLE ACTINIDE SEPARATIONS CONCEPT

1. SEPARATIONS MUST BE MADE WITHOUT COMPLICATING HIGH-LEVEL WASTE SOLIDIFICATION, SHIPMENT, AND DISPOSAL.
 2. SEPARATIONS MUST BE MADE FROM ALL ACTINIDE WASTES (~ 1% Pu LOST IN FUEL PREPARATION, FABRICATION AND CLADDING).
 3. MUST BE ABLE TO BURN THE SEPARATED ACTINIDES WITHOUT UNDULY COMPLICATING OTHER FUEL CYCLE OPERATIONS.
-

SEALED STORAGE CASK CONCEPT STORAGE AREA

POSSIBILITIES FOR LONG-TERM STORAGE AND DISPOSAL

1. ISOLATION ON EARTH

STORAGE AS LIQUIDS IN TANKS

STORAGE AS SOLIDS IN CONCRETE STRUCTURES

STORAGE AS SOLIDS IN HARD ROCKS

DISPOSAL AS SOLIDS IN SALT FORMATIONS

DISPOSAL AT GREAT DEPTHS UNDERGROUND

DISPOSAL AT SEA

DISPOSAL WITHIN POLAR ICE CAPS

2. TRANSMUTATION TO NONRADIOACTIVE SPECIES

3. DISPOSAL INTO OUTER SPACE

ADVANTAGES OF SALT FORMATIONS FOR
STORAGE OF RADIOACTIVE WASTES

1. ESSENTIALLY IMPERMEABLE
 2. WIDESPREAD AND ABUNDANT
 3. HIGH STRUCTURAL STRENGTH
 4. LOW COST OF DEVELOPING SPACE
 5. GOOD THERMAL CONDUCTIVITY
 6. LOCATED IN AREAS OF LOW SEISMICITY
-

ORNL - DWG 70-5361A

Thick Bodies of Shale, Mudstone, and Claystone in the U.S.

Crystalline Rocks in the U.S.

PILOT PLANT REPOSITORY

ORNL DWG 79-627

DOE WASTE ISOLATION PROGRAM ELEMENTS

- WIPP (WASTE ISOLATION PILOT PLANT)
- PASCO BASIN BASALT ..
- NEVADA TEST SITE
- ONWI (OFFICE OF NUCLEAR WASTE ISOLATION)

ORNL DWG 79-628

WIPP

- RESPONSIBILITY: SANDIA, BECHTEL, WESTINGHOUSE
- MISSION: DEFENSE TRU WASTES, HLW EXPERIMENTS,
PROPOSED SPENT FUEL STORAGE
- STATUS: SITE SELECTED IN BEDDED SALT
2200 FT BELOW SURFACE
- SCHEDULE: OPERATIONAL IN 1985/86

ORNL DWG 79-629

PASCO BASIN BASALT

- RESPONSIBILITY: ROCKWELL-HANFORD
- MISSION: COMMERCIAL- SPENT FUEL OR HLW BUT
HAS OBVIOUS APPLICABILITY FOR
HANFORD DEFENSE WASTES
- STATUS: EXTENSIVE SITE INVESTIGATIONS;
CONSTRUCTION UNDERWAY ON USTF
(5000-FT TUNNEL SYSTEM) FOR
TEMPERATURE AND MATERIALS TESTING
- SCHEDULE: OPERATIONAL IN 1990/92

ORNL DWG 79-630

NEVADA TEST SITE

- RESPONSIBILITY: SANDIA, LIVERMORE
- MISSION: COMMERCIAL SPENT FUEL AND HLW
STORAGE/DISPOSAL
- STATUS: FIELD TESTS/INVESTIGATIONS OF
GRANITE, ARGILLITE, TUFF, AND
ALLUVIUM HAVE NOT SHOWN EXPECTED
PROMISE TO-DATE
- SCHEDULE: UNCERTAIN

ORNL DWG 79-631

ONWI

- RESPONSIBILITY: BATTELLE MEMORIAL INSTITUTE
- MISSION: COMMERCIAL SPENT FUEL, HLW, TRU WASTES
IN SALT, SHALE, AND GRANITE
- STATUS AND SCHEDULE
 - SITE SELECTED IN SALT DOME IN 1981
 - SITE SELECTED IN PARADOX BASIN SALT IN 1983
 - SITE SELECTED IN PERMIAN BASIN SALT IN 1983
 - SITE SELECTED IN SALINA BASIN SALT IN 1984/85
 - EFFORT INCREASING ON SHALE AND GRANITE

FOREIGN PROGRAMS

- WEST GERMANY
 - OPERATING LLW REPOSITORY IN SALT AT ASSE
 - PROPOSED LLW-HLW REPOSITORY IN SALT AT GORLEBEN
- SWEDEN - DESIGN/TESTING STUDIES OF GRANITE
- UK - HEATING TESTS IN GRANITE
- CANADA - DEVELOPMENT STUDIES IN GRANITE AND SALT
- BELGIUM - STUDIES OF CLAY DEPOSITS
- EAST GERMANY - OPERATING LLW REPOSITORY IN SALT
- USSR - APPARENTLY STUDYING SALT DEPOSITS