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INTEGRAL MONITORED RETRIEVABLE STORAGE (MRS) FACILITY

CONCEPTUAL DESIGN REPORT

VOLUME VI BOOK I – DESIGN STUDIES

Prepared for

UNITED STATES DEPARTMENT OF ENERGY
Richland Operations Office

Report No. MRS 11
Contract No. DE-AC06-84RL 10436
September 1985

THE RALPH M. PARSONS COMPANY OF DELAWARE
Westinghouse Electric Corporation
Golder Associates

MASTER

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DESIGN STUDIES

FOREWORD

The design studies contained in this volume were prepared to support MRS design decision making during the course of the contract and reflect technical data developed during the design evolution. The design studies included range from interoffice correspondence to more formal reports.

Although revisions to the Functional Design Criteria (FDC) resulted in design changes, the technical validity of the studies for use as data input remains.

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IN-PROCESS LAG STORAGE PIT CAPACITIES

1.0 INTRODUCTION

The in-process lag storage temporarily stores waste material, either in its unprocessed form or after it is processed and packed for the transporters in drums, canisters, and overpacks. The unprocessed form of spent-fuel assemblies is stored in the incoming lag storage; the containers for the transporters are stored in the discharge lag storage, which is also capable of storing HLW and RHTRU canisters. Both storage locations serve the purpose of absorbing fluctuations in the delivery, processing, and transporting schedules. Both storage locations are basically rectangular embedded pits into which are fitted the storage compartments. The steel-lined concrete walls of the storage pits are estimated not to exceed 210°C. This value is based on a thermal analysis (see Appendix) that was conducted to evaluate the adequacy of the lag storage natural convection cooling. This study enumerates the capacities of the two storage locations. (For the MRS Facility R&H Building, both of these are shown on Drawing H-3-56880.)

2.0 INCOMING LAG STORAGE

The incoming lag storage stores both PWR and BWR spent-fuel assemblies. These assemblies will arrive at the MRS Facility in casks shipped on trucks or by rail. Casks designed for trucks have a different capacity for carrying spent-fuel assemblies than those designed for rail shipment. These capacities are listed in Table 2-1. The table also lists the number of casks expected at the MRS Facility per day, and the total number of PWR and BWR spent-fuel assemblies expected per day.

There are four incoming lag storage locations for the four shielded process cells. (Each cell has the capability of processing both PWR and BWR spent-fuel assemblies.) At any time there may be more PWR storage space required than BWR and vice versa, and therefore, each lag storage is of a modular design to respond efficiently to changing needs.

Spent-fuel assemblies are stored in removable modules. The modules are of two types, one each for PWRs and BWRs. Both modules have square cross-sections of equal dimensions, thus enabling them to fit in the same space in the storage pit. Module heights are designed to completely envelop the shortest assemblies and partially envelop the longest ones without sacrificing adequate cooling of both sizes. (Lengths of PWR and BWR spent-fuel assemblies were derived from Fig. 2 of Ref. 2.) One PWR module stores 9 PWR assemblies; each BWR module stores 16 BWRs. Modules are inserted into the pit as they are needed; therefore, if the demand for PWR storage outgrows that for BWRs, the excess BWR modules can be easily replaced with those of PWRs. Maximum PWR and BWR capacities of each location of the Incoming Lag Storage are shown in Table 2-2.

Table 2-1 - MRS Facility Spent-Fuel Receivables

Shipping Mode	Cask Number	Assemblies/Cask PWR	Assemblies/Cask BWR	Casks Processed per day[a]		Assemblies/day PWR	Assemblies/day BWR
Truck	NLI-1/2[b]	2	5	12		24	60
Rail	REA2023[c]	24	52	2		48	104
					Total	72	164

[a]See Ref. 3, Section 2.5.2. This column is based on the peak processing rates for which the cells are designed. The peak estimations stem from the requirement in Ref. 1, Section 2.5.2.B, which states that the concurrent receiving and shipping rates of waste packages at the MRS Facility shall not exceed 3,600 MTU/yr.

[b]This is the highest capacity truck cask. For further details, see Ref. 1, Section 2.5.2.B.3.

[c]This is the highest capacity rail cask, also called the transportable metal cask. For further details, see Ref. 1, Section 2.5.2.B.2.

Table 2-2 - Incoming Lag Storage Capacities

Lag Storage	Capacity
Number of PWRs per PWR module	9
Number of BWRs per BWR module	16
Maximum pit capacity for PWRs (i.e., if all modules are PWR)	180
Maximum pit capacity for BWRs (i.e., if all modules are BWR)	320

It is expected that Cells 1 and 3 of the MRS Facility will process primarily PWR spent-fuel assemblies, while Cells 2 and 4 will process primarily BWR assemblies. Assuming the worst case that each day is a peak processing day, a comparison of Table 2-2 with Table 2-1 shows that each incoming lag storage location of Cells 1 and 3 has space enough to store a maximum of 3 peak days' supply of PWR assemblies, and likewise, each storage location of Cells 2 and 4 has space enough to store a maximum of 2 peak days' supply of BWR assemblies. These capacities are sufficient to insulate the processing lines from fluctuations in cask deliveries.

3.0 DISCHARGE LAG STORAGE

The discharge lag storage is required to store processed spent fuel, HLW, RHTRU, and nonfuel-bearing waste generated by either the MRS Facility or external offsite sources. Under normal circumstances, processed spent fuel should not reach the discharge lag storage unless it is contained in an overpacked canister. HLW will be received precanistered at the facility and may be stored as such in the discharge lag storage, provided the canisters are not damaged; if damaged, the HLW canisters will be first overpacked at the facility and then stored. RHTRU waste will also arrive precanistered or in drums and will be stored in the discharge lag storage. If canisters or drums of RHTRU are received in a damaged condition, they will be overpacked at the facility and then stored in the discharge lag storage. The nonfuel-bearing waste will also be packed into standard drums and, if necessary, overpacked. The discharge lag storage is designed to accommodate the above drums, canisters, and overpacks. Table 3-1 lists the rates at which these containers are expected to be transported out of storage.

The maximum numbers of canisters/overpacks and drums that can be stored in the existing discharge lag storage design are shown in Table 3-2.

A comparison of Table 3-2 with Table 3-1 shows that the discharge lag storage has a capacity of storing a maximum of 3 days' supply of nonfuel-bearing and RHTRU drums; 1 day's supply of spent-fuel overpacked canisters or 4.5 days' supply of HLW canisters; and 5 days' supply of RHTRU canisters. These capacities are sufficient to ensure a steady supply of processed waste to the transporters.

4.0 CONCLUSIONS

As is clear from the conclusion of Section 2.0, the incoming lag storage meets its minimum requirements with a very comfortable margin to spare. Furthermore, the modular design of the storage gives it the efficiency of allowing a change from one type of storage to another (PWR to BWR and vice versa). Finally, the fact that the modules can all be removed from the storage pit means that ample room is afforded for easy decontamination of the pit. The decontamination of the modules themselves becomes easier, too, because they can be decontaminated anywhere and not necessarily in the constricted space of the pit. These features make the incoming lag storage satisfy all the requirements specified in Ref. 1.

Table 3-1 - Waste Container Shipping Rates

Waste Form	Storage Container	Quantity/yr	Quantity/day[a]
Nonfuel	Overpacked drums	1,582[b]	4
RHTRU	Overpacked drums	699[c]	2
	Drum Total	2,281	6
Spent fuel	Overpacked canisters	3,256[d]	9
HLW	Canisters[e]	705[c]	2
RHTRU	Canisters[e]	555[c]	2

[a]Numbers in this column were calculated by assuming a 365-day year.

[b]See Ref. 1, Section 3.5.2.B. Regardless of what waste form the facility is processing, nonfuel-bearing waste will always be generated; therefore, this number is based on the maximum processing capability of 3,600 MTU/yr.

[c]See Ref. 1, Section 2.5.2.B.3. This number is based on 1,500-MTU/yr capacity. The remaining 2,100 of the 3,600-MTU/yr capacity is allocated to processing spent-fuel assemblies.

[d]See Ref. 1, Section 3.5.2.B. This is an extremely conservative number that assumes that not all the spent-fuel assemblies will be in a condition to be consolidated, in which case these assemblies will have to be canistered intact, thereby increasing the number of canisters.

[e]These canisters may or may not be overpacked, depending upon their condition. In determining the capacity of the discharge lag storage, it is immaterial whether the canisters are overpacked or not.

Table 3-2 - Discharge Lag Storage Capacities

Storage Container	Capacity
Nonfuel-bearing overpacked drums[a]	20
RHTRU overpacked drums[a]	20
Spent-fuel overpacked canisters[b]	9
HLW canisters, with or without overpacks[b]	9
RHTRU canisters, with or without overpacks	10

[a]The full complement of both nonfuel-bearing and RHTRU drums cannot be stored together at the same time.

[b]Similarly, the full complement of both the spent-fuel overpacked canisters and the HLW canisters (with or without overpacks) cannot be stored together at the same time.

* * * * * * * * * * * *

The discharge lag storage also meets its minimum storage requirements with a comfortable margin to spare, as is clear from the conclusion of Section 3.0. That it stores only one day's supply of overpacked spent-fuel canisters is not a concern because, under normal conditions, no spent-fuel canisters should reach the discharge lag storage. Only if a canister is damaged during processing will it be overpacked and stored, and for such a contingency, more than 1 day's storage space is not necessary. The discharge lag storage's ALARA efficiency is high because this storage, too, is of modular design. Unlike the incoming lag storage, storage space in the discharge lag storage cannot be interchanged between containers, but the storage chambers can be removed in conveniently sized modules to clear the pit and facilitate its easy decontamination, and also to facilitate the easy decontamination of the modules outside the constricted space of the pit. Thus, the discharge lag storage satisfies all of the requirements specified in Ref. 1.

REFERENCES

1. "Integral Monitored Retrievable Storage (MRS) Facility, Conceptual Basis for Design," Report No. MRS.09, The Ralph M. Parsons Company of Delaware, May 1985.

2. "Spent Fuel Consolidation Optimization Study for the Monitored Retrievable Storage Facility Receiving and Handling Building," Design Study DS-9.

3. "Conceptual Design Report," Section 2, Receiving & Handling Building.

APPENDIX

IN-PROCESS LAG STORAGE ANALYSIS

SE:WJS:85:169
FROM: Waste Technology Services Division
WIN: 224-5363
DATE: September 4, 1985
SUBJECT: MRS, In-Process Lag Storage Heat Removal Analysis

TO: L. P. Pollono, Manager
Storage Applications Design

CC: G. C. Clare
R. J. Steffen

References: (1) ASR-85-010, "Integrated MRS; In-Process Lag Storage Heat Removal Analysis," W. J. Severson June 11, 1985

(2) Letter, W. J. Severson to M. Bali, "Monitored Retrievable Storage; Evaluation of Heat Removed by Natural Circulation Through the Lag Storage Pit," SE:WJS:85:110, June 12, 1985

(3) Letter, W. J. Severson to L. P. Pollono, "MRS Concrete Temperature Adjacent the Lag Storage Pit," SE:WJS:85:139, July 18, 1985

Per your request on August 30, 1985, a copy of the first 4 pages of the Reference 1 ASR is forwarded for your information and use. These pages outline the assumptions, references, analysis methods and conclusions of the analysis and may be transmitted to PNC and R. M.Parsons for their review. The details of the calculations themselves have not been included since they contain some Westinghouse proprietary information.

Also attached are copies of References 2 and 3 which discuss the results of the Reference 1 calculations. As noted in Reference 2, the evaluation of the natural circulation heat removal has not considered many of the conditions or configurations which may exist in the lag storage area. However, from a conceptual standpoint it should be possible to adequately cool the assemblies by natural or free convection. Consequences of high exhaust gas temperatures, heat loads on concrete structures, effects of a partially filled storage pit and effects of mixes of types of assemblies will all require further evaluation as the design moves from the conceptual stage to a more detailed design.

Wayne J. Severson

W. J. Severson, Manager
Engineering Analysis

/dlh
Attachment

Waste Technology Services Division	ANALYSIS SUMMARY REPORT	ASR NO. ASR-85-010 REVISION 0 SHEET 1 OF 24

CUSTOMER/PROJECT	GENERAL ORDER/PROD. DEV. NO.
Monitored Retrievable Storage Facility	XAL-72876

SUBJECT/TITLE

Integrated MRS; In-Process Lag Storage Heat Removal Analysis

1. PURPOSE OR OBJECTIVES 2. ASSUMPTIONS/DESIGN INPUTS 3. REFERENCES
4. ANALYSIS METHODS 5. CONCLUSIONS 6. APPENDIX (IF APPLICABLE)

1.0 PURPOSE

The purpose of this analysis was to evaluate the design of the MRS in-process lag storage (modified) facility from a heat removal standpoint and to make recommendations for design changes if these were indicated.

2.0 ASSUMPTIONS/DESIGN INPUTS

2.1 Design

As shown in Dwg. SK-MH002, Sheets 1, 2 & 3 of 4, drawn 4/8/85.

2.2 The spent fuel is to be cooled by natural circulation of the R and H hot cell air through the lag-storage pit. Air enters the hot cell at 80°F, has a bulk cell air temperature (as seen by the exhaust from the cell) of 120°f. It is assumed that the air entering the downcomers to the lag storage pit is at 100°F.

2.3 The maximum permissible fuel cladding temperature is 220°C (MRS-3-85, Rev. 3).

2.4 It is assumed that the principal flow resistances are:

a) the fuel assembly
b) Downcomers
c) Exhaust ducting

other flow resistances can be evaluated during final design.

2.5 Heat Loads

a) PWR assemblies - 550 watts each
b) BWR assemblies - 180 watts each

2.6 Exhaust Air Temperature

It is assumed that the exhaust air from the lag-storage area can be any temperature so long as the clad temp limit is not violated. Implicit in this assumption is the assumption that the HVAC system will be designed so as to preclude the existance of unacceptable temperature environments within the hot cell.

ORIGINATOR	DATE	COGNIZANT MANAGER	DATE
W. J. Severson	June 10, 1985	[signature]	6/11/85

3.0 REFERENCES

3.1 Letter SAD:MB:85:006, M. Bali to W. J. Severson, "Integrated MRS Design, In-Process Lag Storage," May 9, 1985.

3.2 MRS-3-85, Rev. 3, "Functional Design Criteria for an Integrated Monitored Retrievable Storage (MRS) Facility," March 1985.

3.3 IOC #520, J. T. Ang/RMP to J. A. Roll/WEC, "Job. No. 6440-Monitored Retrievable Storage Facility In-Cell Lag Storage Heat Load," May 15, 1985.

3.4 E.R.G. Eckert and R. M. Drake, Heat and Mass Transfer, 2nd edition, McGraw-Hill Book Company, Inc., New York, N.Y. 1959.

3.5 William H. McAdams, Heat Transmission, 3rd Edition, McGraw-Hill Book Company, Inc., New York, NY 1954.

3.6 I. E. Idel'chick, Handbook of Hydraulic Resistance, 1966, AEC-TR-6630.

3.7 "Flow of Fluids Through Valves, Fittings, and Pipe," CRANE Technical Paper No. 410, 1957.

3.8 Telecon with Carl Olson, Westinghouse NFD, May 17, 1985 (data on Westinghouse 17x17 fuel assemblies).

3.9 Telecon with Kuofu Chen, Westinghouse NFD, May 20, 1985 (data on BWR fuel assemblies).

3.10 DOE/ET/49912-3, "Domestic Light Water Reactor Fuel Design Evolution," Vol. III, September 1981.

3.11 Calculation by W. Lundberg, "Fuel Assembly Cooling," dated 8/9/84, six pages.

4.0 ANALYSIS METHODS

The analysis is performed by first establishing the required air flows for various exhaust temperatures. The available thermal driving heads are then computed assuming 1) no heat addition to the air in the downcomers and 2) linear temperature increase across a fuel assembly (taken as 12.7 feet). The pressure drop through an average PWR assembly is then computed assuming average conditions on flow and temperature. The difference between the thermal head and the head loss through the fuel assemblies provides the allowable ΔP through the downcomer and exhaust risers. These ΔP's are then compared with the ΔP's associated with the designs shown in the drawings attached to Reference 3.1.

Hand calculations are used throughout. All ΔP's, flows, and temperature conditions are based on conditions for an average or typical assembly.

5.0 CONCLUSIONS

5.1 The design as shown in Dwg. SK-MH002 will not work because the combined resistance of the downcomers and risers is too high.

5.2 The expected exhaust temperature is on the order of 350°F. With this exhaust temperature, the total thermal head (which provides the driving force for the natural circulation of air through the lag storage pit) is about 0.0014 psi. The ΔP through a PWR assembly would be 0.0004 psi. The difference between the thermal head and the ΔP through the assemblies (0.001 psi) is available for flow losses in the downcomer, risers and other miscellaneous losses within the structure.

5.3 The downcomers should be changed from eight (8) 6" I.D. pipes to eight (8) 10" schedule 20 pipes (10.25" I.D.). The inlet should be flared with a radius of 2" and the top cover should be 4" above the entrance to the downcomer. In addition, the inlet miter bend should be changed to a long radius elbow.

5.4 The exhaust risers should be ten (10) in number having an internal cross section of 4.5" x 21" and the mitered bends should be modified to be rounded. The screen at the exhaust should have a flow area $\geq$ 90% of total flow area.

5.5 The estimated ΔP (for a 350°F outlet temperature) for a BWR assembly is 0.00031 psi - about 75% of that for a PWR assembly. Thus the PWR assembly is controlling.

5.6 With a 350°F outlet temperature, the clad temperature will be at least 35 ~~350~~°C below the temperature limit.

5.7 Other observations:

1) The downcomers and exhaust risers should be placed on opposite sides of the lag storage pit to minimize the change of pulling exhaust air into the downcomers.

2) The racks holding the assemblies should be lengthened to assure that the fueled portion of any of the assemblies is within a confined duct.

Waste Technology Services Division

REVIEW RECORD

RR NUMBER

SHEET 1 OF ____

CUSTOMER/PROJECT	GENERAL ORDER/PROD. DEV. NO.	CHARGE NUMBER
Monitored Revrievable Storage Facility	XAL-72876	

SUBJECT OF REVIEW: Integrated MRS: In-Process Lag Storage Heat Removal Analysis

REVIEWERS/FUNCTION: W. L. LUNDBERG

PURPOSE OF REVIEW: CHECK APPROACH, REASONABLENESS OF RESULTS, AND RANDOM CHECK OF CALCULATIONS

REVIEW COMMENTS MUST BE DOCUMENTED FOR WRITTEN RESOLUTION. YES ____ NO ____

PREPARER: [illegible] DATE: 6/11/85

REVIEW COMMENTS:

p. 8 - What is Reynolds no. range of applicability for the fuel assembly form loss coefficient.

p. 12 - Total K value should be 4.44 not 4.79. Slight effect on some subsequent calculations

p. 17 - Need to adjust downcomer volumetric flow rate by density ratio to use it in predicting upstream velocity.

p. 18 - Entrance K of .04 is low for sq wave edged inlet. Not effect on conclusion drawn from calculation.

p. 21 - another method for estimating the cladding surface film heat transfer coeff is attached (p. 24). The resulting coefficient is larger than that on p. 21-22 and leads to lower cladding temperature predictions

REVIEWER: [signature] DATE: 6/11/85

WTSD 0039

SE:WJS:85:110
Waste Technology Services Division
224-5363
June 12, 1985
Monitored Retrievable Storage; Evaluation of Heat Removal by Natural Circulation Through the Lag Storage Pit

Ref: 1) SAD:MB:85:006, Mrinal Bali to W. J. Severson, "Integrated MRS Design, In-Process Lag Storage
2) Drawing SK-MH-002, Material Handling In-Process Lag Storage (Modified) Sheets 1, 2 and 3 of 4.
3) ASR-85-010

To: M. Bali

cc: G. H. Clare
W. L. Lundberg
L. P. Pollono
R. J. Steffen

Per your request, (Reference 1) a thermal analysis has been done to determine the adequacy of the lag storage from the standpoint of cooling by free or natural convection.

It is concluded that:

1. The downcomers need to be made larger in diameter. Eight (8) downcomers are probably sufficient but they should have a 10.25 inch I.D. (10" Sch 20 pipe). In addition, the mitered bend at the bottom of the downcomer should be a long radius elbow; and the entrance to the downcomer should be flared with a 2" radius. The cover over the downcomer entrance should be 4" above the top of the downcomer.

2. The exhaust risers should be 10 in number with each one having internal dimensions of 4.5"x21" or equivalent. As with the downcomers, the bends should be rounded. The screen over the exhaust should be selected such that the net flow area is $\geq$90% of total duct area.

3. It will take an exhaust temperature of about 350°F to establish the thermal head necessary to overcome the resistances provided by the fuel assemblies, the downcomers (described in 1 above) and the exhaust risers (described in 2 above). The thermal head at 350°F exhaust temperature (with an assumed 100°F inlet temperature) is small: 0.0014 psi.

4. There are other configuration changes that should be made:

   A. The downcomers and exhaust risers should be on opposite sides of the lag storage pit to minimize the potential of pulling hot exhaust air into the downcomers.

B. The racks holding the assemblies should be lengthened to assure that the fueled portion of any of the assemblies is within a confined duct.

5. The estimated ΔP (for a 350°F outlet temperature) for a BWR assembly is 0.00031 psi - about 75% of that for a PWR assembly. Thus the PWR assembly is controlling.

6. With a 350°F (177°C) exhaust air temperature, the maximum cladding temperature will be at least 35°C below the limit of 220°C.

It should be recognized that this evaluation has not considered many of the conditions that will normally exist during fuel handling; namely, mixtures of fuel types, empty lifting fixtures (or racks), covers removed etc. These conditions will have to be analyzed to evaluate the effect on cooling of the hottest assembly. Bypass flows, internal recirculation flows and other conditions may be expected.

The analysis has been documented in an ASR (Reference 3). The ASR was not done on R. M. Parsons calculation sheets although a transfer of the work can be made to these sheets if really required. (It was not required for ASR's 001 through 004 documenting earlier conceptual work.)

It is recognized that the Reference 2 drawing has been replaced by H-3-56880. This later drawing has not been addressed by this analysis. It is requested that proposed revisions to drawings be reviewed by Engineering Analysis if they impact thermal, shielding, or structural aspects that we would normally be involved with.

W. J. Severson, Manager
Engineering Analysis

/mmb

SE:WJS:85:139
Waste Technology Services Division
224-5362
July 18, 1985
Subject: MRS Concrete Temperature Adjacent the Lag Storage Pit

To: L. P. Pollono

cc: G. H. Clare
W. L. Lundberg
R. J. Steffen

References: 1. Letter, R. J. Steffen to W. R. Morris; "MRS Trip Report - Ralph M. Parsons Company, 24 June 85 - 28 June 85," July 1, 1985, MRS:RJS:85:105

2. Letter, W. J. Severson to M. Bali, "Monitors Retrievable Storage; Evaluation of Heat Removal by Natural Circulation through the Lag Storage Pit," June 12, 1985; SE:WJS:85:110.

The purpose of this letter is to respond to your verbal request on July 15, 1985 for a statement regarding lag storage pit concrete wall temperatures which was an outgrowth of the discussion given in the second paragraph of Reference 1.

Reference 2 provided results of an evaluation of the heat removal by natural circulation through the lag storage pit. That evaluation concluded that exhaust temperatures of approximately 350°F (177°C) would be required to establish the thermal heads necessary to provide the required air flows. Reference 2 also states that the evaluation did not consider many of the conditions that will normally exist during fuel handling; namely, mixtures of fuel types, empty lifting fixtures, covers removed, etc. These conditions will have to be analyzed to evaluate the effect on cooling of the hottest assembly. In other words, it is conceivable that there may be local areas where the air is near the maximum clad temperature limit of 220°C.

Consequently, for purposes of investigating concrete degradation, (and without performing an additional thermal analysis,) it is recommended that a maximum concrete temperature of 210°C be used. Depending on the outcome of the concrete evaluations, it may be necessary to alter the design to include schemes which reduce the concrete temperatures (insulation or other methods).

W. J. Severson, Manager
Engineering Analysis

/mmb

3107w-240w:2
(F0000) 17

FOREWORD

This design study was based upon the requirements of Revision 3 of the FDC. The impact of Revision 4 of the FDC on this study is the change in the truck/rail split for the receipt of spent-fuel shipping casks. The split was changed from 50/50 to 70/30 rail/truck split, with no change in the 3,600-MTU requirement. The effect of this change on the study is as follows:

(1) There will be an increase in the number of railcars received and a decrease in the number of trucks received.

(2) Demand on the 150-ton receiving and inspection area crane will be reduced.

(3) Demand on the cask cart and installation of adapters will be reduced.

(4) Demand on the process cell power mast to manipulate process cell shield plugs will be reduced.

(5) Demand on facilities and tests associated with cask handling will be reduced.

(6) Demand on all other processes needed to ensure the 3,600-MTU/yr throughput from spent-fuel handling to offloading and storage will not be changed.

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DESIGN STUDY DS-2

WASTE RECEIPT AND HANDLING CHARACTERISTICS OF THE MRS FACILITY

1.0 INTRODUCTION

The purpose of this study is to identify time and motion estimates for operations in the MRS Receiving and Handling (R&H) Building and to demonstrate that the conceptual design meets the base-case throughput requirements.

The conceptual design of the R&H Building includes all facilities and equipment necessary to receive, unload, and prepare for storage, spent fuel (SF), high-level waste (HLW), and future remotely handled transuranic waste (RHTRU). The facility must be capable of retrieval, packaging, and shipment of material stored, using either the sealed storage cask or drywell storage concept. The canisterized spent-fuel and HLW canisters are to be packaged into a repository overpack (RO) and shipped to a permanent remote repository storage location. The base-case facility is designed primarily for the receipt, processing, packaging, storage, and shipment of spent fuel, along with a small amount of canisterized HLW. The key features of the conceptual design are the capability to dismantle fuel assemblies, consolidate and package spent-fuel rods, dispose of nonfuel-bearing waste, and package waste forms into a repository container for final disposition.

2.0 FACILITY THROUGHPUT REQUIREMENTS

The base-case throughput requirements and assumptions for the MRS Facility are:

(1) Receive and store at least 3,600 metric tons of uranium (MTU) per year as spent fuel.

(2) Receive and store up to 300 canisters of HLW per year.

(3) Assume that the spent fuel received will consist of 60% PWR-type fuel assemblies and 40% BWR-type fuel assemblies. The percentages are based on weight of contained uranium.

(4) Assume that, on the average, a PWR-type fuel assembly will contain 0.462 MTU and that a BWR-type fuel assembly will contain 0.186 MTU.

(5) Retrieve from storage and ship at least 3,600 MTU, or equivalent, per year. Receiving and shipping are concurrent.

(6) Assume that 50% (by weight) of spent fuel and equivalent waste will be received in casks shipped by truck and 50% will be received in casks transportable by railcar.

(7) Assume that truck casks will contain either two PWR fuel assemblies or five BWR fuel assemblies.

(8) Assume that rail casks will contain either 12 PWR fuel assemblies or 32 BWR fuel assemblies.

(9) Assume that the facility will operate three shifts/day for 365 days/yr (defined as a four-shift operation).

(10) Assume that spent-fuel storage canisters will contain one of the following:

(a) Fuel rods from three PWR fuel assemblies.
(b) Fuel rods from seven BWR fuel assemblies.
(c) One intact PWR fuel assembly.
(d) Two intact BWR fuel assemblies.

(11) Assume that the RO contains four MRS canisters.

(12) Assume that the shipping cask for the repository overpack (SCFRO) contains only one RO.

(13) Assume that spent fuel, HLW, RHTRU, and onsite-generated waste that could possibly contain spent-fuel residue or TRU will be stored in either sealed storage casks or drywells.

(14) Assume that each sealed storage cask will contain one of the following:

(a) Twelve canisters of consolidated spent fuel.

(b) Twelve canisters of intact spent fuel.

Note: Canisters containing intact and consolidated spent fuel could be stored in the same concrete cask, if necessary

(c) Five HLW (base case) canisters.

(d) Fifteen 55-gal drums containing nonfuel waste generated by the consolidation process.

(e) Either 35 or 45 (depending on specific activity) 55-gal drums containing onsite-generated waste, such as first-stage HEPA filters.

(15) Ensure that each drywell can contain one of the following:

(a) One canister of consolidated or intact spent fuel.
(b) One HLW canister.
(c) Five 55-gal drums of secondary waste.

3.0 R&H BUILDING DESIGN FEATURES

Features of the R&H Building that have an impact on throughput rates are described in the paragraphs that follow.

Each of the two shipping cask receiving and inspection areas is serviced by a single bridge crane with a 150-ton capacity and a mobile 40-ton crane. The mobile crane is used for lower-capacity lifts, such as transport vehicle personnel barriers and cask impact limiters. Smaller lifts can be made by using self-propelled handling equipment. Each of the receiving and inspection areas will prepare casks for unloading spent fuel at two cells (with two ports per cell) and unloading HLW and ROs at a single port at the shielded canyon cell. A mirror image of the receiving and inspection area, two shielded process cells, and the shielded canyon cell is provided to meet the throughput and provide independent handling of fuel.

Four shielded process cells are provided for processing spent-fuel assemblies. Two of the shielded process cells, located in the north end of the R&H Building (Cells 1 and 3), are used primarily to process PWR spent fuel. The two southern shielded process cells (Cells 2 and 4) are used primarily to process BWR spent fuel. All four shielded process cells have the capability to consolidate either the PWR or BWR fuel assemblies. The HLW and future RHTRU are processed in Shielded Canyon Cell 6, located in the southern half of the building. The RO is processed in the eastern ends of Shielded Canyon Cells 5 and 6.

Shielded Process Cells 1 through 4 are each provided with two waste intake ports. Only one intake port in each cell may be open at any one time. Each of these process cells is provided with two fuel transfer ports to pass consolidated fuel and intact fuel into the shielded canyon cells for encapsulation in canisters.

Each shielded process cell intake port is serviced by a rail-mounted, self-powered cart. This cart is used to move the spent-fuel shipping cask from the receiving and inspection area to a position beneath the intake port for unloading.

Shielded Process Cells 1 through 4 each contain a large incoming spent-fuel lag storage area for temporary storage and cooling before the consolidation process is begun. Lag storage is capable of storing either 180 PWR or 320 BWR spent-fuel assemblies. The lag storage support cages are modular to permit storage of all PWRs or BWRs or a combination thereof. The large lag storage pit ensures adequate storage to reduce possible supply- and-demand interference that would affect the fuel-processing rate.

Consolidation operations will be performed concurrently on either three PWR fuel assemblies or seven BWR fuel assemblies.

Shielded Canyon Cell 5 shares an adjoining wall with the shielded process cells (1 and 3) and a decontamination cell located between Cells 1 and 3. The spent-fuel canistering or packaging is performed in the shielded canyon cells. Two canister upenders, mounted on a common set of rails, are used to position empty canisters to receive consolidated or intact fuel elements from the shielded process cells. These same upenders are used to alternatively feed the canisters, with the fuel rod bundle inside, into the single welding station located in the western end of the shielded canyon cell. A mirror image of this configuration exists for Shielded Canyon Cell 6 and Shielded Process Cells 2 and 4.

The spent-fuel canister welder centerline (one for each shielded canyon cell) is located to permit the west upender to be positioned against the west wall and still allow access to the welder from the east upender. This arrangement reduces the quantity of welders and increases the utility of the welder. A pass-through cart and a port exist to transfer filled canisters between shielded canyon cells for welding if a welder decontamination chamber is down for repair or maintenance.

An RO packaging (welding and decontamination) station is located in each of the eastern ends of the shielded canyon cells. These packaging stations can operate independently of the other canyon cell operations, except during the repository overpack fill and discharge operations, which require the 35-ton crane.

The processing of HLW, future RHTRU, and damaged spent-fuel canisters occurs at the canister overpack welding station, located at the eastern end of Shielded Canyon Cell 6. All operations are primarily independent of other canyon cell operations, except for the use of the overhead crane during upender loading and unloading operations. The overpack upender services both shielded canyon cells via a pass-through port, located at the eastern ends of the canyon cells for the above-mentioned processing.

A storage discharge port is located in each of Shielded Canyon Cells 5 and 6 at the eastern end. Sealed storage casks or drywells are loaded through this discharge port. An independent plug-jacking mechanism is used to lift and slide the plug to the side to permit full access to the port.

A nonfuel-bearing waste drum processing and decontamination cell is located between Shielded Process Cells 1 and 3. An identical cell is located between Shielded Process Cells 2 and 4. Clean drums are brought into the decontamination cell, transferred to the shielded process cell for filling, and then returned to the decontamination cell for decontamination and transfer to the shielded canyon cells. All of these operations are independent and can be performed, as required, by the nonfuel-bearing waste volume-reduction systems located in each of the shielded process cells.

4.0 ANALYSIS

The throughput requirements and assumptions listed herein were analyzed to develop annual estimated throughput quantities of various waste types to be received, processed, packaged for repository disposition, or stored, using either the primary (sealed storage cask) or alternate (drywell) concept. The results of the analysis are summarized and shown in Table 4-1. The analysis presented is based on deterministic evaluation methods, and does not include statistical variations in delivery or processing.

4.1 SHIPPING CASK UNLOADING TIME REQUIREMENTS

Handling operational tasks for spent-fuel shipping casks can be divided into three categories:

(1) Cask receiving
(2) Cask unloading
(3) Cask discharging

The equipment for the R&H Building conceptual design includes, for each cell, two cask carts, each serving a waste entry port. Table 4-2 shows the operational tasks and estimated times for receipt, unloading, and discharge of truck and rail casks. The critical-path activities for two entry ports include operational activities 11 through 31 of Table 4-2, which require a total time of 460 minutes (7 hr 40 min) for PWR truck casks and 520 minutes (8 hr 40 min) for BWR truck casks. Critical-path times for truck casks with two PWR spent-fuel assemblies is 3.83 hr per assembly; with five BWR assemblies, the critical-path time is 1.73 hr/assembly. The critical-path times for a rail cask with 12 PWR spent-fuel assemblies is 750 minutes (12 hr 30 min) or 1.04 hr/assembly. Similarly, the critical-path time for a rail cask with 32 BWR spent-fuel assemblies is 1,150 minutes (19 hr 10 min) or 0.60 hr/assembly. A summary of these cask handling time values is shown in Table 4-3A. The tasks not on the critical path can be performed independently or in parallel with the critical-path activities occurring in the receiving and inspection area. All times included in the evaluation are based on minimum times required to perform the stated activities. These critical-path times represent the cask handling, cask unloading, and cask discharge handling times. All three of these aspects are included because the key to meeting the receiving throughput is the optimized use of the cask carts and service cranes (150-ton and 40-ton cranes required for the receiving and inspection area). The receiving and discharge cask handling operations represent the largest contributors to the critical-path times. This is particularly true for both the PWR and BWR truck casks.

The receiving and handling requirements of the MRS Facility, when combined with the assumed 50/50 truck/rail shipping split and 50% operating efficiency, produce the following cask process rate requirements:

(1) PWR truck casks/cell = 1.601 casks/day
(2) BWR truck casks/cell = 1.060 casks/day
(3) PWR rail casks/cell = 0.267 cask/day
(4) BWR rail casks/cell = 0.166 cask/day

Table 4-1 - Annual Throughput for MRS Facility
(3,600 MTU/yr)

Waste Type	Receiving		Processing			Storage		Repository Overpack
	Number of Fuel Assemblies	No. of Casks	No. of Canisters Consolidated Fuel Assemblies	No. of Canisters Intact Fuel Assemblies	No. of Drums	No. Casks (Primary Concept)	No. Drywells (Alternate Concept)	No. of Overpacks Shipped Offsite [a] [c]
PWR spent fuel	2,338 (by truck) 2,338 (by rail)	1,169 (by truck) 195 (by rail)	1,404	468	0	156	1,872	390
BWR spent fuel	3,870 (by truck) 3,870 (by rail)	774 (by truck) 121 (by rail)	996	388	0	116	1,384	277
PWR nonfuel-bearing components	-	-	0	0	421	29	85	84
BWR nonfuel-bearing components	-	-	0	0	1,161	78	232	232
West Valley HLW	60 (canisters of HLW)	4 to 6 (by rail)	60 (HLW)	0	0	12	60	60
Onsite-generated HAW[b]	0	0	0	0	1,383	31	277	276
Onsite-generated LLW/CHTRU	0	0	0	0	533	CHTRU Facility		

[a]Annual shipping rate of consolidated spent fuel is based on all 3,600 MTU/yr being consolidated.
[b]HAW = high-activity waste.
[c]Based on the event that repository overpacking is performed at the MRS.

Table 4-2 - Estimated Process Times for Shipping Casks

CASK HANDLING/ RECEIVING AND HANDLING AREA (All time in minutes)

ACTIVITY NO.	OPERATION DESCRIPTION	TRUCK CASK	RAIL CASK	150 TON CRANE	40 TON CRANE	CASK CART-1A	CASK CART-1B	CASK CART-3A	CASK CART-3B
1	Cask inspection at gate	5	5						
2	Move cask/vehicle to protect. area	15	15						
3	Check BOL to determine contents	15	15						
4	Survey cask/vehicle for radiation and visually inspect	45	45						
5	Move cask/vehicle to washdown area and position cask for unloading	15	15						
SUBTOTAL		95	95	0	0	0	0	0	0
6	Remove road dirt for cask/vehicle	45	45						
7	Move cask/veh. to cask handling area	25	30						
SUBTOTAL		70	75	0	0	0	0	0	0
8	Remove personnel barriers from vehicle	25	30	30	25				
9	Remove impact limiters & shipping rest.	25	30	30	25				
10	Perform contamination survey on cask and complete preparations	20	30						
11	Attach grapple & remove cask from vehicle	15	15	15	15	15	15	15	15
12	Place cask on cask cart & install rest.	20	20	20	20	20	20	20	20
13	Move cask to Cask Handling and Decon Room	10	10			10	10	10	10
14	Remove outer cask lid	30	30			30	30	30	30
15	Take gas sample from cask interior-check cask internal pressure - vent or purge if required to controlled vent system	30	45			30	45	30	45
16	Loosen inner cask cover bolts	20	30			20	30	20	30
17	Install contamination barrier adapter	5	10			5	10	5	10
18	Move cask into Unloading Room, engage contamination barrier, close shadow shield and close shield door	20	20			20	20	20	20
SUBTOTAL		220	270	95	85	150	180	150	180
19	Remove cell entry port plugs	20	20			20	20	20	20
20	Remove cask inner closure	15	20			15	20	15	20
21	Confirm contents of cask	5	10			5	10	5	10
22	Unload contents of cask								
	PWR SFA-20 min ea	40	240			40	240	40	240
	BWR SFA-20 min ea	100	640			100	640	100	640
	HLW Canisters-20 min ea	20	100			20	100	20	100
23	Inspect cask cover seal & replace if req.	20	25			20	25	20	25
24	Replace inner cask cover	15	30			15	30	15	30
25	Replace entry shield port plugs	15	15			15	15	15	15
26	Open shadow shield & shield door-disengage contamination barrier-move cask to Decon room	20	20			20	20	20	20

PARSONS

Table 4-2 (Contd)

CASK HANDLING/ RECEIVING AND HANDLING AREA (All time in minutes)

ACTIVITY NO.	OPERATION DESCRIPTION	TRUCK CASK	RAIL CASK	150 TON CRANE	40 TON CRANE	CASK CART-1A	CASK CART-1B	CASK CART-3A	CASK CART-3B
SUBTOTAL PWR		150	380	0	0	150	380	150	380
SUBTOTAL BWR		210	780	0	0	210	780	210	780
SUBTOTAL HLW		130	240	0	0	130	240	130	240
27	Remove contamination barrier	5	10			5	10	5	10
28	Survey for radiation/contamination	30	40			30	40	30	40
29	Decon if necessary & replace outer cover	90	105			90	105	90	105
30	Move cask to Receiving and Handling area	10	10			10	10	10	10
31	Move cask from cart to transport vehicle & remove lifting yoke	25	25	25	25	25	25	25	25
SUBTOTAL PWR (CRITICAL PATH ITEMS 11-31)		460	750	60	60	460	750	460	750
SUBTOTAL BWR (CRITICAL PATH ITEMS 11-31)		520	1150	60	60	520	1150	520	1150
SUBTOTAL HLW (CRITICAL PATH ITEMS 11-31)		440	610	60	60	440	610	440	610
32	Install cask tie downs, impact limiters, personnel barriers, etc	45	60	60	45				
33	Move cask & trans. veh. to dispatch area	15	15						
34	Discharge empty cask/vehicle through gate	15	15						
TOTAL PWR		770	1100	180	155	460	750	460	750
TOTAL BWR		830	1500	180	155	520	1150	520	1150
TOTAL HLW		750	960	180	155	440	610	440	610

PARSONS

Table 4-3A - Summary of Cask Receiving and Inspection Area Operations

SUMMARY OPERATIONS DESCRIPTION — CASK HANDLING/ RECEIVING AND HANDLING AREA:

	TRUCK CASK TIME (TOTAL MIN)	(HR) & (MIN)	RAIL CASK TIME (TOTAL MIN)	(HR) & (MIN)
A. Tasks not on Critical Path	310	5 10	350	5 50
B. Tasks on Critical Path				
(1) Casks with PWR Fuel Assemblies	460	7 40	750	12 30
(2) Casks with BWR Fuel Assemblies	520	8 40	1150	19 10
(3) Casks with HLW Canisters	440	7 20	610	10 10
C. Total				
(1) Casks with PWR Fuel Assemblies	770	12 50	1100	18 20
(2) Casks with BWR Fuel Assemblies	830	13 50	1500	25 0
(3) Casks with HLW Canisters	750	12 30	960	16 0

Table 4-3B - Summary of Cask Receiving and Inspection Area Equipment Usage Values

CASK HANDLING/ RECEIVING AND HANDLING AREA (NORTH-PWR)

EQUIPMENT DESCRIPTION	TOTAL TIME TO PROCESS SPENT FUEL (TOTAL MIN)	(HRS & MIN)	PERCENT USAGE FOR SPENT FUEL (24 HRS)	TIME TO PROCESS REPOSITORY OVERPACKS (RO) (TOTAL MIN)	(HRS & MIN)	PERCENT USAGE INCLUDING RO (24 HRS)
EQUIPMENT:						
150 TON CRANE	650	10 50	45.14%	185	3 5	57.99%
40 TON CRANE	530	8 50	36.81%	120	2 0	45.14%
CASK CART 1A (TRUCK)	1325	22 5	92.01%			-
CASK CART 1B (RAIL)	740	12 20	51.39%			-
CASK CART 3A (TRUCK)	1325	22 5	92.01%			-
CASK CART 3B (RAIL)	805	13 25	55.90%			-

CASK HANDLING/ RECEIVING AND HANDLING AREA (SOUTH-BWR)

EQUIPMENT DESCRIPTION	TOTAL TIME TO PROCESS SPENT FUEL (TOTAL MIN)	(HRS & MIN)	PERCENT USAGE FOR SPENT FUEL (24 HRS)	TIME TO PROCESS REPOSITORY OVERPACKS (RO) (TOTAL MIN)	(HRS & MIN)	PERCENT USAGE INCLUDING RO (24 HRS)
EQUIPMENT:						
150 TON CRANE	480	8 0	33.33%	185	3 5	46.18%
40 TON CRANE	395	6 35	27.43%	120	2 0	35.76%
CASK CART 2A (TRUCK)	1050	17 30	72.92%			-
CASK CART 2B (RAIL)	1135	18 55	78.82%			-
CASK CART 4A (TRUCK)	1040	17 20	72.22%			-
CASK CART 4B (RAIL)	1135	18 55	78.82%			-

These values are based on a 3,600-MTU/yr delivery rate, with two cells dedicated to PWR processing and two cells dedicated to BWR processing, as calculated in the Appendix. For each of the two cells receiving PWR spent fuel, the cask cart servicing the truck casks is required for 51.1% of the available operating hours; the cask cart servicing the rail casks is required for only 13.9% of the operating hours. This results in an average cell required availability of 32.5% of the total available operating time of 24 hr/day. This average cell availability is less than the 50% efficiency limit; therefore, some excess capacity is available. Similarly, for each of the two cells receiving BWR spent fuel, the truck cask cart is required for 38.3% of the available operating hours; the rail cask cart is required for only 13.3% of the operating hours. This results in an average cell required availability of 25.7% of the total available operating time of 24 hr/day. Some excess capacity also exists for the BWR cask handling because the average required availability is less than the 50% efficiency value. The cask delivery requirements indicate partial cask unloading situations (this is caused by average values). If integral cask unloading requirements are assumed, the average cell required availability values would increase, as well as the receiving throughput. These integral cask unloading availability rates would become 58.0% for the PWR cells and 59.1% for the BWR cells. These values exceed the 50% efficiency value; however, each PWR cell would have available nine assemblies more per day and each BWR cell would have 26 assemblies more per day (see Appendix).

Scheduling of the cask carts for each shielded process cell is important to meeting the required receiving and unloading throughput. The receiving, unloading, and discharge operations (as defined in Table 4-2 and summarized in Table 4-3A) are shown in Table 4-4 with a graphical representation of the scheduling required to optimize the cask handling operations. Crane availability is a key parameter in the scheduling function. This is particularly important in the unloading of truck casks. The number of crane operations necessary for the spent-fuel assemblies is considerably higher than it is for rail casks. Table 4-4 provides an unloading schedule for each of the two receiving and inspection areas developed for a 24-hr period in which the cask handling operations for Shielded Process Cells 1 through 4 are represented. The major equipment used for cask handling operations is shown at the top of the table. Truck casks are unloaded by a single cask cart (Cask Cart 1) in each of the shielded process cells. Similarly, rail casks are unloaded by a single cask cart (Cask Cart 2) in each of the shielded process cells.

The critical-path times defined in Table 4-3A were used to generate the cask cart/crane schedules to help optimize the cask handling and unloading activities. These schedules provide a means to calculate the maximum number of casks that can be unloaded in a 24-hr period, as well as to determine the resulting equipment usage values. A summary of the equipment usage values is provided in Table 4-3B. Since these values represent the maximum number of casks that can be handled in a 24-hr period, the usage values may be conservative.

Table 4-4 is divided into Table 4-4A and Table 4-4B, which represent spent-fuel cask handling operations for the receiving and inspection areas unloading PWR and BWR fuel, respectively. Table 4-4A indicates the operations and sequence required to unload two PWR rail casks and four PWR truck casks through a single receiving and inspection area feeding two shielded process cells (1 and 3). This value exceeds the required receiving rate for the base case 50/50 truck/rail delivery split. Table 4-4B indicates the operations and sequence required to unload two BWR rail casks and two BWR truck casks feeding two shielded process cells (2 and 4). This table also indicates that two additional truck casks can be partially unloaded during the 24-hr period.

The purpose of Table 4-4 is to indicate a schedule of operations and to develop a tool to quantify the cask cart and crane usage percentages. Truck casks are represented by the letters A, B, E, F, G, and H. Rail casks are represented by the letters C and D. Each letter represents a 5-min increment of time in the schedule. This time line shows that certain activities may be performed simultaneously, whereas others must be performed sequentially (e.g., rail cask lifts via the 150-ton crane). The upper section of the schedule indicates the equipment and time duration during which the equipment is used. A sequential summary is provided in Table 4-3B of the crane and cask cart usage as derived from Table 4-4. The crane unloading and cask cart schedule for the repository overpack is not shown because of the page constraints of Table 4-4. However, a review of the 150-ton crane and 40-ton mobile crane usage lines indicates that the RO can be serviced within the 24-hr period. One RO must be received, unloaded, processed, and shipped offsite through each of the receiving and inspection areas within a 24-hr period. This requirement can be met on a normal basis provided that maintenance and downtime of the 150-ton crane do not exceed 42% for the north receiving and inspection area or 53% for the south receiving and inspection area.

Table 4-4A indicates that a maximum of six PWR truck casks and two PWR rail casks can be unloaded in 25 hr and 20 min. This quantity of casks exceeds the design base case and provides an indication of a peak unloading schedule. Therefore, the percent usage values listed in Table 4-3B are conservatively estimated. Table 4-4A also indicates that some of the cask cart activities must be delayed (wait period) because of the schedule of crane activities.

Table 4-4B indicates that a maximum of four BWR truck casks and two BWR rail casks can be unloaded in 25 hr and 30 min. This quantity of casks exceeds the design base case and provides an indication of a peak unloading schedule. The long unloading schedule of the BWR rail cask delays the unloading of the truck cask because only one entry port may be open at any one time. This causes a reduction in the number of trucks that can be unloaded.

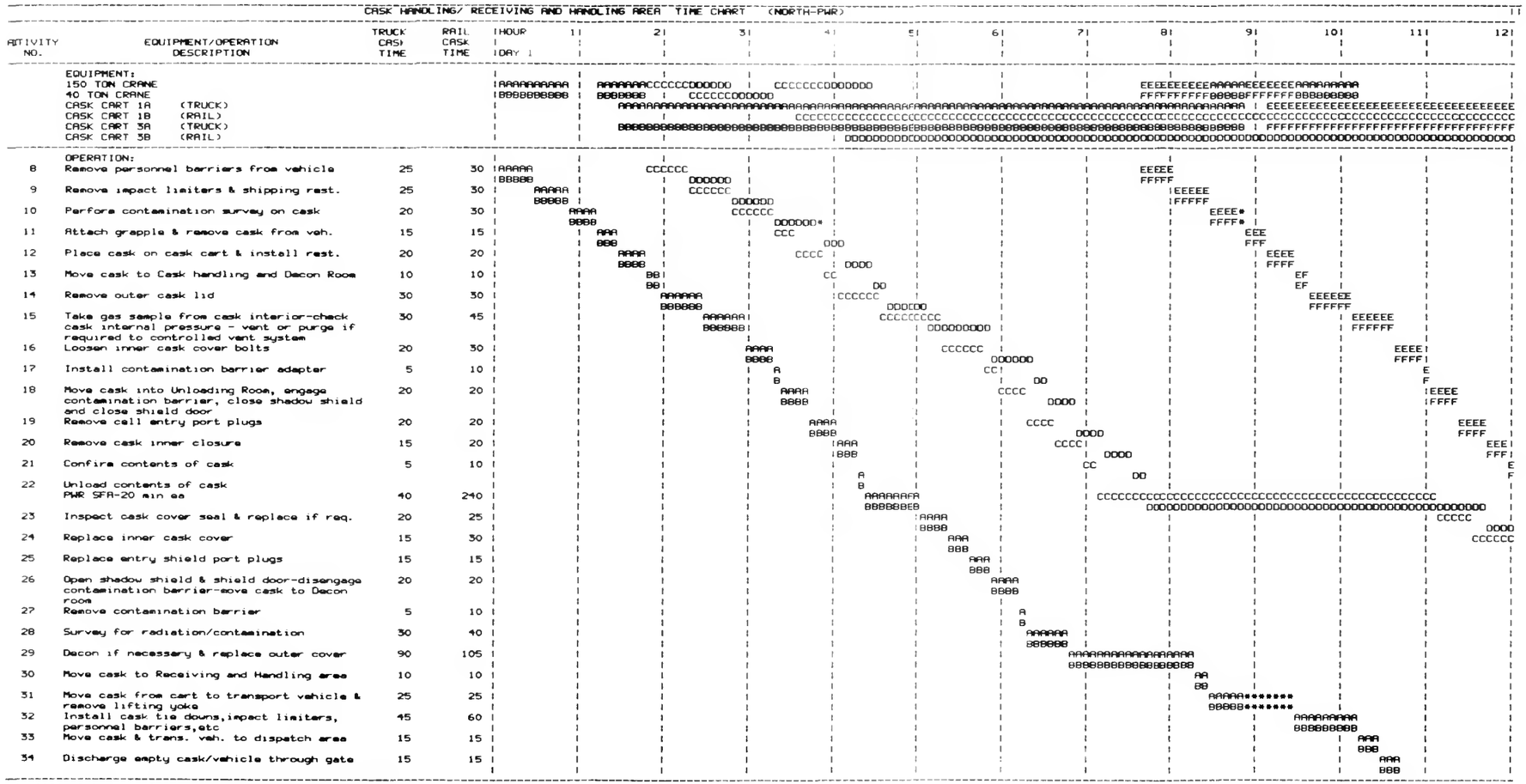
The process time estimates in Table 4-4B were compared to times measured for similar operations when using the Transnuclear TN-9 (BWR) shipping cask at the Barnwell Nuclear Fuel Plant as reported in Reference 1. That comparison, for the MRS R&H Building critical-path cask-handling operations, is shown in Table 4-4C. In this comparison, it can be seen that the values in Table 4-4B are conservative, as well they should be, because a variety of casks can be expected at the MRS Facility, whereas the Reference 1 times were obtained after significant operating experience with only the TN-9 cask.

Table 4-4A

Estimated Cask Receiving and Inspection Area Time Schedule for PWR Spent Fuel

CASK HANDLING/ RECEIVING AND HANDLING AREA TIME CHART (NORTH-PWR)

ACTIVITY NO.	EQUIPMENT/OPERATION DESCRIPTION	TRUCK CASK TIME	RAIL CASK TIME
	EQUIPMENT:		
	150 TON CRANE		
	40 TON CRANE		
	CASK CART 1A (TRUCK)		
	CASK CART 1B (RAIL)		
	CASK CART 3A (TRUCK)		
	CASK CART 3B (RAIL)		
	OPERATION:		
8	Remove personnel barriers from vehicle	25	30
9	Remove impact limiters & shipping rest.	25	30
10	Perform contamination survey on cask	20	30
11	Attach grapple & remove cask from veh.	15	15
12	Place cask on cask cart & install rest.	20	20
13	Move cask to Cask handling and Decon Room	10	10
14	Remove outer cask lid	30	30
15	Take gas sample from cask interior-check cask internal pressure - vent or purge if required to controlled vent system	30	45
16	Loosen inner cask cover bolts	20	30
17	Install contamination barrier adapter	5	10
18	Move cask into Unloading Room, engage contamination barrier, close shadow shield and close shield door	20	20
19	Remove cell entry port plugs	20	20
20	Remove cask inner closure	15	20
21	Confirm contents of cask	5	10
22	Unload contents of cask PWR SFA-20 min ea	40	240
23	Inspect cask cover seal & replace if req.	20	25
24	Replace inner cask cover	15	30
25	Replace entry shield port plugs	15	15
26	Open shadow shield & shield door-disengage contamination barrier-move cask to Decon room	20	20
27	Remove contamination barrier	5	10
28	Survey for radiation/contamination	30	40
29	Decon if necessary & replace outer cover	90	105
30	Move cask to Receiving and Handling area	10	10
31	Move cask from cart to transport vehicle & remove lifting yoke	25	25
32	Install cask tie downs,impact limiters, personnel barriers,etc	45	60
33	Move cask & trans. veh. to dispatch area	15	15
34	Discharge empty cask/vehicle through gate	15	15

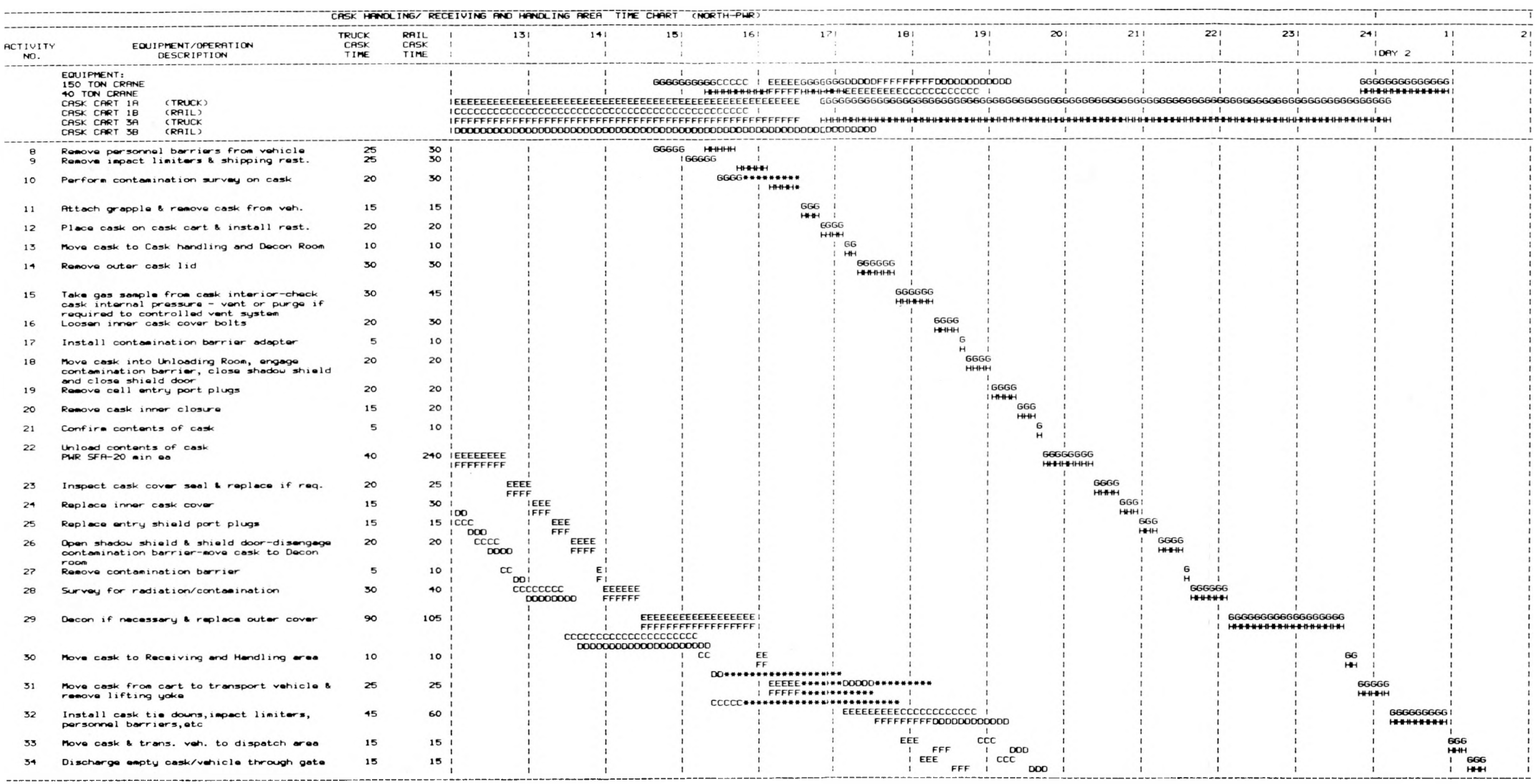


RAIL CASK (C,D) TRUCK CASK (A,B,E,F,G,H) WAIT PERIOD (*)

Table 4-4A (Contd)

CASK HANDLING/ RECEIVING AND HANDLING AREA TIME CHART (NORTH-PWR)

ACTIVITY NO.	EQUIPMENT/OPERATION DESCRIPTION	TRUCK CASK TIME	RAIL CASK TIME
	EQUIPMENT: 150 TON CRANE 40 TON CRANE CASK CART 1A (TRUCK) CASK CART 1B (RAIL) CASK CART 3A (TRUCK CASK CART 3B (RAIL)		
8	Remove personnel barriers from vehicle	25	30
9	Remove impact limiters & shipping rest.	25	30
10	Perform contamination survey on cask	20	30
11	Attach grapple & remove cask from veh.	15	15
12	Place cask on cask cart & install rest.	20	20
13	Move cask to Cask handling and Decon Room	10	10
14	Remove outer cask lid	30	30
15	Take gas sample from cask interior-check cask internal pressure - vent or purge if required to controlled vent system	30	45
16	Loosen inner cask cover bolts	20	30
17	Install contamination barrier adapter	5	10
18	Move cask into Unloading Room, engage contamination barrier, close shadow shield and close shield door	20	20
19	Remove cell entry port plugs	20	20
20	Remove cask inner closure	15	20
21	Confirm contents of cask	5	10
22	Unload contents of cask PWR SFA-20 min ea	40	240
23	Inspect cask cover seal & replace if req.	20	25
24	Replace inner cask cover	15	30
25	Replace entry shield port plugs	15	15
26	Open shadow shield & shield door-disengage contamination barrier-move cask to Decon room	20	20
27	Remove contamination barrier	5	10
28	Survey for radiation/contamination	30	40
29	Decon if necessary & replace outer cover	90	105
30	Move cask to Receiving and Handling area	10	10
31	Move cask from cart to transport vehicle & remove lifting yoke	25	25
32	Install cask tie downs,impact limiters, personnel barriers,etc	45	60
33	Move cask & trans. veh. to dispatch area	15	15
34	Discharge empty cask/vehicle through gate	15	15



RAIL(C,D) TRUCK(A,B,E,F,G,H) WAIT PERIOD(*)

Table 4-4B

Estimated Cask Receiving and Inspection Area Time Schedule for BWR Spent Fuel

CASK HANDLING/ RECEIVING AND HANDLING AREA TIME CHART (SOUTH-BWR)

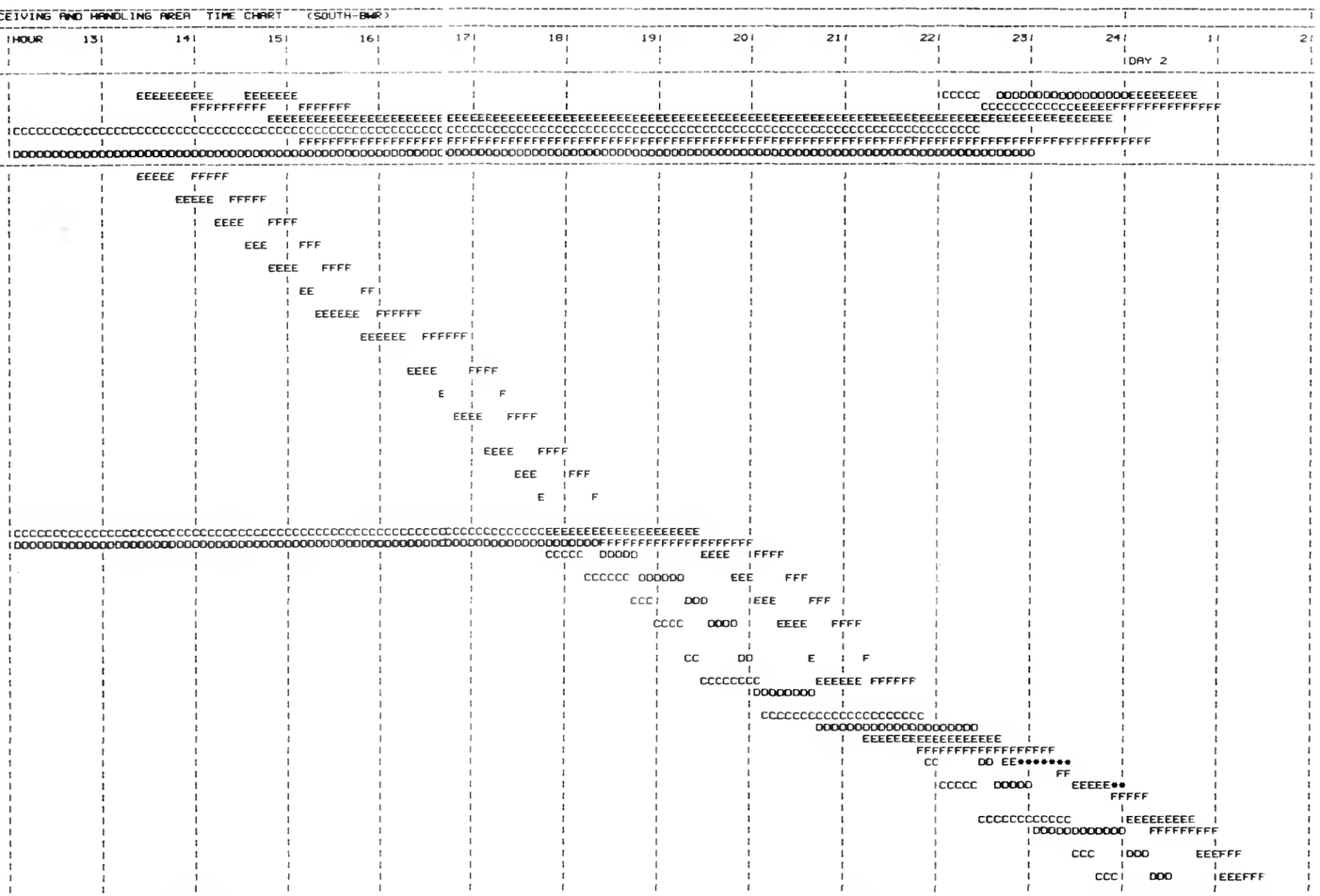
ACTIVITY NO.	EQUIPMENT/OPERATION DESCRIPTION	TRUCK CASK TIME	RAIL CASK TIME
	HOUR		
	DAY 1		
	EQUIPMENT:		
	150 TON CRANE		
	40 TON CRANE		
	CASK CART 2A (TRUCK)		
	CASK CART 2B (RAIL)		
	CASK CART 4A (TRUCK)		
	CASK CART 4B (RAIL)		
	OPERATION:		
8	Remove personnel barriers from vehicle	25	30
9	Remove impact limiters & shipping rest.	25	30
10	Perform contamination survey on cask	20	30
11	Attach grapple & remove cask from veh.	15	15
12	Place cask on cask cart & install rest.	20	20
13	Move cask to Cask handling and Decon Room	10	10
14	Remove outer cask lid	30	30
15	Take gas sample from cask interior-check cask internal pressure - vent or purge if required to controlled vent system	30	45
16	Loosen inner cask cover bolts	20	30
17	Install contamination barrier adapter	5	10
18	Move cask into Unloading Room, engage contamination barrier, close shadow shield and close shield door	20	20
19	Remove cell entry port plugs	20	20
20	Remove cask inner closure	15	20
21	Confirm contents of cask	5	10
22	Unload contents of cask BWR SFA-20 min ea	100	640
23	Inspect cask cover seal & replace if req.	20	25
24	Replace inner cask cover	15	30
25	Replace entry shield port plugs	15	15
26	Open shadow shield & shield door-disengage contamination barrier-move cask to Decon room	20	20
27	Remove contamination barrier	5	10
28	Survey for radiation/contamination	30	40
29	Decon if necessary & replace outer cover	90	105
30	Move cask to Receiving and Handling area	10	10
31	Move cask from cart to transport vehicle & remove lifting yoke	25	25
32	Install cask tie downs, impact limiters, personnel barriers, etc	45	60
33	Move cask & trans. veh. to dispatch area	15	15
34	Discharge empty cask/vehicle through gate	15	15

RAIL CASK (C,D) TRUCK CASK (A,B,E,F,G,H) WAIT PERIOD (*)

Table 4-4B (Contd)

CASK HANDLING/ RECEIVING AND HANDLING AREA TIME CHART (SOUTH-BWR)

ACTIVITY NO.	EQUIPMENT/OPERATION DESCRIPTION	TRUCK CASK TIME	RAIL CASK TIME
	EQUIPMENT: 150 TON CRANE 40 TON CRANE CASK CART 2A (TRUCK) CASK CART 2B (RAIL) CASK CART 4A (TRUCK) CASK CART 4B (RAIL)		
8	Remove personnal barriers from vehicle	25	30
9	Remove impact limitars & shipping rest.	25	30
10	Perform contamination survey on cask	20	30
11	Attach grapple & remove cask from veh.	15	15
12	Place cask on cask cart & install rest.	20	20
13	Move cask to Cask handling and Decon Room	10	10
14	Remove outer cask lid	30	30
15	Take gas sample from cask interior-check cask internal pressure - vent or purge if required to controlled vent system	30	45
16	Loosen inner cask cover bolts	20	30
17	Install contamination barrier adapter	5	10
18	Move cask into Unloading Room, engage contamination barrier, close shadow shield and close shield door	20	20
19	Remove cell entry port plugs	20	20
20	Remove cask inner closure	15	20
21	Confirm contents of cask	5	10
22	Unload contents of cask BWR SFA-20 min ea	100	640
23	Inspect cask cover seal & replace if req.	20	25
24	Replace inner cask cover	15	30
25	Replace entry shield port plugs	15	15
26	Open shadow shield & shield door-disengage contamination barrier-move cask to Decon room	20	20
27	Remove contamination barrier	5	10
28	Survey for radiation/contamination	30	40
29	Decon if necessary & replace outer cover	90	105
30	Move cask to Receiving and Handling area	10	10
31	Move cask from cart to transport vehicle & remove lifting yoke	25	25
32	Install cask tie downs,impact limiters, personnel barriers,etc	45	60
33	Move cask & trans. veh. to dispatch area	15	15
34	Discharge empty cask/vehicle through gate	15	15



RAIL(C,D) TRUCK(A,B,E,F,G,H) WAIT PERIOD(*)

This discussion indicates that, for the design basis, an initial spent-fuel receipt rate of 3,600 MTU/yr can be accommodated by using four processing cells, provided that each cell is serviced by two shipping cask carts and two inlet ports. It is also assumed that at least one 150-ton overhead crane and one 40-ton mobile crane are used to service a single receiving and inspection bay containing only two spent-fuel processing cells. The current R&H Building reflects this configuration and operational philosophy. If a breakdown or an unanticipated event were to occur in any of the processing cells, a redistribution of fuel processing and higher cell use values, with a minimum of downtime, would be required to meet the annual throughput requirements.

Table 4-4C - Comparison of Measured and Estimated Cask-Handling Times for BWR Spent Fuel in R&H Building Critical-Path Operations

Task Description	TN-9[a]		MRS	
	Section No.	Time (min)	Activity No.	Time (min)
Prepare cask for unloading	6.13 - 6.37	40	10 - 11	35
Move to unloading station	6.38 - 6.52	30	12 - 21	155
Unload fuel from cask	6.53	70[b]	22	100[c]
Move cask to decon room	6.54 - 6.62	30	23 - 26	70
Drain, dry, and test	6.63 - 6.74	90	Not applicable	
Prepare for shipment	6.75 - 6.86	180	27 - 31	160
Total Times		440		520

[a]Reference 1.
[b]10 minutes per assembly.
[c]20 minutes per assembly.

It is expected that, for the base-case design, in addition to spent fuel, approximately 60 canisters of vitrified HLW will be received annually at the MRS Facility. The HLW canisters will be processed through Shielded Canyon Cell 6 to avoid interruption of spent-fuel processing. Processing of the HLW canisters would include visual inspection, contamination survey, decontamination (if necessary), and possibly overpacking in the unlikely event that severe damage to the canister is detected. Shielded Canyon Cell 6 is equipped to process the HLW canisters, which have a larger diameter than that of the spent-fuel storage canisters.

In addition to the receipt rate of 3,600 MTU/yr to the MRS Facility, an offsite shipping rate of 3,600 MTU/yr must occur concurrently. This concurrent shipping rate is performed by placing canisters of consolidated fuel into an RO capable of holding four 12.75-in.-dia canisters. Repository overpack processing can be performed in the eastern end of each of Shielded Canyon Cells 5 and 6. Each of these shielded canyon cells contains a single entry port for receiving, unloading, and discharging the RO and its appropriate shipping cask. The north receiving and inspection area services two shielded process cells (1 and 3), as well as Shielded Canyon Cell 5. The south receiving and inspection area services Shielded Process Cells 2 and 4, as well as Shielded Canyon Cell 6. Both Shielded Canyon Cells 5 and 6 contain the same welding and decontamination equipment to process the RO on a singular basis. A single cask cart is used to service the single RO entry port. Table 4-5 lists the operational activities and estimated times for the RO receipt, unloading, and processing, as well as the shipping cask for the RO loading and discharge. Because of receiving and inspection area crane height restrictions, the SCFRO must be transferred and positioned under the RO entry port for receipt of the completed RO as a parallel operation to RO processing.

The RO is brought into the shielded canyon cell via the cask cart and RO cask adapter. The RO cask adapter provides lateral support for the RO, and also provides a contamination barrier. Once inside the canyon cell, the RO cask adapter is removed; the SCFRO is placed onto the cask cart, and positioned beneath the entry port. These cask handling activities are defined in Table 4-5 as Repository Overpack Parallel Operations (Activities 350 through 360). The critical-path time for the receipt, unloading, processing of the RO, and discharge of the SCFRO is 745 minutes (12 hr 25 min). This value includes a 75-min delay caused by the handling time required for the SCFRO. This critical-path time represents a cell required availability of 51.7% of the total operational time of 24 hr. The annual RO processing requirement is 667, using all consolidated spent fuel. Distributing this processing requirement between the two shielded canyon cells (5 and 6), only 0.913 RO must be processed each day. Using an integral number of 1 RO/day, a required cell availability of 51.7% of the operational time is required. This critical-path time exceeds the 50% overall efficiency, but does not appear to cause a problem. Based on this evaluation, the design basis receipt, processing, and discharge of the RO at a rate of 3,600 MTY/yr can be accommodated by using two

Table 4-5 - Estimated Process Times for Repository Overpack and Shipping Cask for Repository Overpack

REPOSITORY OVERPACK (RO)/ SHIPPING CASK FOR REPOSITORY OVERPACK (SCFRO)
OPERATIONS IN SHIELDED CANYON CELL
(All time in minutes)

ACTIVITY NO.	OPERATION DESCRIPTION	OPERATION TIME RO	SCFRO
301	RO/SCFRO inspection at gate	5	5
302	Move RO/SCFRO/vehicle to protect. area	15	15
303	Check BOL to determine contents	10	10
304	Survey SCFRO/vehicle for radiation	0	45
305	Move RO/SCFRO/vehicle to washdown area	15	15
306	Remove road dirt for RO/SCFRO/vehicle	45	45
307	Move RO/SCFRO/veh. to cask handling area	20	20
308	Remove personnel barriers from vehicle	0	30
309	Remove impact limiters and shipping rest.	30	30
310	Perform contamination survey on SCFRO	0	30
SUBTOTAL		140	245
311	Place RO cask adapter on cask cart	20	
312	Attach grapple & remove RO from transporter	15	
313	Place RO on cask cart, install restraints, and RO lid	30	
314	Move RO to Cask Handling and Decon Room	10	
315	Install contamination barrier adapter on RO cask cart adapter	10	
316	Move RO into Unloading Room, engage contamination barrier, close shadow shield and close shield door	20	
317	Remove cell entry port plug	20	
318	Unload overpack with lid and place into weld/decon station	20	
319	Exchange grapple, remove RO lid, and place on floor	10	
320	Exchange grapple and replace cell entry port plug to permit preparations for SCFRO	25	
SUBTOTAL		180	0
321	Load consolidated fuel canisters in RO 20 min/SF canister	80	
322	Insert RO lid in place and rotate welding head into position for weld	20	
323	Weld RO lid via electron beam process and disengage weld head from RO	60	
324	Perform visual inspection on welded RO	10	
SUBTOTAL		170	0
SUBTOTAL	(Maximum of 321-324 or 350-360)	245	145

Table 4-5 (Contd)

REPOSITORY OVERPACK PARALLEL OPERATIONS (All time in minutes)

PARALLEL ACTIVITY	PARALLEL OPERATION DESCRIPTION	OPERATION TIME	SCFRO
350	Open shadow shield and shield door, disengage contamination barrier, move cask cart with empty RO cask adapter to Cask Handling and Decon Room (after activity 320)	20	
351	Remove the contamination barrier adapter from the RO cask adapter	10	
352	Survey for contamination and decon if necessary	40	
353	Move cask cart to Receiving and Inspection area	10	
354	Remove RO cask adapter from cask cart and place in set-down area	15	
355	Exchange 150-ton grapple for shipping cask yoke	5	
356	Engage SCFRO, rotate to vertical, place on cask cart, and secure restraints (SCFRO prepared from activity 310)	35	35
357	Move cask cart/SCFRO into Cask Handling and Decon Room, close door, and install contamination control barrier adapter	20	20
358	Remove outer lid of SCFRO and remove all but four bolts of inner lid	30	30
359	Move SCFRO in Unloading Room, engage contamination barrier, close shadow shield and close shield doors	20	20
360	Remove cell entry port plugs, unbolt inner lid fasteners, and lift lid into cell	40	40
TOTAL		245	145

Table 4-5 (Contd)

REPOSITORY OVERPACK (RO)/ SHIPPING CASK FOR REPOSITORY OVERPACK (SCFRO) OPERATIONS IN SHIELDED CANYON CELL

(All time in minutes)

ACTIVITY NO.	OPERATION DESCRIPTION	OPERATION TIME RO	SCFRO
325	Engage RO pintle grapple and lift completed RO into SCFRO (SCFRO prepared and ready from from activity 360)	25	25
326	Exchange grapple, replace inner lid of SCFRO, tighten bolts, and replace entry port plug	80	80
327	Open shadow shield, shield door, disengage contamination barrier and move cask cart with full SCFRO to Cask Handling and Decon Room	20	20
328	Complete SCFRO closure installation, remove barrier adapter, survey for contamination, decon if necessary	150	150
329	Move cask cart to Receiving and Inspection area	10	10
330	Remove full SCFRO from cask cart, place SCFRO on transport vehicle, and remove lifting yoke	35	35
331	Install cask tie down impact limiters, personnel barriers, etc.	60	60
332	Complete preparations for release of full SCFRO and transporter from Receiving and Handling building	30	30
SUBTOTAL		410	410
TOTAL (CRITICAL PATH ITEMS 311-330)		745	465
TOTAL (NON-CRITICAL PATH ITEMS)		230	230
TOTAL		975	695

SUMMARY OPERATIONS DESCRIPTION	REPOSITORY OVERPACK (RO) OPERATION (TOTAL MIN)	(HR) & (MIN)
A. Tasks not on Critical Path	230	3 50
B. Tasks on Critical Path	745	12 25
C. Total	975	16 15

	SHIPPING CASK FOR REPOSITORY OVERPACK (SCFRO) OPERATION					
	OPERATION			PARALLEL OPERATION		
	(TOTAL MIN)	(HR) & (MIN)		(TOTAL MIN)	(HR) & (MIN)	
A. Tasks not on Critical Path	230	3	50			
B. Tasks on Critical Path	465	7	45			
C. Total	695	11	35	245	4	5

shielded canyon cells, provided that each cell is serviced by one cask cart and one entry port. If a breakdown or an unanticipated event were to occur in either of the two shielded canyon cells, the discharge shipping rate of RO could not be met.

The canisters of consolidated spent fuel used to fill the RO are supplied by any one of three areas or a combination of these areas:

(1) Directly from spent-fuel processing upender.

(2) In-building vault lag storage.

(3) Onsite storage as retrieved and returned to the R&H Building from sealed storage casks or drywells.

Retrieval and return to the R&H Building would be accomplished through Shielded Canyon Cells 5 and 6. The canisters and/or drum would be loaded into the shielded canyon cell via the discharge port located in each of the canyon cells. The waste forms would be inspected, repaired, processed, and placed into vault lag storage or placed into the RO for processing. This would not affect the spent-fuel consolidation process. For decommissioning, the shielded canyon cells would be used primarily; however, the other shielded process cells (1 through 4) could be used under special provisions.

4.2 IN-CELL PROCESSING TIME REQUIREMENTS

Table 4-6 lists estimated times for consolidation of PWR and BWR fuel assemblies in the processing cells. Details of the consolidation process for both PWR and BWR fuels are shown in Tables 4-7 and 4-8. The processing times for consolidation of PWR and BWR represent the minimum uninterrupted time required to load, disassemble, consolidate, and push the spent-fuel bundle into the storage canister. The large incoming lag storage area in each of Shielded Process Cells 1 through 4 provides a large buffer supply to create steady-state processing of spent fuel. This allows the operators either to draw from lag storage or to draw directly from the incoming shipping cask. Provided that lag storage is filled to a sizable capacity and the delivery schedule is maintained, the spent-fuel processing can operate at a steady-state rate and can be independent of the delivery rate.

During the spent-fuel processing, nonfuel-bearing waste (nozzles, grids, water tubes, thimble tubes, and support springs) is removed from the downender table clamping module. During the disassembly of BWR spent fuel, it has been assumed that BWR assemblies arrive at the MRS Facility without flow channels. Since the Functinal Design Criteria (Rev. 3) and the Basis for Design (Rev. 0) do not indicate a quantitative number of BWR assemblies that would arrive with flow channels, no time was included on Table 4-8 for removal of the BWR flow channel. This nonfuel-bearing waste is either volume-reduced or placed directly into 55-gal drums for storage. A disassembly robot, mounted on a powered transverse track, is capable of removing the small amounts of nonfuel-bearing waste and placing them into the appropriate volume-reduction unit (shredder) chutes. Here, the PWR

Table 4-6 - Estimated Process Times for Fuel Rod Consolidation

Procedure	Time			
	PWR[a]		BWR[a]	
	Hr	Min	Hr	Min
Verify fuel, load, and secure assemblies (if fuel assemblies are in lag storage)	2	0	4	30
Disassemble fuel	-	36	1	42
Consolidate fuel rods	-	42	-	48
Load fuel rods into canister	-	15	-	15
Total[b]	3	33	7	15

[a]Process times are based on consolidating and loading fuel rods from three PWR fuel assemblies or seven BWR fuel assemblies into a storage canister.

[b]These total time values are based on the series operations (activities 36 through 46 for PWR processing and activities 401 through 416 for BWR processing) defined on Table 4-7 and 4-8, respectively.

skeletons, water tubes, grids, and support springs are volume-reduced by a low-speed shredding operation. This nonfuel-bearing waste processing and the clean drum processing are performed in parallel with the spent-fuel processing. The clean drum processing occurs in special cells (defined as decontamination cells) located between Shielded Process Cells 1 and 3, and subsequently between Cells 2 and 4. The parallel operations relative to the spent-fuel processing and the nonfuel-bearing waste processing are shown in Tables 4-7 and 4-8. These tables also relate the amount of time the cell equipment is being used during specific processing operations. Other equipment is listed in these tables that is not directly used during the processing operation. This equipment is included for a maintenance operation evaluation to be performed at a later date.

Table 4-9 lists estimated times for packaging of the spent fuel, inspection and decontamination of the storage canister, and placement of the canister into the vault lag storage, into RO, or into a sealed storage cask. For the drywell storage concept, the canister is loaded either into the vault lag storage or directly into the transfer shield. Table 4-10 provides a summary table of the spent-fuel rod consolidation and packaging processes. These process time estimates are applicable to both PWR and BWR spent-fuel rod canisterization. The critical-path activities begin with the loading of the consolidated bundle into the canister, and end with the unloading of the sealed canister into an appropriate storage arrangement. These processing activities are based on minimum time required and uninterrupted supply of the welder and inspection stations. These activities all occur in Shielded Canyon Cells 5 and 6 for the PWR and BWR processing, respectively. Two upenders are used in conjunction with each welder, ultrasonic inspection station, and lid cutoff station. This same configuration is used at each of the canister welding stations located in the western ends of each of Shielded Canyon Cells 5 and 6. The east upender has the capability to transfer an open-ended canister into the weld/decontamination chamber while the west upender is parked against the west wall. This allows access to a single welder with two upenders on the same track. Because only one welder is used to service two spent-fuel processing cells, sequencing of both the spent-fuel process and the canister welding and inspection processes is required. This sequencing of operations is critical to meet the cell throughput within the operational time limits. The process times from Tables 4-7, 4-8, and 4-9 were used to develop the time-line diagrams shown in Figures 4-1 and 4-2. Figure 4-1 shows the PWR cyclic production rate achievable when the shielded process cells are operated as a steady-state operation without supply interruptions. The cyclic production rate for PWR storage canisters is, on the average, 5 hr and 8 min. For BWR storage canisters, the cyclic production rate is 7 hr and 15 min. The cyclic operation sequence for BWR processing is shown in Figure 4-2. These times represent the time required for an entire cycle from start of disassembly to the time the disassembly sequence is repeated.

As shown in Figure 4-1, the PWR canister production rates are limited by the consolidation and welding process, whereas BWR canister production rates are limited by the consolidation process times plus time for loading fuel assemblies into the disassembly upender.

Table 4-7
Detailed Estimated Processing Times
for PWR Fuel Rod Consolidation

SHIELDED PROCESS CELL 1 OR CELL 3 OPERATIONS FOR PWR SPENT FUEL (All time in minutes)

ACTIVITY NO.	OPERATION DESCRIPTION	OPERATION TIME	CELL CRANE	DISASSY/ LASER	DISASSY/ ROBOT	CONSOLI-DATION	INTACT UPENDER	MAINT. HATCH	WALL MANIPUL.	SHREDDER	DRUM LID STATION	DRUM XFER CART	DRUM PROCESSING AREA						
													CLEAN DRUM ELEV.	CLEAN DRUM PUSHER	DRUM XFER JIB CRANE	DECON CELL CRANE	DRUM DECON STATION	DRUM SWIPE STATION	DRUM XFER PALLET
36	Visually verify fuel type	30	30																
37	Secure Assy. No. 1 on downender	30	30	30															
38	Sever top nozzle using I.D. Laser cutter and place top nozzle into shredder chute	12		12															
39	Repeat activities 37 thru 38 twice	84	60	84															
40	Grip all fuel rods on 3 assemblies	6		6		6													
41	Extract all fuel rods & install combs	6		6		6													
42	Rotate horizontal combs out of position	6		6		6													
43	Lower fuel rods into semi-circular rod configuration structure	6				6													
44	Return carriage to push position	6				6													
45	Lower upper die into position for push	12				12													
46	Push consolidated bundle into storage canister through seal valve	15				15													
TOTAL		213	120	144	0	57													

SHIELDED PROCESS CELL 1 OR CELL 3 OPERATIONS FOR PWR SPENT FUEL (PARALLEL OPERATIONS)

PARALLEL ACTIVITY	PARALLEL OPERATION DESCRIPTION	OPERATION TIME	CELL CRANE	DISASSY/ LASER	DISASSY/ ROBOT	CONSOLI-DATION	INTACT UPENDER	MAINT. HATCH	WALL MANIPUL.	SHREDDER	DRUM LID STATION	DRUM XFER CART	DRUM PROCESSING AREA						
													CLEAN DRUM ELEV.	CLEAN DRUM PUSHER	DRUM XFER JIB CRANE	DECON CELL CRANE	DRUM DECON STATION	DRUM SWIPE STATION	DRUM XFER PALLET
41A	Sever bottom nozzles of 3 assys	36		36															
41B	Collect 3 bottom nozzles and place in Shredder nozzle chute	12		12	12														
SUBTOTAL		48	0	48	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
51	Place clean drum on elev. platform & exit	5											5						
52	Open shield door & lift drum to 34 ft elev.	3											3	3					
53	Push drum into position & reposition outer most drum for grappling	1											1	1					
54	Return drum elev. to bottom position & close shield door	3											3	3					
55	Rotate jib crane/grapple & place drum onto translation cart	2								2					2				
56	Move cart into consolidation cell	1								1	1								
57	Remove drum lid at lidding station	1								1	1								
58	Position cart under shredder & engage discharge hopper of shredder	1						1		1									
SUBTOTAL		17	0	0	0	0	0	0	0	1	2	5	12	7	2	0	0	0	0
59	Feed MFBH into shredder and volume reduce Place Top nozzles into bypass chute Place Bottom nozzles into bypass chute Place thimble tubes w/ grids into shredder	40						40	40	40									
60	Transfer filled drum to lidding station	1						1	1	1									
61	Crimp lid & transfer back into decon cell	6							6	6						6			
62	Place empty drum pallet on decon cell flr.	4								4						4			
63	Change grapple & lift filled drum onto decon cell floor and accumulate 5 drums	4														4			
SUBTOTAL		55	0	0	0	0	0	0	0	41	47	51	0	0	0	14	0	0	0
64	Place filled drum into decon station and decon w/freon and air dry	24															24		
65	Lift & rotate drum while swiping with dedicated swipe arm	8																8	
66	Deposit swipe into swipe transfer system & count sample	5														5		5	
67	Transfer drum onto empty drum pallet	3																	3
68	Repeat activities 64 to 67 until pallet is full	160															96	52	12
69	Exchange grapple & place filled pallet on transfer cart	5																	5
70	Open shield door & move cart into Canyon Cell elevated platform	6																	6
TOTAL		331	0	48	12	0	0	0	0	42	49	56	12	7	2	19	120	65	26

Table 4-8
Detailed Estimated Processing Times
for BWR Fuel Rod Consolidation

SHIELDED PROCESS CELL 2 OR CELL 4 OPERATIONS FOR BWR SPENT FUEL (All time in minutes)

ACTIVITY NO.	OPERATION DESCRIPTION	OPERATION TIME	CELL CRANE	DISASSY/ LASER	DISASSY/ ROBOT	CONSOLI- DATION	INTACT UPENDER	MAINT. HOIST	WALL MANIPUL.	SHREDDER	DRUM LID STATION	DRUM XFER CART	DRUM PROCESSING AREA: CLEAN DRUM ELEV.	CLEAN DRUM PUSHER	DRUM XFER JIB CRANE	DECON CELL CRANE	DRUM DECON STATION	DRUM SWIPE STATION	DRUM XFER PALLET
401	Visually verify fuel type	60	60																
402	Secure Assy. No. 1 on downender	30	30	30															
403	Sever top nozzle using I.D. Laser cutter	6		6															
404	Repeat activities 402 thru 403 six times	216	180	216															
405	Remove seven top nozzles for disposal	18		18	18														
406	Remove and collect springs	12		12															
407	Rotate capture rod	12		12															
408	Grip all elements except 8 tie rods/assembl	12		12		12													
409	Extract rods approximately 3 inch	6		6		6													
410	Grip remaining tie rods	12		12		12													
411	Extract all fuel rods and insert horizontal and vertical combs	6		6		6													
412	Rotate horizontal combs out of position	6		6		6													
413	Lower fuel rods into semi-circular rod configuration structure	6				6													
414	Return carriage to push position	6				6													
415	Lower upper die into position for push	12				12													
416	Push consolidated bundle into storage canister through seal valve	15				15													
TOTAL		435	270	336	18	81													

SHIELDED PROCESS CELL 2 OR CELL 4 OPERATIONS FOR BWR SPENT FUEL (PARALLEL OPERATIONS)

PARALLEL ACTIVITY	PARALLEL OPERATION DESCRIPTION	OPERATION TIME	CELL CRANE	DISASSY/ LASER	DISASSY/ ROBOT	CONSOLI- DATION	INTACT UPENDER	MAINT. HOIST	WALL MANIPUL.	SHREDDER	DRUM LID STATION	DRUM XFER CART	DRUM PROCESSING AREA: CLEAN DRUM ELEV.	CLEAN DRUM PUSHER	DRUM XFER JIB CRANE	DECON CELL CRANE	DRUM DECON STATION	DRUM SWIPE STATION	DRUM XFER PALLET
409A	Sever bottom nozzles of 7 assys	48		48															
409B	Collect 7 bottom nozzles and place in Shredder nozzle chute	18		18	18														
SUBTOTAL		66	0	66	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
421	Place clean drum on elev. platform & exit	5											5						
422	Open shield door & lift drum to 34 ft elev.	3											3	3					
423	Push drum into position & reposition outer most drum for grappling	1											1	1					
424	Return drum elev. to bottom position & close shield door	3											3	3					
425	Rotate jib crane/grapple & place drum onto translation cart	2										2			2				
426	Move cart into consolidation cell	1									1	1							
427	Remove drum lid at lidding station	1									1	1							
428	Position cart under shredder & engage discharge hopper of shredder	1								1		1							
SUBTOTAL		17	0	0	0	0	0	0	0	1	2	5	12	7	2	0	0	0	0
429	Feed NFBW into shredder and volume reduce Place Top nozzles into bypass chute Place Bottom nozzles into bypass chute Place thimble tubes w/ grids into shredder	40								40	40	40							
430	Transfer filled drum to lidding station	1								1	1	1							
431	Crimp lid & transfer back into decon cell	6									6	6				6			
432	Place empty drum pallet on decon cell flr.	4										4				4			
433	Change grapple & lift filled drum onto decon cell floor and accumulate 5 drums	4														4			
SUBTOTAL		55	0	0	0	0	0	0	0	41	47	51	0	0	0	14	0	0	0
434	Place filled drum into decon station and decon w/freon and air dry	24															24		
435	Lift & rotate drum while swiping with dedicated swipe area	8																8	
436	Deposit swipe into swipe transfer system & count sample	5														5		5	
437	Transfer drum onto empty drum pallet	3																	3
438	Repeat activities 434 to 437 until pallet i full	160															96	52	12
439	Exchange grapple & place filled pallet on transfer cart	5																	5
440	Open shield door & move cart into Canyon Cell elevated platform	6																	6
TOTAL		349	0	66	18	0	0	0	0	42	49	56	12	7	2	19	120	65	26

Table 4-9 - Estimated Process Time for Packaging of Spent Fuel

SHIELDED CANYON CELL PACKAGING OPERATIONS FOR SPENT FUEL (All time in minutes)

ACTIVITY NO.	OPERATION DESCRIPTION	OPERATION TIME	WEST CELL CRANE	UPENDER NO. 1	UPENDER NO. 3	CANISTER WELD/DC CHAMBER	MASTER/ SLAVE MANIP.	UT INSPECT STATION	LID CUTTING STATION	CLEAN CANISTER CAROUSEL
100	Index clean canister carousel, raise rack, lift port plug, set down plug, lift canister, place on Upender No. 1, replace plug	30	30	30						30
101	Downend Upender No. 1 (with canister), rotate, translate, and position to receive fuel bundle	15		15						
102	Receive fuel bundle from consolidation process Cell 1 (simultaneously with activity 46 from Cell 1 or Cell 3)	15		15						
103	Retract from position, rotate canister, and translate to welder centerline	15		15		5				
104	Insert canister into chamber, evacuate canister and chamber, backfill with inert gas and weld	20		20		20				
105	Transfer canister into decon chamber, decontaminate, drain chamber and evacuate chamber for leak check	35		35		35				
106	Open air lock, swipe canister while transferring to upender	15		15		15	15			
107	Transfer welded canister to ultrasonic station, inspect and verify weld	45		45				45	45	
108	Retract canister, translate to open position, upend canister and place canister into vault lag storage or repository overpack	15	15	15						
SUBTOTAL (CRITICAL PATH ITEMS 102-108)		160	15	160	0	75	15	45	45	0
TOTAL		205	45	205	0	75	15	45	45	30

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Table 4-10 - Summary of Spent-Fuel Consolidation and Packaging Operations for Both PWR and BWR Assemblies

SUMMARY OPERATIONS DESCRIPTION

SHIELDED PROCESS CELL 1 OR CELL 3 OPERATIONS FOR PWR SPENT FUEL:

	OPERATIONS TIME			PARALLEL OPERATIONS TIME		
	(TOTAL MIN)	(HR) &	(MIN)	(TOTAL MIN)	(HR) &	(MIN)
A. Total	213	3	33	331	5	31

SHIELDED PROCESS CELL 2 OR CELL 4 OPERATIONS FOR BWR SPENT FUEL:

	OPERATIONS TIME			PARALLEL OPERATIONS TIME		
	(TOTAL MIN)	(HR) &	(MIN)	(TOTAL MIN)	(HR) &	(MIN)
A. Total	435	7	15	349	5	49

SHIELDED CANYON CELL CANISTER PACKAGING OPERATIONS FOR PWR OR BWR SPENT FUEL

	(TOTAL MIN)	(HR) &	(MIN)
A. Tasks not on Critical Path	45	0	45
B. Tasks on Critical Path	160	2	40
C. Total	205	3	25

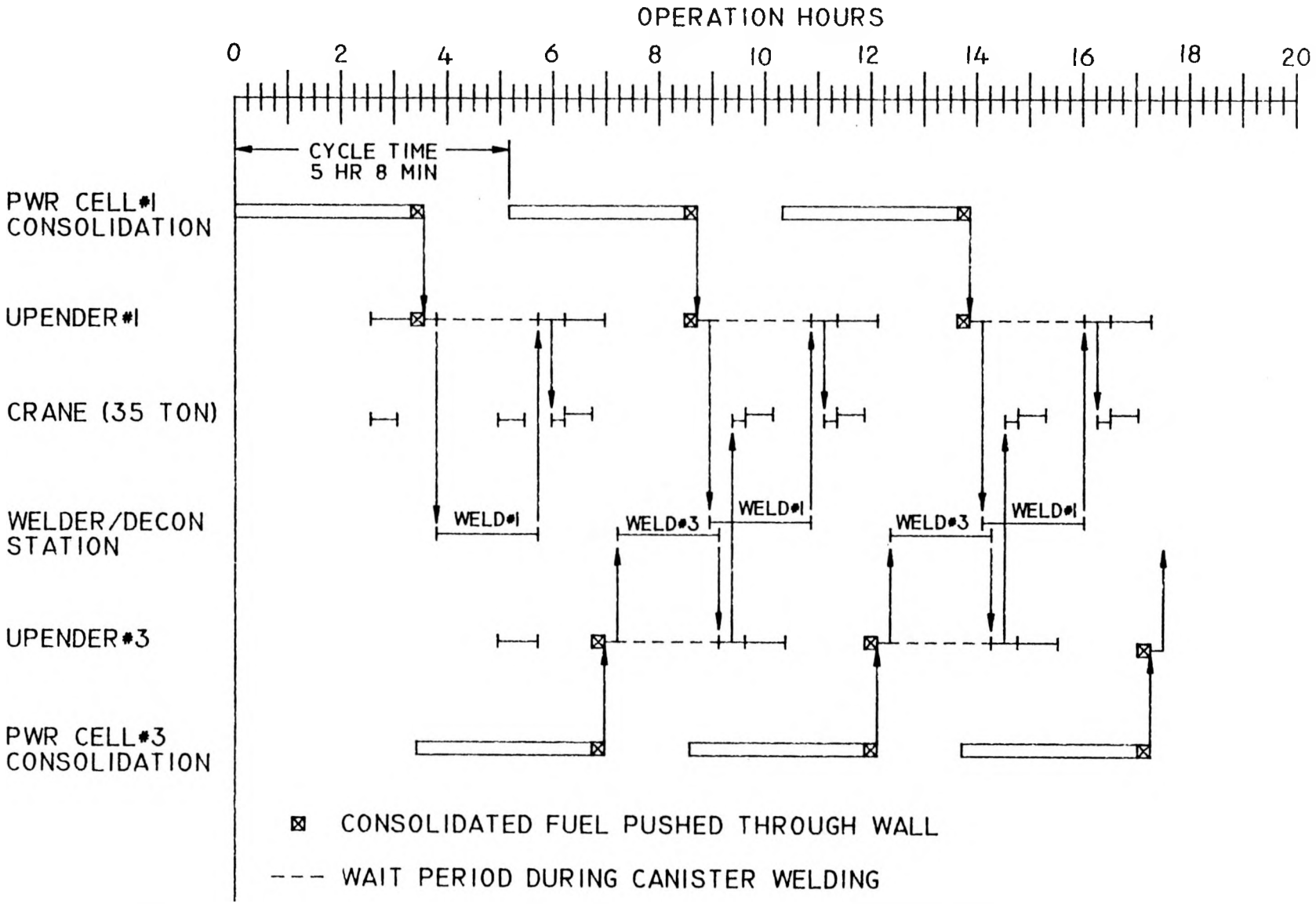

Figure 4-1 - PWR Consolidation and Packaging Process Time Chart

PARSONS

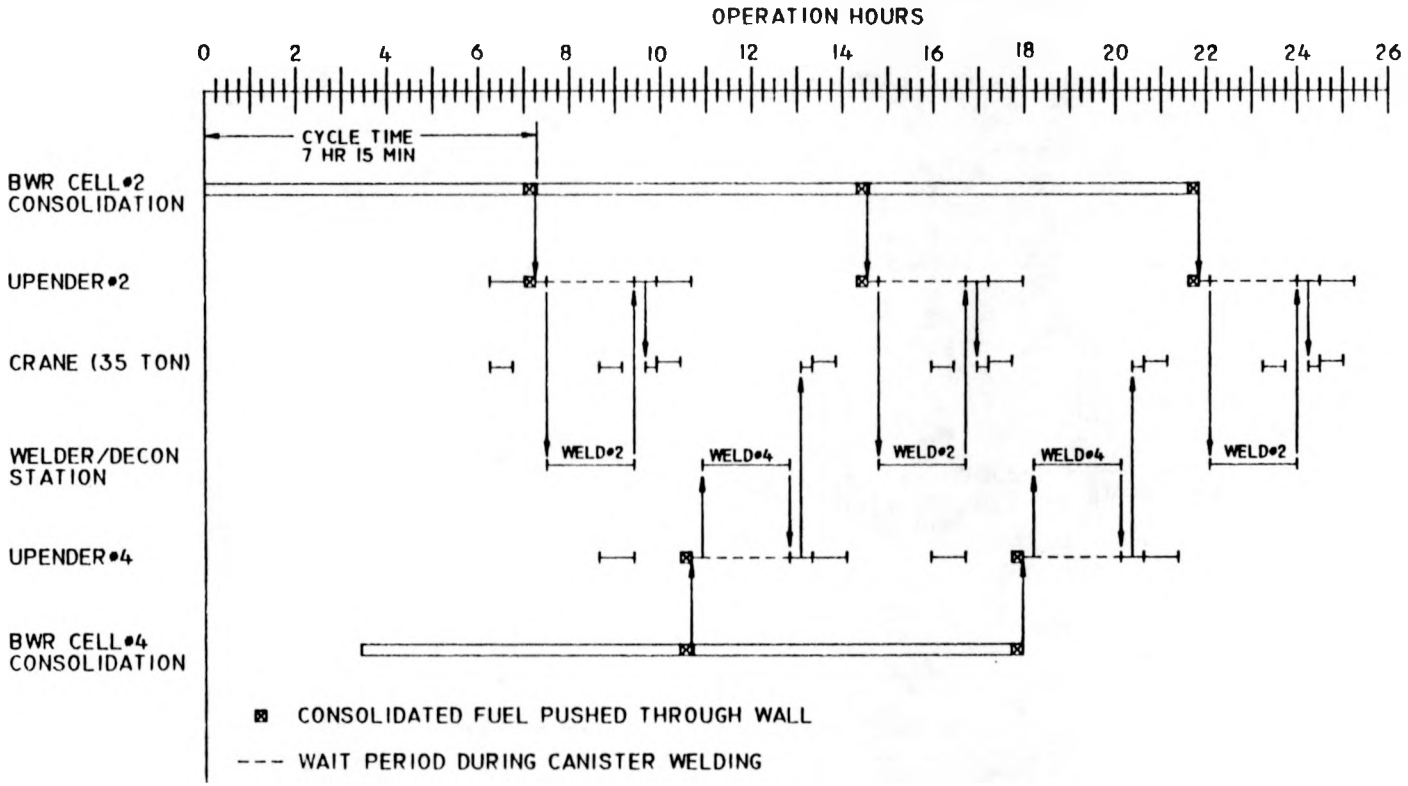

Figure 4-2 - BWR Consolidation and Packaging Process Time Chart

The throughput requirement for the base-case MRS Facility is 3,600 MTU/yr, of which 2,160 MTU (60%) are assumed to be PWR fuel assemblies and 1,440 MTU (40%) are assumed to be BWR fuel assemblies. For this study, it is assumed that all PWR and BWR spent fuel would be received as intact fuel assemblies (no preconsolidation). It is also assumed that all fuel assemblies received would be consolidated except 10% of both PWR and BWR assemblies. These would be processed as intact fuel elements, and placed in canisters. Only this base-case production case was evaluated for this study. This case refers to a 50/50 truck/rail split of spent fuel delivered to the MRS Facility.

4.3 PROCESS CELL EFFICIENCIES

In determining the throughput capacity of the MRS Facility conceptual design, it was assumed that the R&H Building is operational for three 8-hr shifts per day, 365 days per year, or a total of 8,760 hr/yr. This defines a four-shift operation of the R&H Building. The definition of cell efficiency or availability, as used in this study, represents the processing hours as a percentage of total available operating hours (8,760 hr/yr) required to meet the base-case throughput requirements for the facility.

The cyclic canister processing rates developed from Figures 4-1 and 4-2 are used below in discussing the cell efficiencies that must be maintained to achieve the annual 3,600-MTU throughput of spent fuel for the design base case identified in Tables 4-11 and 4-12. These tables reflect the number of canisters produced to meet the throughput. Table 4-11 shows the quantities required if all assemblies can be consolidated. Table 4-12 shows the quantities and cell efficiencies for a processing mixture of 10% intact elements and 90% consolidatable assemblies. This distribution is provided by the Basis for Design (Rev. 3) for the maximum number of canisters processed per year.

For the base case of 3,600 MTU/yr of all spent fuel arriving at a relatively uniform distribution of PWR and BWR assemblies, as defined in Table 4-11, an average shielded process cell efficiency or availability of 54.1% can be achieved. The PWR processing cells require a slightly higher availablity of 55.5% because of the larger quantity of canisters that must be produced. The BWR processing cells have a slightly lower availability of 52.6% mainly because of the faster processing rate for intact spent-fuel elements. Lower required availability is achievable for all four cells if all of the 3,600 MTU of spent fuel can be consolidated. A total of 590 fewer canisters are required if all of the 3,600 MTU of spent fuel can be consolidated.

A reduction in canister production will, in turn, result in lower required cell availabilities. Therefore, the inclusion of processing of intact spent-fuel elements results in a more conservative estimate of the process cell availability or cell efficiency. These values are higher than the general cell efficiency guideline of 50%; however, estimates of possible lost production time, on a per-cell basis, were made as follows:

Table 4-11 - Summary of Annual Receiving and Canister Production Rates for Consolidation of 3,600-MTU/yr Throughput

Cell No.	Fuel Type	Quantity (MTU/yr)	Cask Type	Number of Casks (per yr)	Number of Fuel Assemblies (per yr)	Number of Canisters[a] (per yr)
1	PWR	540.5	Truck	585	1,170	390.0
	PWR	542.4	Rail	98	1,174	391.3
2	BWR	359.9	Rail	387	1,935	276.4
	BWR	362.7	Truck	61	1,950	278.6
3	PWR	539.6	Truck	584	1,168	389.3
	PWR	537.8	Rail	97	1,164	388.0
4	BWR	359.9	Truck	387	1,935	276.4
	BWR	357.1	Rail	60	1,920	274.3
					12,416	2,664.3

[a]This number of canisters represents the quantity of canisters if all assemblies can be consolidated.

Table 4-12 - Summary of MRS Facility Annual Shielded Process Cell Throughput Rates and Cell Efficiencies (for combination of Intact and Consolidated Spent Fuel)

Waste receipt at MRS Facility: 3,600 MTU/yr of spent fuel (SF)
Maximum of 300 canisters of high-level waste (HLW)

(1) PWR spent-fuel assy[a]: 4,676/yr (handled in Process Cells 1 and 3)
PWR truck casks = 1,169/yr PWR rail casks = 195/yr
(2) BWR spent-fuel assy[a]: 7,740/yr (handled in Process Cells 2 and 4)
BWR truck casks = 774/yr BWR rail casks = 121/yr
(3) Spent-fuel processing parameters: Four shielded process cells, two shielded canyon cells
Four canister upenders and two spent-fuel canister welders

Total of 3,600 MTU/yr throughput rate

Cell Production Distribution	Cell 1	Cell 2	Cell 3	Cell 4	Avg of Four Cells
Spent-fuel assys for consolidation	2,106	3,486	2,102	3,479	-
Spent-fuel assys processed as intact	234	388	234	388	-
Canisters of consolidated spent fuel	702	498	701	497	599.5
Processing time for each canister of consolidated spent fuel (in hours)	5.2	7.25	5.2	7.25	-
Canisters of intact fuel	234	194	234	194	214.0
Processing time for each canister of intact spent fuel (in hours)	5.2	5.2	5.2	5.2	-
Total No. of canisters per cell	936	692	935	691	813.5
Required cell availability to meet throughput rate[b]	55.5%	52.6%	55.5%	52.6%	54.1%

Summary of total canisters/yr = 3,254

(4) Repository package: 667 units/yr or 2 per day based on 12 PWR or 28 BWR equivalent assemblies per repository package and 3,600-MTU/yr shipping rate

[a]The PWR/BWR spent-fuel assembly distribution is based on a 60/40 split of spent fuel. The percentages are based on weight of metric tons of uranium (MTU). The spent fuel will be delivered by truck and rail, using a 50/50 split by weight of the spent fuel.
[b]Cell availability represents the percentage of the processing hours required of the total yearly operating hours (8,760 hr/yr) to meet the base throughput rate.

Loss of worker productivity at 1 hr/shift	1,095 hr/yr
Maintenance (scheduled and unscheduled) and minor decontamination at 1.5 days/wk	1,872 hr/yr
Major decontamination at 20 days/yr	480 hr/yr
Tool changeout at 2 days/month	576 hr/yr
Total	4,023 hr/yr

The remaining 4,737 hr, or approximately 54%, are available for fuel processing. The required cell efficiencies for two of the four cells are less than 54%. If PWR fuel processing is shared with either of the two BWR cells, all four cells will meet the required cell efficiency value of 54%.

4.4 STORAGE CANISTER LOADOUT TIME REQUIREMENTS

To assess integration of the production rates in the R&H Building processing cells with those of the storage facilities, estimated times for processing sealed storage casks and for drywell emplacement of canisters or other waste forms are given in Tables 4-13 and 4-14. When the processing rates for consolidated spent-fuel canisters are compared with either the processing times for concrete casks or the emplacement times for drywells, it is apparent that storage operations will not limit throughput of the facility. At the maximum consolidation canister production rate of 5 hr and 8 min, which can be achieved when PWR spent fuel is received in rail casks, it will take at least 62 hr to generate sufficient canisters (12) to fill a sealed storage cask. This can be compared with the critical-time estimate of 5 hr and 25 min required for sealed storage cask processing, transport, and placement.

4.5 WASTE-RETRIEVAL REQUIREMENTS

Throughput rates and equipment use for shipment of waste forms from the MRS Facility to the repository are based on the following assumptions:

(1) Reconfiguration or repackaging of the waste forms is not required before shipment from the MRS Facility.

(2) All offsite shipments from the MRS Facility are to be by rail casks.

  (a) Repository overpack contains four canisters of spent fuel or HLW canisters (nominal 12-in. pipe).
  (b) Other shipping casks are used for larger-diameter waste forms (HAW drums), which have not been defined.

(3) Spent fuel can be shipped through either of the two shielded canyon cells (5 or 6).

Table 4-13 - Estimated Process Times for Sealed Storage Casks

SHIELDED CANYON CELL FIELD OPERATIONS FOR SEALED STORAGE CASK (All time in minutes)

ACTIVITY NO.	OPERATION DESCRIPTION	OPERATION TIME	MONO-RAIL CRANE	CASK XPORTER	WEST CELL CRANE
201	Move cask into unloading room	15		15	
202	Install contamination barrier & shield ring, move into corridor	15	15	15	
203	Remove shield plug, install canisters, install shield plug	300			300
204	Remove contamination barrier & shield ring, move into corridor	20	20	20	
205	Perform contamination survey of cask top	10		10	
206	Remove plug lifting eyes, install cover & welder, set-up welder	20	20	20	
207	Make weld	60		60	
208	Remove welder	5	5	5	
209	Visually inspect weld	10		10	
210	Magnetic particle inspect weld	30		30	
210A	Pressure check cask interior	40		40	
211	Clean weld area & coat	15		15	
212	Move cask to storage area	30		30	
213	Position lifting fixture & lift cask	10		10	
214	Emplace cask & disengage lift fixture	15		15	
214A	Complete thermocouple instrumentation connections (parallel operation to 214)	30			
215	Return cask transporter to Cask Manf. Facility	30		30	
216	Set new cask on transporter & move to Receiving & Handling area	30		30	
SUBTOTAL (CRITICAL PATH ITEMS 201-216 LESS 203&214A)		325	60	325	0
TOTAL (201-216 WHERE 210 & 210A ARE PARALLEL & 214A IS ALSO A PARALLEL OPERATION)		655	60	325	300

Table 4-14 - Estimated Process Times for Drywell Emplacements

Procedure	Time Hr	Time Min
Replace exit port shield plug. - Retract contamination barrier. - Open shadow shield and door. - Prepare transfer cask for transporting to storage area.	-	15
Transport transfer shield (with storage canister) to drywell storage area.	-	20
Align transfer shield with drywell liner; place storage canister in drywell; place shield plug in drywell liner.	-	30
Transport empty transfer shield to R&H Building; load shield plug.	-	25
Position transfer shield under exit port. - Engage contamination barrier. - Close shadow shield and door. - Remove shield plugs from exit port.	-	20
Total	1	50

(4) The large-diameter HLW canisters and 55-gal drums are shipped via the alternative shipping cask.

(5) A total of 10% of the spent-fuel assemblies are stored intact.

(6) Annual retrieval and ship-out rates corresponding to the initial receiving rate of 3,600 MTU/yr are:

(a) 1,403 canisters of consolidated PWR fuel
(b) 468 canisters of intact PWR fuel
(c) 995 canisters of consolidated BWR fuel
(d) 388 canisters of intact BWR fuel
(e) 1,582 drums of nonfuel-bearing components
(f) 60 HLW base-case canisters (for 5 yr)

(7) The contents of approximately 2% of the storage units (sealed storage casks or drywells) require decontamination before shipping.

Estimated processing times for the repository overpack are given in Table 4-5. Estimated times for processing retrieved canisters through the shielded canyon cells are given in Table 4-15. Estimated times for handling sealed storage casks are given in Table 4-16, and estimated times for retrieval from drywells are given in Table 4-17. Operations that can be performed so as not to have an impact on overall retrieval times, such as disconnecting instrumentation and drywell cover removal, are not included. A conservative assumption, made to simplify the sealed storage cask evaluation, was that a single cask transporter is used for each shielded canyon cell. For the drywell evaluation, it was assumed that at least two transfer casks and transfer vehicles would be available, as required.

With the assumptions made for this evaluation and the times given in Tables 4-15 and 4-16, the turnaround time for a sealed storage cask containing spent-fuel canisters is approximately 24.75 hr, including decontamination of 12 canisters, and 14.75 hr with no decontamination.

The required annual ship-out rate is 1,560 canisters of PWR fuel and 1,104 canisters of BWR fuel, for a total of 2,664 canisters. The maximum number of spent-fuel sealed storage casks that would be required to be retrieved annually is 222, of which approximately five are assumed to contain contaminated canisters. The total annual operating time required to retrieve and ship out spent-fuel canisters stored in sealed storage casks is:

$$217 \times 14.75 \text{ hr} + 5 \times 24.75 \text{ hr} = 3{,}325 \text{ hr}$$

The total annual canyon cell operating time required to process retrieved spent-fuel canisters from sealed storage casks is:

$$217 \times 8.333 \text{ hr} + 5 \times 18.333 = 1{,}809 \text{ hr}$$

Table 4-15 - Estimated Times for Processing
Retrieved Canisters
(Spent Fuel and HLW)

Procedure	Time Hr	Time Min
Remove canister from concrete cask or drywell transfer shield; place on Shielded Canyon Cell 6 upender.	-	20
Perform contamination survey of canister.[a]	-	20
Decontaminate canister if required.[a]	-	30
Resurvey canister for contamination.	-	20
Transfer clean canister to in-building lag storage in preparation for repository overpack processing or alternative shipping processing.	-	20
Total	1	50
Total (if decontamination not required)	-	40
Total (if contamination survey indicates canister is clean)	1	00

[a]First canister removed from cask is surveyed for contamination; if contamination is indicated by survey, the canister and all subsequent canisters from the cask are decontaminated. All canisters from drywells are surveyed when removed from the transfer shield.

Total cask (12 canisters) processing time required for all to be decontaminated = 18 hr 20 min.

Total cask (12 canisters) processing time required for all clean canisters = 8 hr 20 min.

Table 4-16 - Estimated Times for Sealed Storage Cask Handling

Procedure	Time Hr	Time Min
Retrieval		
Load cask onto transporter.	-	35
Move cask to R&H Building.	-	30
Prepare cask for unloading.	2	00
Subtotal	3	5
Unloading		
Position cask under exit port.	-	20
- Engage contamination barrier. - Close shadow shield.		
Remove shield plugs from exit port; remove shield plug from cask.	-	20
Unload and decontaminate canisters.	Variable (See text)	
Subtotal (minimum time)	-	40
Discharge		
Replace cask shield plug and exit port shield plugs.	-	20
Open shadow shield and disengage contamination barrier; remove cask from unloading room.	-	15
Prepare cask for temporary storage.	1	00
Transport cask to temporary storage area; remove lifting yoke.	-	30
Place cask onto storage pad.	-	35
Subtotal	2	40
Total	6	25

Table 4-17 - Estimated Times for Retrieval From Drywells

Procedure	Time Hr	Time Min
Align transfer shield with drywell liner; retrieve drywell shield plug; retrieve storage package.	-	30
Transport storage package to R&H Building.	-	20
Position transfer shield under exit port; engage contamination barrier; close shadow shield and door; remove shield plugs from exit port.	-	20
Remove storage package from transfer shield, survey for decontamination, and place onto Shielded Canyon Cell 6 upender.	-	35
Decontaminate canister if required (optional).	-	30
Resurvey canister for contamination if decontaminated.	-	20
Replace exit port shield plugs; disengage contamination barrier; open shadow shield and door; prepare transfer cask for transport to storage area.	-	20
Transport transfer shield to storage area.	-	20
Total	3	10

Total canyon cell operational time required to retrieve and decontaminate canister = 1 hr 45 min.

A total of 3,600 MTU of spent fuel can be retrieved from sealed storage casks and shipped through two shielded canyon cells operating at an efficiency of approximately 10%. The total annual canyon cell operating time required to retrieve 60 HLW canisters per year is approximately 220 hr. Combining all of the annual canyon cell operational times required to retrieve spent fuel and HLW from sealed storage casks gives a total annual operating time of 2,029 hr divided between the two shielded canyon cells (if decontamination is required), requiring a canyon cell operating efficiency of approximately 11.6%.

The shielded canyon cell operational time for retrieval is approximately 1.75 hr per drywell. The annual operational times required for drywell operations are:

Spent fuel	2.664 x 1.75	=	4,662 hr
HLW	60 x 1.75	=	105 hr
	Total =		4,767 hr

Single canyon cell operating efficiency: $\frac{2,224}{8,760} \times 100 =$ 27.2%

The waste retrieval time values are included only for spent fuel and high-level waste because the vehicle for shipment of high-activity waste (HAW) drums has not been defined. These waste retrieval times must be incorporated into the RO loading sequence as defined in Table 4-5. However, the RO may be filled from three possible sources:

(1) Consolidated canisters from canister upender.
(2) Retrieved canisters from sealed storage casks or drywells.
(3) Canisters drawn from the in-building vault lag storage.

This variation in the loading of the RO precludes a quantitative evaluation of the combined retrieval and shipment time interval.

5.0 CONCLUSIONS

The foregoing discussion has shown that the proposed R&H Building, equipped with four shielded process cells and two shielded canyon cells, will satisfy the design basis receiving rate, provided that each cell has two inlet ports and two cask carts. However, spent-fuel shipping situations other than the assumed 50/50 truck/rail split should also be considered. If all shipments were to arrive by rail, there is no doubt that the R&H Building has overcapacity. It is unlikely that this will happen because many utility cranes cannot handle the larger rail casks.

It is probable that more than half of the spent fuel will arrive by truck. Calculations (see Appendix) show that, if the north and south receiving and inspection areas are operated at 58 and 59.1% efficiencies, respectively, the facility can accept the 50/50 truck/rail shipping split; a 75/25 truck/rail split (based on integral number of casks) can be supported at about 76% of capacity.

These percent-of-capacity values for the receiving and inspection area are based on the average of the capacity values defined for each of the two cask carts used to service a single shielded process cell. The use of average-capacity values may provide nonconservative estimates of the facility capacity if these values are used for extrapolation purposes.

The receiving and inspection area cranes percentage-of-usage values for servicing the north receiving and inspection area (PWR) fuel are relatively close to the 50% efficiency limit, with 45.1 and 36.8% for the 150- and 40-ton cranes, respectively. The use of the 150- and 40-ton cranes to service the shielded canyon cell for the RO application will increase the percentage-of-usage value to 57.9 and 45.1% for these cranes, respectively. Therefore, the crane usage is marginally adequate to meet the 50% overall facility efficiency value. Similarly, the south receiving and inspection area (BWR) fuel crane percentage-of-usage values are below the 50% efficiency limit, with 33.3 and 27.4% for the 150- and 40-ton cranes, respectively. Including the effects of the RO handling, these crane-usage values increase to 46.2 and 35.7%, respectively. Therefore, the receiving and inspection areas, with their associated handling equipment, meet the base-case receiving rate.

The large incoming lag storage capacity ensures an adequate supply of spent-fuel assemblies to maintain a steady-state operation of the consolidation process. The consolidation process cyclic time for PWR assemblies is controlled by both the consolidation and the welding processes. However, the consolidation process cycle time for BWR assemblies is controlled only by the consolidation process. The consolidation process and canister welding/decon/inspection processes must be sequenced to achieve the cell efficiency values defined in Section 4.3 and the throughput rate of 3,600 MTU/yr. The PWR processing cell production is more susceptible to unplanned minor failures in the area of the welding/decon/inspection than are the BWR processing cells because of the shorter processing time. Table 4-12 indicates that the base-case throughput rate of 3,600 MTU/yr can be met provided that Shielded Process Cells 1 and 3, which process PWR fuel, operate at 55.5% of the total available time, and Cells 2 and 4 can process BWR fuel at a cell efficiency of 52.6%.

It is also concluded that all retrieval operations for either the sealed storage cask or drywell storage concept can be accomplished in an equal distribution between Shielded Canyon Cells 5 and 6. These cells are equipped to process spent-fuel canisters, HLW canisters, and waste drums. The retrieved spent-fuel canisters can be placed into the in-building vault lag storage before offsite shipment via the RO. Because the RO contents can be drawn from storage, vault lag storage, or directly from the consolidation process, the retrieval process from storage can be treated independently. Operating efficiencies of a single shielded canyon cell for retrieval of spent fuel from sealed storage casks or drywells are 11.6 and 27.2%, respectively. These are relatively low compared to the efficiency value limit of 50% for the shielded canyon cells.

On the basis of these discussions, the MRS Facility can accommodate the design basis receiving and processing throughput rate of 3,600 MTU/yr. Further evaluation of this system should include statistical variations in delivery, consolidation processing, and RO processing. This further evaluation should be included in the detailed design.

6.0 REFERENCE

1. McCreery, P.N., "Studies and Research Concerning BNFP; Operational Assessment of the Transnuclear TN-9 Truck Spent Fuel Shipping Cask," AGNS-35900-1-1-159, Allied-General Nuclear Services, Nov. 1981.

APPENDIX

CALCULATION OF SHIELDED PROCESS CELL RECEIVING CAPABILITY

A.1 REQUIRED RECEIVING RATES

MTU = 3,600
Operational time available = 365 days @ 24 hr/day (four shifts)
MTU/assembly = 0.462 (PWR); 0.186 (BWR)
Assumed truck/rail split: 50/50 (MTU basis)
PWR/BWR split: 60/40 (MTU basis)
Efficiency: e = 50%
Cask capacities: PWR truck = 2
BWR truck = 5
PWR rail = 12
BWR rail = 32
No. of cells receiving spent fuel: PWR fuel = 2
BWR fuel = 2

Receiving rate =

$$\frac{\text{Delivery fraction x MTU rate x assy fraction}}{\text{365 days/yr x MTU/assy fraction x cask type x No. of cells}}$$

A.1.1 TRUCK CASKS

For PWR:

$$TR_P = \frac{0.5 \times 3{,}600 \times 0.6}{365 \times 0.462 \times 2 \times 2} = 1.601 \text{ casks/day}$$

For BWR:

$$TR_B = \frac{0.5 \times 3{,}600 \times 0.4}{365 \times 0.186 \times 5 \times 2} = 1.060 \text{ casks/day}$$

A.1.2 RAIL CASKS

For PWR:

$$RR_P = \frac{0.5 \times 3{,}600 \times 0.6}{365 \times 0.462 \times 12 \times 2} = 0.267 \text{ cask/day}$$

For BWR:

$$RR_B = \frac{0.5 \times 3{,}600 \times 0.4}{365 \times 0.186 \times 32 \times 2} = 0.166 \text{ cask/day}$$

A.2 NORMAL THROUGHPUT EVALUATION

Each of the four shielded process cells is supplied by two cask carts through two separate entry ports. The scheduling of the cask receiving, unloading, and discharge is dependent on availability of both crane and cask carts. Using the critical-path time values defined in Table 4-2 for the appropriate cask types, the time required for each assembly may be calculated. A comparison of this time with the available daily operational time (24 hr/day/cask cart) will provide a percentage of time the cask cart must be available to meet the throughput. An average of these percentage values for each of the two cask carts represents the receiving efficiency of that cell.

Shielded Process Cell 1 (PWR):

Cask cart 1 (truck) = 460 min (7.666 hr/cask)

From Section A.1.1 TR_P = 1.601 casks/day

Time required = TR_P x 7.666 hr/cask = 12.273 hr

Cask cart 1 percentage required = $\frac{12.273}{24}$ = 51.1%

Cask cart 2 (rail) = 750 min (12.5 hr/cask)

From Section A.1.2 RR_P = 0.267 cask/day

Time required = RR_P x 12.5 hr/cask = 3.337 hr

Cask cart 2 percentage required = $\frac{3.337}{24}$ = 13.9%

Average Cell 1 percentage required = 32.5%

This value is less than the 50% efficiency available to cover uncertainties and maintenance downtimes. Because the truck and rail shipments are divided equally for PWR between Shielded Process Cells 1 and 3, therefore, both shielded process cells that handle PWR will have the same receiving and inspection efficiency of 32.5%.

Shielded Process Cell 2 (BWR):

Cask Cart 1 (truck) = 520 min (8.666 hr/cask)

From Section A.1.1 TR_B = 1.060 casks/day

Time required = TR_B x 8.666 hr/cask = 9.19 hr

Cask cart 1 percentage required = $\frac{9.19}{24}$ = 38.3%

Cask cart 2 (rail) = 1,150 min (19.166 hr/cask)

From Section A.1.2 RR_B = 0.166 cask/day

Time required = RR_B x 19.166 hr/cask = 3.1816 hr

Cask cart 2 percentage required = $\frac{3.1816}{24}$ = 13.3%

Average Cell 2 percentage required = 25.7%

It should be noted that these percentages are based on partial casks (specifically for rail casks). Normally, full or complete casks would be unloaded during a single day, if possible. Integral cask values would indicate a higher required usage percentage as listed below:

For Cell 1 (PWR): 2 trucks = 63.8%
1 rail = 52.1%

Average required efficiency = 58.0%
(Cell 3 values are same as Cell 1 values.)

For Cell 2 (BWR): 1 truck = 38.3%
1 rail = 79.8%

Average required efficiency = 59.1%
(Cell 4 values are same as Cell 2 values.)

These values exceed the 50% efficiency number defined for the receiving and inspection area. The amount of spent fuel delivered exceeds the average daily cell requirement of 7 PWR assemblies/day and 11 BWR assemblies/day by 9 PWR assemblies/day and 26 BWR assemblies/day.

A.3 OFF-NORMAL USE

A.3.1 100% RAIL SHIPMENTS (TN-12 CASK)

For Cell 1 (PWR): On the average, 0.534 cask/day must be unloaded to Cell 1 (twice the normal rail shipment).

Average Cell 1 percentages required = 2 x 13.9% = 27.8%

However, full casks are usually unloaded. Therefore, a single cask cart would be required @ 52.1%.

Average cell percentage required = 52.1%

This evaluation also applies to Cell 3, which handles PWR fuel.

For Cell 2 (BWR): On the average, 0.332 cask/day must be unloaded to Cell 2 (twice the normal rail shipment).

Assume that one cask cart can handle this unloading.

Average Cell 2 percentage required = 2 x 13.3% = 26.6%

However, full casks are usually unloaded. Therefore, a single cask cart would be required @ 79.8%. This evaluation also applies to Cell 4, which handles BWR fuel.

A.3.2 100% TRUCK SHIPMENTS (TC - 2 PWR/5 BWR)

For Cell 1 (PWR): On the average, 3.202 casks/day must be unloaded (twice the normal truck shipment).

Two cask carts would be required to handle this unloading process.

Cask cart 1: 2 casks x 7.666 hr/cask = 15.332 hr

$$\text{Cask cart 1 percentage required} = \frac{15.332}{24 \text{ hr}} = 63.8\%$$

Cask cart 2: 1.202 casks x 7.666 hr/cask = 9.214 hr

$$\text{Cask cart 2 percentage required} = \frac{9.214}{24 \text{ hr}} = 38.4\%$$

Average percentage required = 51.1%

However, full casks are usually unloaded.

Cask cart 2: 2 x 7.666 hr/cask = 15.332 hr

Cask cart 2 percentage required = 63.8%

Average percentage required = 63.8% for each cask cart; this exceeds the 50% efficiency value established for unloading. This evaluation also applies to Cell 3, which handles PWR fuel.

For Cell 2 (BWR): On the average, 2.120 casks/day must be unloaded (twice the normal truck shipment).

Two cask carts would be required to handle this unloading process.

Cask cart 1: 2 casks x 8.666 hr/cask = 17.332 hr

$$\text{Cask cart 1 percentage required} = \frac{17.332}{24 \text{ hr}} \text{ hr} = 72.2\%$$

Cask cart 2: 0.120 cask x 8.666 hr/cask = 1.0399 hr

$$\text{Cask cart 2 percentage required} = \frac{1.0399}{24 \text{ hr}} \text{ hr} = 4.3\%$$

Average Cell 2 percentage required = 38.2%

However, full casks are usually unloaded.

Cask cart 2: 1.0 x 8.666 hr/cask = 8.666 hr

$$\text{Cask cart 2 percentage required} = \frac{8.666}{24 \text{ hr}} \text{ hr} = 36.1\%$$

Average Cell 2 percentage required = 54.15%

Each cask cart exceeds the 50% efficiency value established for unloading. This evaluation also applies to Cell 4, which handles BWR fuel.

A.3.3 MAXIMUM TRUCK/RAIL SPLIT FOR FOUR CELLS

Preliminary analysis indicates that a 75/25 truck/rail split is probably the maximum distribution that may be accommodated for the receiving and inspection area. In support of this distribution, the following analysis applies, using information from Sections A.1 and A.2:

For PWR: TR_P = 2.402 casks/day
RR_P = 0.133 cask/day

For BWR: TR_B = 1.59 casks/day
RR_B = 0.083 cask/day

Shielded Process Cell 1 (PWR):

Cask cart 1 (truck)

Time required = TR_P x 7.666 hr/cask = 18.413 hr

Cask cart 1 percentage required = $\frac{18.413}{24}$ = 76.7%

Cask cart 2 (rail)

Time required = RR_P x 12.5 hr/cask = 1.66 hr

Cask cart 2 percentage required = $\frac{1.66}{24}$ = 6.9%

Average Cell 1 percentage required = 41.8%

The same evaluation applies for Shielded Process Cell 3. If an integral number of casks are unloaded, the percentage-required values would increase to the following:

Cask cart 1: $\frac{22.998 \text{ hr}}{24 \text{ hr}}$ = 95.8%

Cask cart 2: $\frac{12.5 \text{ hr}}{24 \text{ hr}}$ = 52.1%

Average Cell 1 percentage required = 73.9%

Shielded Process Cell 2 (BWR):

Cask cart 1 (truck)

Time required = TR_B x 8.666 hr each = 13.778 hr

Cask cart 1 percentage required = $\frac{13.778}{24}$ = 57.4%

Cask cart 2 (rail)

Time required = RR_B x 19.166 hr/cask = 1.59 hr

Cask cart 2 percentage required = $\frac{1.59}{24}$ = 6.6%

Average Cell 2 percentage required = 32.0%

The same evaluation applies to Shielded Process Cell 4. If an integral number of casks are unloaded, the percentage-required values would increase to the following:

$$\text{Cask cart 1: } \frac{17.332 \text{ hr}}{24 \text{ hr}} = 72.2\%$$

$$\text{Cask cart 2: } \frac{19.166 \text{ hr}}{24 \text{ hr}} = 79.8\%$$

Average Cell 2 percentage required = 76.0%

These values are considerably larger than the 50% efficiency-limit values required for the receiving and inspection area. Further increase in the truck/rail split would exceed the capacity of the cask carts to service the shielded process cells. Therefore, a 75/25 truck/rail split appears to be an upper limit.

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DESIGN STUDY 3

RATIONALE FOR SELECTION OF THE INTACT AND RECOVERY UPENDER

1.0 INTRODUCTION

The primary purpose of the Monitored Retrievable Storage (MRS) Facility is to receive, consolidate, package, and store commercial spent fuel. However, the FDC states that, in addition to intact fuel, HLW canisters or future RHTRU drums, and canistered intact fuel must be accepted. Therefore, a system must be incorporated to accept and transfer the above materials from the shielded process cells to shielded canyon cells for processing, if required. A safe, reliable, and economic system that can accept and transfer both spent fuel and other radioactive waste for storage would be consistent with the national waste management goals and the FDC. The comparison of two candidate methods is presented herein.

2.0 PERFORMANCE REQUIREMENTS

Both of the intact and recovery transfer methods evaluated must be compatible with a number of physical, procedural, and operating conditions. The following parameters were defined for the evaluation of the intact and recovery transfer methods:

(1) The system must be capable of accepting, in a vertical mode, both PWR and BWR intact spent fuel assemblies.

(2) The system must transfer either one PWR or two BWR spent fuel assemblies.

(3) The system must transfer intact spent fuel from the shielded process cell to the shielded canyon cell.

(4) The system must provide repeatable alignment interfaces with the storage canister in the welding station upender.

(5) The system must be capable of accepting off-normal fuel assembly components from the fuel consolidation operation, regardless of size or geometry.

(6) The system for shielded canyon cells 5 and 6 must be capable of processing future RHTRU drums or HLW canisters, intact fuel, off-normal events from the consolidation process, and 55-gal drums of nonfuel-bearing components.

(7) Minimization of operating space is desirable.

(8) Modular design of equipment is desirable to minimize maintenance and equipment changeout consistent with ALARA principles.

3.0 CANDIDATE TRANSFER METHODS

The selection process considered the following candidate intact and recovery transfer methods:

- Belt-driven upender
- Clamshell-pushing head upender

The following sections briefly describe both of the methods that were studied and evaluated.

3.1 BELT-DRIVEN UPENDER

Transfer of intact fuel from the shielded process cell to a canister located on the shielded canyon cell upender can be accomplished with a belt-driven upender. A fuel assembly, with its axis in a vertical mode, would be presented to the upender in a vertical position. Once proper position is achieved, rotary-actuated grid clamps will secure the fuel assembly. In the case of BWR processing, a second fuel assembly could be positioned, the upending table rotated to a horizontal position, and the belt drive activated to transfer the fuel assembly into a storage canister. An additional push mechanism will be required to fully insert the fuel into the storage canister. The belt-driven upender must be capable of being raised and lowered to accommodate variations in fuel assemblies to align with a storage canister.

3.2 CLAMSHELL-PUSHING HEAD UPENDER

Transfer of intact fuel from the shielded process cell into a storage canister, positioned and secured on the shielded canyon cell upender, can be accomplished with a clamshell clamping structure and ballscrew-driven pushing head. A candidate fuel assembly that is not to be consolidated will be presented to the upender in a vertical mode. Once proper positioning is achieved, the hinged sides of the clamshell will be actuated to a closed position. The closed clamshell will simulate a storage canister to eliminate orientation problems associated with processing intact fuel assemblies. Two outboard ballscrews, integral with a die-pushing head, will provide translation and full-depth insertion of the fuel(s) being handled.

In addition, off-normal recovery from the shielded canyon cell can be handled with the clamshell-pushing head upender. By removing both end caps on the canister and pushing the bundle or intact fuel(s) back into the closed clamshell, a new canister may be presented to the shielded canyon cell upender and then reinserted for subsequent welding operations. This would eliminate overpacking of canisters.

4.0 EVALUATION OF CANDIDATE METHODS

Both of the transfer methods described above are feasible solutions. However, they employ different processes, equipment, and auxiliary systems. This comparison evaluates these differences with respect to the specific MRS Facility requirements, constraints, and objectives.

The comparison categories for this evaluation are:

(1) Design considerations
(2) BWR/PWR interchangeability
(3) Alignment
(4) Fuel assembly orientation
(5) Remote disassembly/modular changeover
(6) Off-normal recovery

4.1 DESIGN CONSIDERATIONS

A standard product line of material transfer equipment for the MRS Facility does not exist. Therefore, the systems described must be custom designed.

4.2 BWR/PWR INTERCHANGEABILITY

This category refers to component changeout or adjustment required to process variations among PWR- and BWR-type fuels. From an overall shielded process cell design, a system that would require minimal equipment modification would be categorized as a preferred system in this category.

4.3 ALIGNMENT

This category refers to the method of alignment between the shielded process cell upender and the shielded canyon cell upender. The ability to repeat operations within the system is the key parameter when evaluating alignment interfaces. The systems presented can be designed to meet all of the various alignment parameters. However, the belt-driven upender must possess the capability of height adjustment; therefore, the belt-driven upender is rated lower than the clamshell upender.

4.4 FUEL ASSEMBLY ORIENTATION

Fuel assembly orientation refers to the position of the fuel assembly on the upending table. The belt drive will require the fuel assembly to lie flat on a side. The clamshell clamping structure does not require the fuel assembly to be positioned in any specific orientation. This provides a degree of freedom not inherent in the belt-driven system. Therefore, a higher rating is assigned to the clamshell-pushing head upender system.

4.5 REMOTE DISASSEMBLY/MODULAR CHANGEOVER

Both systems can be designed to facilitate remote disassembly and modular changeover. On a quantitative component basis, the belt-driven system

requires many more mechanical components, which will require service/ replacement during the design life of the system.

4.6 OFF-NORMAL RECOVERY

Off-normal events include:

(1) Broken fuel rods resulting from the consolidation process.

(2) Severed skeletons containing broken fuel rods.

(3) Unacceptable canister welds, which require a reinsertion of canister contents into a new canister for rewelding.

This category refers to the ability of the transfer method to handle the off-normal events in the MRS Facility consolidation and welding station. The belt-driven system will require contingency tooling to accommodate the above off-normal events. This implies an increased cost and a decrease in system reliability. However, the clamshell approach will use existing equipment to perform off-normal activities. Therefore, a high ranking has been assigned to the clamshell upender in the off-normal recovery category.

5.0 SUMMARY OF EVALUATION

A rating of the process evaluation, based on the foregoing discussions, is presented in Table 3-1. The table shows the rating of each of the two possible transfer methods in each of the evaluation categories. The evaluations were ranked on a scale of 1 to 3, with 3 being the highest. These ratings were used to tally scores for each system. As shown in Table 5-1, the clamshell, intact and recovery upender is rated substantially above the belt-driven upender on the basis of this evaluation.

6.0 FINAL CONCLUSIONS AND RECOMMENDATIONS

The intact and off-normal fuel recovery operations for category ratings and final rating are defined in Table 5-1. These ratings reflect the scalar quantities assigned during the evaluation process. A final total of 11 was determined for the clam-hell upender system. This high rating indicates the preferred system to transfer wastes between the shielded process and shielded canyon cells. The belt-driven system was rated five points lower, suggesting a less-desirable system. Based on these selection parameters, therefore, it is recommended that the clamshell upender system be selected as the waste and recovery transfer method for the MRS Facility.

Table 3-1 - Intact and Recovery Upender System Selection

Selection Category	Belt-Driven	Clamshell
Design considerations	1	1
BWR/PWR interchangeability	1	2
Alignment	2	3
Fuel assembly orientation	1	2
Off-normal recovery	1	3
Rating[a]	6	11

[a]Higher rating is preferable.

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DESIGN STUDY 4

SELECTION OF STORAGE CANISTER MATERIAL AND SIZE

1.0 STORAGE CANISTER REQUIREMENTS

Storage of nuclear waste at the Monitored Retrieval Storage (MRS) Facility, requires a canister to provide a safe storage medium for the waste for up to 100 years. The criteria and requirements of the canister are as follows:

(1) The canister shall be a cost-effective method to store either intact fuel assemblies or consolidated fuel rods.

(2) Canisters shall be designed to overpack 12-in.-dia, high-level-waste (HLW) canisters and 24-in.-dia transuranic waste (TRU) containers.

(3) The canister, with its contents, shall be capable of being shipped offsite in licensed spent-fuel shipping casks.

(4) The canister shall be capable of maintaining its integrity for up to 100 years.

(5) The canister shall be designed to provide a containment for spent fuel assemblies and fission products during handling and storage.

(6) Canister material shall maintain its integrity despite accumulated radiation effects.

(7) The canister must resist applied loads caused by weight, internal pressure, routine handling impact, and seismic loads.

(8) All fuel rods from a fuel assembly shall be consolidated in the same canister.

2.0 CANISTER DESIGN BACKGROUND

The canister design for MRS was based upon an intact fuel storage canister design developed as part of the Experimental Demonstration Package (EDP) program in support of the Nuclear Waste Terminal Storage program. This canister, designed to the intent of the ASME Code, Section III, Class 3, and 10 CFR 50, Appendix B, was constructed of carbon steel, with a 10-yr design lifetime, as part of the geologic storage testing program in basalt. Many of the criteria applied to this canister design are applicable to MRS. In addition, many of the supporting analyses and much of the design development work were completed along with operational drop testing (simulating a 30-ft drop at 700°F) and seismic testing (0.7g horizontal with 2/3 of 0.7g

vertical). Details of the canister criteria, design, analyses, and testing are described in Reference 1.

The EDP canister design was applied to MRS as a conceptual design, and was modified as needed to meet the requirements and criteria defined above. The bases for the selection of MRS canister size and material are presented in the next section.

3.0 SELECTION BASES

The canister material and size selection considered cost effectiveness and generic compatibility of a canister as the primary rationale for its choice. Cost effectiveness is enhanced by being able to use standard, off-the-shelf products in its construction (as well as purchasing them in large quantities). For this reason, standard pipe was chosen as the primary form for the MRS canister. Pipe is readily available and, when bought in large amounts, is reasonably priced (such as on a dollar-per-pound basis). However, any selected material and fabrication methods shall meet Quality Assurance Level I requirements.

The size of the standard pipe that would be chosen had to be compatible with the packaging of an integral number of intact PWR/BWR spent-fuel assemblies or consolidated PWR/BWR fuel rods. Considering the different types of PWR and BWR intact assemblies and the envelope sizes needed to enclose integral numbers of consolidated fuel assemblies, the 12.75-in.-OD Schedule 20 (0.25) pipe size was chosen. This size of pipe accommodates either one PWR intact assembly, two BWR intact assemblies, three consolidated PWR assemblies, or seven consolidated BWR assemblies. The canister wall thickness (0.25 in.) was determined to be adequate to sustain the weight load of approximately 5,500 lb and internal pressures from the gas entrained with the fuel rods.

The overall size of intact PWR and BWR fuel assemblies and consolidated fuel rods was investigated to ensure canister size capability. Details of these investigations for the EDP canister are described in Reference 1. In addition, the sizes of arrays of consolidated fuel rod bundles were reassessed for the MRS Facility conceptual design. The largest round bundle sizes were 11.70 in. for three assemblies worth of PWR rods and 11.51 in. for seven assemblies worth of BWR rods. The clearances between these diameters and the canister inside diameter were considered sufficient (for purposes of advanced conceptual design) to accommodate bowed fuel rods and to allow fuel rod insertion. No spacers inside the canisters or other measures for restraining fuel rod or fuel assembly motion within the canister were considered.

Pipe with internal diameters less than 12.25 in. was eliminated as possible canisters because it could not contain the size of a Babcock and Wilcox 15 x 15 PWR assembly. Pipe with internal diameters greater than 13 in. was eliminated because it would mandate increasing the canister wall thickness, making welding more difficult, increasing the canister heat output if additional fuel were placed in it, and possibly violating the internal centerline fuel-cladding temperature restriction. It also may require a specially

designed cage to restrain a PWR or BWR assembly from movement because of the large clearance between the assembly and the pipe inner wall.

For overpacking 12-in.-OD HLW canisters and 24-in.-OD waste canisters, 14-in.-OD Schedule 10 and 26-in.-OD Schedule 10 standard pipe sizes were chosen. The same rationale as given above determined their choices.

On all three different-size canisters, an ellipsoidal end cap will be welded to the top of each canister and a circular, flat end plate will be welded to the bottom. The ellipsoidal end cap was chosen for its structural strength against hoop and longitudinal stresses caused by weight loads and possible internal pressures. A flat, circular, bottom end cap was chosen to simplify the remote welding operations. The end caps were designed to meet the intent of the ASME Boiler and Pressure Vessel Code, Section III, Division I, Class 3. Alternative end cap configurations were considered for the upper ends of the canisters, but none offered any advantage over the ellipsoidal end caps, so the ellipsoidal upper end cap design was retained.

The canister length of 15 ft-7 in. is used to store both intact and consolidated fuel. Using one length was considered for conceptual design to simplify overall procurement, processing, handling, welding, and storage operations. The lifting pintle design for the spent-fuel canisters was modified from that of the EDP canister design to eliminate the bullet nose on the top of the pintle. This allows a slightly shorter overall canister length (and the length of the canister overpack). For the conceptual design, this pintle was chosen so that the overall canister and overpack length (16 ft-1 in.) would fit into the internal cavity of the sealed storage cask (16 ft-2 in.).

AISI Type 304 stainless steel was chosen as the most appropriate material for the canister for several reasons. Type 304 stainless steel is an austenitic alloy that has excellent corrosion resistance and toughness characteristics. This stainless steel displays good electrical resistivity (76.2 micro-cm), and it contains few impurities, porosities, or inclusions, all of which will augment the resistance welding process. Type 304L stainless steel, a low-carbon version of Type 304, was considered for this application because it is less subject to sensitization during welding. However, the resistance upset welding (RUW) process allows the weld metal and heat-affected zone to go through the sensitization temperature range very quickly, and thus limits the potential for carbide precipitation. Consequently, the less-expensive Type 304 material was judged to be adequate for this application.

Several other alternative materials for packaging spent fuel for MRS were examined. Carbon steel was the original choice of material for housing the spent fuel, based on the EDP canister design, but was later replaced with Type 304 stainless steel. The reasons for replacement were: the auxiliary treatments (sand blasting, cleaning, and painting) necessary to prepare the carbon steel for its storage period; the uncertainty of its corrosion resistance for a 100-yr period; and its incompatibility with the welding operation. Carbon steel contains greater porosity, inclusions, discontinuities, and impurities than does Type 304 stainless steel. These all affect the quality of the weld.

Titanium and some of its alloys were also considered, but rejected because, despite their excellent corrosion resistance, they are not as cost effective as stainless steel.

4.0 CONCLUSION AND RECOMMENDATIONS

In conclusion, canisters and overpacks fabricated of AISI Type 304 stainless steel pipe (including 12.75-, 14-, and 26-in.-OD pipe fabricated of Schedule 20, 10, and 10, respectively) were chosen for the conceptual design of the MRS Facility. It is expected that they will provide reliable packaging of nuclear wastes within the requirements established for MRS.

REFERENCE

1. Kurasch, D.H., et al., "Experimental Demonstration Package Program Canister Final Design Report," AESD-TME-3047, Westinghouse Advanced Energy Systems Division, Aug. 1980.

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DESIGN STUDY DS-5

SHIELDED PROCESS CELL HANDLING EQUIPMENT

1.0 INTRODUCTION

Handling equipment for use in the shielded process cell consists of cranes and wall-mounted manipulators.

2.0 CRANES

The primary function of the hot cell crane is to transport fuel assemblies and canisters. In addition, the crane will be used for maintenance operations and lifting of miscellaneous items, such as hatches, plugs, drums, and cask lids.

The 3,600-MTU/yr throughput rate established for the MRS Facility translates to processing 4,676 PWR assemblies in Cells 1 and 3 and 7,740 BWR assemblies in Cells 2 and 4. Because of the large number of lifts required, the primary objective in selecting a crane was to make fuel-assembly handling as simple as possible. The top of the fuel assembly will be 10 ft below the floor of the hot cell. Visual feedback for this operation will rely on closed-circuit television (CCTV) cameras. Two crane options were examined for this lifting operation: a standard crane with a hook block and a power mast crane.

2.1 CRANE SELECTION RATIONALE

In comparing the two options, the power mast was selected for the following reasons:

(1) The power mast has telescoping sections that provide a rigid connection to the load. This makes for a quicker and easier grapple operation when compared to a hook-block arrangement.

(2) With a power mast, swinging of the load is eliminated. This feature is important when bringing fuel assemblies to the downender. This is a precise positioning operation, and a stationary load is desirable.

2.2 QUANTITY OF CRANES REQUIRED

The next step in the design was to determine the number of cranes required in each cell. From a space and economic standpoint, a single crane in each cell was preferred. A simple analysis was performed to determine whether or not a single crane would be sufficient to support the required throughput. The analysis consisted of making conservative quantity and time estimates of crane operations. The analysis showed that a single crane could support the

throughput requirements and still have sufficient time for ancillary operations, such as moving fuel assemblies to lag storage, and maintenance operations.

2.3 CRANE CAPACITY

In connection with the above analysis, weights of all components that the crane must hoist were tabulated. Because the heaviest lift for the in-cell crane is the lead portion of the inlet and outlet ports, which have a dead weight of 14 tons, a rated capacity of 20 tons was selected for the crane. By stacking the vertical dimensions of the power mast, the fuel-handling grapple, the longest fuel assembly, and the required lift height, the cell height of 35 ft was established.

2.4 CRANE OPERATIONS

To assist in maintenance and grappling operations, an overhead mechanical arm (capable of being positioned anywhere in the cell) is desired. The first option examined is a mechanical arm, on a separate bridge and trolley, at an elevation lower than that of the power mast. This provides maximum flexibility because the mechanical arm is independent of the power mast. However, this arrangement complicates the crane maintenance bay, increasing the cell height, and increasing the vertical reach required of the power mast. The second option, which was selected, mounts the mechanical arm on the same trolley with the power mast. This design option eliminates all of the problems associated with the first option while meeting the functional requirements of the mechanical arm; it was, therefore, selected for use in the MRS Facility design.

Because azimuthal orientation of the cask basket cannot be guaranteed, a method to rotate the fuel-handling grapple is necessary to accomplish alignment of the grapple to the fuel assembly. By mounting the power mast and mechanical arm on a common turntable bearing, this alignment can be achieved. This rotational capability will also be used in making connections between the power mast and various grapples with a breech-lock-type connection.

2.5 MAINTENANCE OPERATIONS

Maintenance of the overhead crane was also evaluated. The concept adopted for the in-cell cranes is similar to those found in existing operating shielded process cells. A shielded crane maintenance bay is located at both ends of each cell. Normal maintenance of crane components, including the mechanical arm, will be performed in these bays. The power mast must be fully retracted before it can be moved into the maintenance bay. In this configuration, contamination between the telescoping parts cannot be removed and, therefore, must be removed while in the shielded process cell. To accomplish this, the power mast can be equipped with internal wiper rings that will scrape any surface contamination off of the telescoping tubes upon each retraction of the mast. Any further decontamination will be performed in the maintenance bay.

Failed components will be removed through a hatch located in the ceiling of this bay. This hatch has been sized to allow replacement of the entire trolley assembly, if necessary. Trolley replacement would be performed only if the crane could not be easily repaired in the maintenance bay, and the shielded process cell would be nonoperational for an extended time. All four process cell trolley assemblies are identical, so a fifth spare trolley can be inserted into any cell. This reduces spare parts inventory, and also reduces the operators' training because identical cranes will be installed in every shielded process cell. Backup retrieval cables will be connected to the bridge, trolley, and hoist drive trains to ensure that the crane can be brought back to the maintenance bay should one of these motions fail in the cell.

Power and control to the crane will be provided through redundant paths. Provisions have been made that allow for a power reel, as well as a power track on both sides of the bridge. The power takeup reel will be located in the maintenance bay, rather than on the crane, to minimize in-cell equipment and, where possible, to keep equipment in an area that is easily accessible for repairs.

3.0 WALL-MOUNTED MANIPULATORS

3.1 MANIPULATOR SELECTION RATIONALE

Early in the design, it was assumed that a series of master/slave manipulators could be used to service the consolidation station. As the design progressed, however, these manipulators were found to be inadequate because of the size of the consolidation equipment. Because of its required distance from the cell wall, a master/slave manipulator could reach only a small portion of the equipment. Therefore, master/slave manipulators at each consolidation station were replaced by a wall-mounted manipulator, installed along the wall adjacent to the consolidation station. Each manipulator arm is capable of several motions, reaching any location on the consolidation equipment. The manipulator arm is mounted on a hinged bracket that can swing the arm to either side of the consolidation equipment. This hinged bracket is an integral part of a trolley assembly that can traverse the entire length of the cell. The mechanical arm is mounted on a set of telescoping tubes that control the vertical elevation of the arm. The arm has shoulder, elbow, and wrist rotations.

3.2 MANIPULATOR FUNCTIONS

The primary function of the manipulator is to service the consolidation equipment. It will be used to complete changeout of various modules, to remove and replace failed equipment, and to be available for contingency conditions during the consolidation process.

In addition to servicing the consolidation station, the wall-mounted manipulator can perform the following ancillary functions:

(1) It provides a "second hand" in the cell to assist in contingency situations.

(2) It provides a means of performing simple, in-cell, remote-maintenance operations.

3.3 MANIPULATOR MAINTENANCE

Should the wall-mounted manipulator fail, repair will first be attempted in the process cell, using the PAR manipulator on the overhead crane. If in-cell repair is not possible (because of the difficulty of the repair or the excessive downtime required), the failed component will be remotely detached by the overhead PAR. It can then be removed from the cell by the power mast, through the maintenance hatch, into the bay below, where it will be decontaminated and repaired.

The manipulator frame (as distinguished from the arm) is primarily a welded structure, with few moving parts, and should have a low incidence of failure. Almost any failure particular to the frame is intended to be repaired in place. Only severe problems will require its removal from the cell.

The maintenance hatch is sized to accommodate the larger equipment in the process cell; therefore, it will also accommodate the manipulator.

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DESIGN STUDY DS-6

DISASSEMBLY STATION EQUIPMENT

1.0 INTRODUCTION

This study describes the four methods evaluated to sever end-fittings from PWR and BWR fuel assemblies. It also describes the selection of the method and its advantages.

For a complete description of the disassembly and consolidation process, please refer to the Spent Fuel Consolidation Optimization Study.

2.0 END-FITTING SEVERING METHODS

The following methods of severing end-fittings on PWR and BWR fuel assemblies were considered:

(1) Laser
(2) Stone saw
(3) Inner-diameter tube cutters, multiple
(4) Milling

The evaluation of severing methods was influenced by a number of physical, procedural, and operational conditions. The following list of conditions was defined for this evaluation:

(1) The severing method must be capable of severing both upper and lower end-fittings on similar fuel assemblies without tooling changeouts.

(2) The severing means (e.g., tube cutter, stone saw blade, laser probe, or milling cutter) must be modular to accommodate variations in fuel types.

(3) The location of the cut must be below the top of the fuel rods to allow adequate clearance to engage the collets on the fuel rods.

(4) The kerf must be clean to prevent burrs and provide minimal distortion during the severing operation.

(5) The severing system must be capable of being moved out of the way while onloading intact assemblies.

The selection of the laser for disassembly of end-fittings is consistent with the above conditions. The basis for this selection and the description of the four severing methods are included below.

2.1 LASER

System studies were accomplished in two discrete tasks: a detailed literature search (including investigation of related fuel-reprocessing and laser programs) and observation of existing laser facilities.

Information for the literature search came from the following sources:

(1) Westinghouse Research and Development Center
(2) United Technologies Research Center
(3) AVCO Everett Metalworking Lasers
(4) SPAWR Optical Research, Inc.
(5) II-VI Incorporated

The results of the search served as the basis for both recommending laser system equipment and evaluating system design requirements. In addition to the literature search, visits were made to the Westinghouse Research and Development Center to observe and discuss laser facilities, laser auxiliary equipment, and laser operation. These visits provided first-hand knowledge of current laser operation and design technology.

The laser provides PWR/BWR interchangeability through modular cutter probe changeouts. A fuel-specific, PWR probe is inserted within a thimble or instrument tube to sever it below the first grid, thereby providing acceptable collet access to grip and extract the fuel rods. Once the rod extraction process is completed, the laser probe translates down to sever the bottom end-fittings in preparation for secondary waste volume-reduction processes. The laser can, therefore, provide both upper and lower end-fitting removal with a single tool.

A fuel-specific BWR probe is inserted within the laser head, and begins the severing process with one modular tooling change. The eight tie rods used to structurally secure the assembly must be severed and the upper end-fitting removed to gain access to the fuel rods. The upper portion of the tie rods is severed slightly below the upper end-fitting, providing gripper access to the fuel rods for extraction. The lower portion of the tie rods is severed above the lower tie plate, freeing the remaining eight fuel rods for extraction. No equipment modification or secondary tooling is required to sever the lower portion of the tie rods.

In summary, the advantages of the laser that led to its selection for severing end-fittings are:

(1) Both upper and lower end-fittings can be severed with one tool.

(2) Both BWR and PWR fuel types can be accommodated by modular changeouts.

(3) The PWR upper end-fitting can be severed below the tops of the fuel rods.

(4) The kerf, approximately 0.030 in. wide, is virtually free of burrs.

(5) The system can be moved out of the way during onloading of intact fuel assemblies.

The following end-fitting severing methods were considered, but not selected for the dry-horizontal spent fuel consolidation system:

(1) Stone saw
(2) Multiple-inner-diameter tube cutter
(3) Milling

2.2 STONE SAW

The stone-saw method would pass a stone wheel through a cutting plane below the upper end-fitting and above the lower end-fitting, providing access for fuel-rod extraction and preparation for secondary waste volume-reduction operations.

PWR upper end-fitting severing would require an approximately 18-in.-dia stone cutting wheel to pass through the thimble and instrument tubes, thereby providing access to fuel rods after upper end-fitting removal. The stone saw cannot sever below the upper elevation of fuel rods without compromising fuel rod integrity. The stone saw technique, therefore, is not compatible with using collets to withdraw the fuel rods. An example of "gap" clearance on a Westinghouse fuel assembly is approximately 0.095 in., decreasing the space available for the collet wall to a structurally unacceptable level. Lower end-fitting severing can easily be accomplished with a stone saw, provided that fuel rods have not dropped because of grid relaxation in pool storage or during transportation and handling at the MRS Facility.

BWR upper end-fitting severing would require an approximately 2-in.-dia stone cutting wheel to pass through the eight tie-rod nuts, providing access to the fuel rods after end-fitting removal. Consequently, the stone-saw method of severing does not combine interchangeability among variations in PWR/BWR fuels. Contamination control of particles from both the stone saw and the part being severed would require secondary collection systems. Repeatability in cutting quality possibly would be difficult to control, on a production basis, from a remote standpoint.

2.3 MULTIPLE-INNER-DIAMETER TUBE CUTTERS

PWR spent-fuel assemblies must be cut below the first grid to allow access and clearance for fuel rod gripper collets. On a production basis, a multiple-inner-diameter tube cutter can provide the required thimble and instrument severing below the first grid; however, lower end-fittings severing would require additional tooling. A stone saw would provide a feasible scenario for lower end-fitting severing. Inner-diameter tube cutters do not provide interchangeability between upper and lower end-fitting severing. Also, BWR tie rod ends are solid, allowing no access by an inner-diameter tube cutter. For these reasons, a multiple-inner-diameter cutter was not selected.

2.4 MILLING

The technique for joining the PWR thimble tubes to the upper end-fitting consists of welded joints, which could be milled away to provide access to fuel rods after nozzle removal. Additionally, the heads on the cap screws used to fasten the lower end-fitting to the thimble tubes can be machined to free the lower end-fitting. During the milling operations, chips would be generated, and a chip-collection system, local to the milling cutter, must be provided, requiring additional support equipment for the nozzle-severing operations. The milling cutter cannot remove enough thimble tube length to expose the fuel rod upper ends for fuel rod gripper collets. For BWR assemblies, a milling technique is not compatible with severing either the upper or lower end-fittings. For these reasons, a milling method of end-fitting severing was not selected.

3.0 MAINTENANCE

The approach taken regarding maintainability was to design the laser disassembly system for remote maintenance through equipment modularization. For example, the laser beam transport system and laser focusing system are an assembly of modular groups of components. Thus, a malfunctioning item is replaced with its module. Each module can be remotely removed and replaced by removing captive bolts or releasing clamps. All major components and modules will be provided with lifting bails, locating pins, and remote-coupling devices.

The remote laser disassembly system, recently designed and installed by Westinghouse at the Oak Ridge National Laboratory, is a prime example of the above maintenance policy.

4.0 SAFETY

The laser system chosen for this application has at least three design features that are safety-related: (1) The beam is shrouded within a metal casing for its entire length up to the actual working area on which the beam is focused; (2) the actual working area of the focused beam is well within the shielded process cell; and (3) an inherent feature of a laser beam is its short focal length. At a very short distance beyond the point of beam focus, the beam diffuses and becomes ineffective.

DESIGN STUDY DS-7

SHREDDER TRADEOFF STUDY

FOREWORD

This study consists of interoffice correspondence (IOC) and Minutes of Meetings (MM) listed below.

The documents were developed during the Task 2A conceptual design effort, but the technical information contained applies to Task 2B. However, the building arrangement has now moved the shredding operation to the shielded process cell for ease in handling of materials and minimizing the quantity of spaces contaminated.

Document No.	Subject	Issue Date
IOC-262	Review of In-Cell and Skeleton Compaction Equipment	Aug. 28, 1984
MM-057	Welding and Waste Reduction Equipment Selection	Sept. 6-7, 1984
IOC-514	Clarification of Previously Issued Document (Ref. MM-057)	May 14, 1985

THE RALPH M. PARSONS COMPANY of DELAWARE
Subcontractor
Westinghouse Electric Corporation
Waste Technology Services Division

INTEROFFICE CORRESPONDENCE IOC #262

STD:RW:84:026

To ALARA Committee Date 8/28/84
From WTSD Phone 224-5616 Location Waltz Mill
SUBJECT Job 6440-MRS Project; IOC #137
Review of In-Cell and Skeleton Compaction Equipment

cc: W. D. Woods
A. K. Jowdy
J. A. Roll
J. W. Voss
S. Huang
R. Steffen
J. Peel
F-5.5.1
Lou Pollono
Dick Unterzuber

To address the issues itemized in this memo, I would first like to address the general concepts for three volume reduction systems that we have seriously studied before selecting the shredding method.

I. Standard shear compaction as currently practiced by Westinghouse NSID in reactor storage pools. This system is composed of a shear which cuts the skeletons to lengths of approximately two feet. These pieces are then compacted into a 9"x9" square shape about 20 inches tall.

II. A large size compactor which volume reduces an entire skeleton to approximately the same size as System I. (The shear is eliminated.)

III. The shredding method that you are familiar with.

It should also be noted that all conceivable options were given consideration; for instance, acid digestion, melting, torch cutting (standard acetylene, plasma, laser), multiple shears, progressive rollers, etc. All of these systems can be made to work if no limit is placed on the cost of the system. As you can imagine, some of these systems would reach a degree of complexity that might result in costs of $10 million or more to implement.

System I, shear-compaction, requires a minimum of two hydraulic cylinders (perhaps 4) to process the skeletons. Alternatives to hydraulic systems are air cylinders or electric linear actuators. The ALARA committee appears to have objections to hydraulic systems inside hot cells. I share that concern and also consider air cylinders operating at the pressures necessary to drive compaction/shear equipment to be unacceptable. Normal hydraulic systems operate at 1500 psi to 5000 psi. Air at these pressures presents safety hazards and design conditions that are unreasonable.

The ALARA committee also appears to have objections to electrical drives located in hot cells (Reference Paragraph 2). Therefore, substitution of electrical linear actuators would be subjected to the same criticism (complexity) because two more motors would be added to each consolidation cell. In addition, linear actuators operating at the forces required for shearing and compacting of skeletons is not recommended because of wear characteristics.

The implication of concerns is that hydraulic cylinders may be the least objectionable solution to the problem. The next logical question is: can the cylinders be removed from the hot cell? They can if the cost of embedded sleeves at exact tolerances with appropriate seals in acceptable and warranted. Assuming for a moment that this is the design direction chosen, I would expect this system to be constructed of solid steel or lead and steel walls so that cylinder rods can be properly guided and supported.

This arrangement will also have to be designed to prevent radiation streaming and contamination of the sliding drive rod during operation of the shear (assumed to be horizontally actuated). The shear requires blade edges that are maintained sharp enough to keep the shearing forces within system bounds. Consequently, a means must be provided for changing out the blades remotely. Remote change out is necessary because the blades will have pieces of highly radioactive skeleton material embedded in the surfaces. Disposal of the blades would be thorough compaction with the rest of the skeleton.

The compaction portion of the system will also require high forces and thus a hydraulic ram, mounted externally to the cell for maintenance purposes. The walls of this chamber will also be come very contaminated because of the compaction ram forces which will cause scraping of the skeleton parts against the wall during compaction. Decontamination of this area will be difficult and consequently a means of remotely removing replacing the compaction chamber would have to be designed.

After compaction there must be a means devised to eject the compacted material into the disposal container. This system, because of relatively light forces involved, may be air or electrically driven but again must be remotely removable and replaceable. Current hardware that is normally used in pools does not have to perform this function because the compacted skeletons are removed to storage stored with long handled tools.

The compacted shape is expected to be approximately 9"x9" square and (for one skeleton) 20 inches tall. This height can be adjusted by adding more skeleton material to each column during the shear compaction process. The square shape is almost mandatory due to the shape of the largest nozzles. If a compactor had to generate forces great enough to deform a nozzle, the degree of complexity, hydraulic forces and overall system size increases beyond reasonable bounds. For instance, the compaction chamber of a high force compactor must be round to take the radial forces during compaction.

The square shape suggests a square can to efficiently package the material. Should this option be chosen, a completely new handling system for empty and full containers would have to be designed and built. For this and other reasons, a 55 gallon drum seems a more logical choice. The drum handling

equipment must exist because part of the incoming waste is expected to be in drums; thus no increased cost for handling equipment.

Square, 33-inch tall columns do not fit well into a 55 gallon drum. The packing efficiency is less than 50%. A 7+ cubic feet drum will hold approximately 3 cubic feet of compacted skeletons or about three skeletons. This will cause a doubling of the number of storage casks required. Considering the cost of these casks it may be worthwhile to design the equipment to handle and store square containers of skeletons. Should you choose this direction, there will certainly be increased design and facility costs involved. The magnitude is not estimated at this time.

Perhaps a secondary sizing operation could be performed on the skeletons to shape them into something that would fit into a drum efficiently. I would assume two criteria for this system; one, a means of moving skeletons from any cell to a central location is warranted because, otherwise, three sizing systems would have to be built. Second, the system will require large, heavy, high pressure components. These two criteria will also result in increased design and construction costs as well as add additional exposure for maintenance even through the system would be designed with ALARA in mind.

The transport system for compacted skeletons would be equal in complexity to a system for handling drums and therefore approximately equal in most respects.

The location of the shear/compact system is assumed to be under the consolidation cells where the shredding system is currently shown. Present size of the cells precludes the location of this equipment in the consolidation cell.

The following is a summary of the components and sub-system of a shear/compact system that must be located in a shielded environment and following that a similar list of components outside the shielded area:

Equipment Located in Hot Cells

		Number Required
1.	Shearing chamber feed chute	3
2.	Shears	3
3.	Compactor chamber	3
4.	Collection chamber	3
5.	Feed System from collection chamber to storage containers	3
6.	Manipulators for remote change out of components	6
7.	Drum handling system	1
		22

Optional Equipment Inside Hot Cell

	Number Required
8. Reconfiguration equipment:	
Ram chamber	1
Ram chamber translator	1
Eject Port	1
Skeleton handling system	1
	4

Shear/Compact Equipment External to Hot Cell

	Number Required
1. Shear drive cylinders	3
2. Compaction chamber wall drive system	3
3. Compactor drive cylinders	3
4. Hydraulic pump	1
5. Hydraulic valve manifold	3
6. Hydraulic piping, hoses, miscellaneous	3
7. Machined shaft, shielding walls & seals	6
	22

Optional External Equipment

	Number Required
8. Large, high pressure hydraulic cylinder	1
9. Machined shaft, shield wall and seal	1
10. High pressure hydraulic drive	1
11. Valve manifold	1
12. Piping system	1
	5

Standard system Components	44
Optional Components	9
Total Major Components	53

System II, the single stroke compactor has considerable merit because it dramatically reduces the number of components that must be designed, fabricated, housed and maintained. There appears, however, to be two major obstacles to engineer around: one, the physical size of the components precludes location in the current consolidation cell or in the area below the cell. To accommodate the overall length of the system, (estimated to be 48 feet in length) the facility would require major revision and expansion. Second, the walls of the completion chamber will become contaminated beyond

the capability of most decontamination systems to decontaminate and consequently the components must be remotely removable and replaceable. Upon removal the components will have to be placed in a shielded area for repair or disposal. It is possible to design a remote handling system to accomplish this task but I currently believe it would neither be cost effective or ALARA effective to provide a facility with this capability.

If the ALARA committee deems this system to be worth spending extra engineering time and money on, then they should identify a means to accomplish the task. It would be an interesting exercise which we would be delighted to pursue further.

The third system, shielding also has some difficult problems to engineer around. The committee has identified several. The following system description will address most concerns.

Recent shredder tests conducted by Westinghouse has provided some information toward design of a shredding system for skeletons. Some of the key issues are:

1. Nozzles can be shredded. The extra tooth size and horsepower requirements imply that nozzle shredding is not worthwhile for the volume reduction achieved.

2. The shredders will have to be designed to eliminate crud traps.

3. Shredder Housings will have to be redesigned for remote hot cell application.

4. Further testing with a custom designed shredder is necessary.

The layout and redesign of the shredders will, as a minimum, consist of:

- Reducing the size of the throat to about 2'x2'.
- Retaining the shaft diameter that is currently in use on the AZ 160. (Very large & heavy)
- Tayloring tooth size to approximately 1-1/2 inches wide.
- Selection of materials for hot cell use.
- Relocating the gear box to outside of the shield wall.
- Redesigning the mount for the gear box for simple removal.
- Redesigning the drive motor mounts for simple removal.
- Designing shielding for the shredder to facilitate removal and maintenance.
- Designing a transportable shield for the rotors and shafts.
- Designs system to allow tooth cleaning (decontamination) with concrete blocks or bricks.

- o Designing a split cavity so that teeth may be removed and replaced easily.

The results of those design efforts (during Title II or detailed design) will reduce the major components in the shielded area to:

	Number Required
1. Shredder feed chute	3
2. Nozzle feed chute	3
3. Housing for rotors	3
4. Drum handling system	1
5. Isolation valves	3
Sub-Total	13

Equipment External to Hot Cell

	Number Required
1. Drive motors	6
2. Gear boxes	3
3. Shielded shaft sleeve and seals	3
Sub-Total	12
Total	22

This number of components should be compared to the prime alternative system (shear/compact) with the options because the shredder system will allow a minimum of six skeletons to be placed in a 55 gallon drum.

Based on this brief and possibly biased analysis, it can be seen that the ALARA committees comment regarding complexity certainly requires further consideration. I am sure you agree that generally as the degree of complexity increases, so does the possibility of component failure and consequently exposure to maintenance personnel is increased due to repairs and decontamination of the equipment.

Regardless of the method used to volume reduce skeletons there will be generation of mobile radionuclides (CRUD) during the processing steps for any system that I can visualize. There will possible by more crud generated with a shredding operation than with a shear/compactor. In either case, the situation can be easily contained and dealt with. The shredder is expected to operate with its throat open to the consolidation cell but the entire system (to drum loading location) will be sealed. The minor air infiltration expected to occur through the inevitable cracks existing in a system such as this will not be of sufficient volume to carry crud up through the loading chute into the consolidation cell. And if it does, so what? There will be a much larger generation of crud during consolidation operations and consequently the amount of crud arriving from volume reduction operations will be a small percentage of the overall crud level.

The shredding layout will be available for review on the 28th of August. The layout shows a slanted feed chute into the shredder. This arrangement helps

prevents long pieces from passing through the shredder. In addition, the tooth designs will have a limited throat length to further eliminate the possibility of long pieces passing through. Past shredder designs use a relatively large gap between idler and tooth. This design is necessary in long shaft, high volume, wide tooth shredders. The MRS shredder will be short shaft, low volume, (relatively) narrow tooth design. This condition allows a very tight clearance to be maintained between the tooth and idler. Consequently, a piece of tube entering the tooth throat area cannot exit any longer than the tooth throat and the distance it can fall during the brief time the tooth throat passes the idler. A rough estimate indicates that with 12" rotors, @ 30 RPM, and 90° throats the longest piece will be approximately 11.4 inches long. This is quite acceptable for MRS purposes but certainly will need to be confirmed during developmental testing.

There are two other consideration that must be given some thought before rejecting shredders. One, should the facility be required to volume reduce shrouds, control rods or other reactor junk, the shredder appears to be more flexible. A brief look at shear/compact operations implies that this system would increase in complexity if this material had to be handled. Whereas the shredder system will easily accommodate this material (e.g., shredding shrouds has been demonstrated).

The second consideration is what to do with roughing filters. The current approach is to design the filter housing for filters that will fit through the skeleton chute. The filters will be removed and shredded into the drums used for skeletons. This approach eliminates the need for a separate contaminated filter handling system. If Parsons has a system for handling these filters, this operation can easily be eliminated.

Attached to this note are the calculations for vaporized material from the laser cutting operations. Contrary to the ALARA committees contention that this operation is the major source of crud generation in the cell, I believe the major source of crud to be the scraping of fuel pins during extraction from the grids and subsequent rubbing on the rod control combs. The accurate answer as to where all of the contaminants come from in this cell is probably best left to a special study, testing or further analysis.

The ALARA committee implies that a laser system is too complex for hot cell operation because it has an optical system with alignment drives as well as drives for the x y and z axis movement necessary to locate the cutting tip. If this system appears complex, then consider the alternatives:

- A mechanical cutter with multiple spindles, each equipped with a cutter wheel about 1/4 inch in diameter.
- An x and z drive system.
- Each cutter head custom designed for a specific fuel type.
- Change out of each of these heads should one of the hundreds of mechanical components break or fail to operate
- This entire arrangement augmented by a laser or plasma or abrasive saw cutter (for BWR components).

In addition, a mechanical system involves the use of mechanical force to accomplish the necessary cutting. Systems such as this will naturally wear more quickly than a system that (theoretically) never touches the component being cut. Upon further consideration I'm sure you will agree that a laser system results in less substantially less components being located in the cell than comparable mechanical cutting systems.

Regarding the confinement of vaporized material generated by the laser, I believe that placing a confinement barrier (duct) over this operation causes the following conditions to exist and consequently must have engineered solutions provided.

- o Vision is obscured.
- o Glass windows for vision will become dirty if used to provide visibility for operations
- o A HVAC duct will have to be designed to follow the movable head.
- o The duct will now become the contaminate collection point.
- o The duct will have to be remotely removable and replaceable.
- o The duct will probably need an internal decontamination system.
- o The laser head drives will have to increase in size to handle the extra mass it must now move.

Should these conditions actually exist, it appears that letting the contaminants migrate toward the roughing filters, located under the consolidation cell, might be the better solution. In the case of thimble tube cutting on PWR elements the vaporized material will probably plate out on the fuel pins which completely surround the thimble tubes. Should this not be the case the vaporized material will probably fall down among and around the fuel pins and grids. When the elements are then laid horizontally, the crud will then fall into (hopefully) the dust collection system under the consolidation system. This particular batch of crud will probably not cause a significant problem because it is composed entirely of zirconium and a fine layer of crud.

When BWR elements are cut the crud will be mostly stainless and consequently a higher crud level is expected. I do not feel confinement is warranted in either situation. Decontaminating an exposed stainless steel surface is always simpler than decontaminating an internally contaminated system.

In summary, I would like to apologize for the somewhat superficial responses provided by this note to the committees concerns. I would be glad to discuss any subject in further detail at your convenience. I would also be glad to evaluate or discuss any systems that you find preferable to what is currently being designed. But, based on limited knowledge at this time, there does not appear to be "better" systems (in my opinion) available and consequently we do not intend to change design directions. Specific system selection directed by the ALARA committee will require additional funds and a schedule extension.

During the RMP, PNL, DOE and Westinghouse meeting at Waltz Mill ALARA compliance was discussed and I thought an agreement was reached. Than agreement was:

1. Our opinion on ALARA was acceptable because of the entirely subjective nature of the term.

2. We would provide an ALARA analysis (if requested) on any system or component if a dollar value for 1 man rem of exposure was provided.

Should this $/man rem value not be provided, then the whole basis as to whether a system meets ALARA is nothing more than a collection of opinions and consequently subjected to endless debate.

R. E. Watts, Manager
Storage Technology Design

/mmb

0597w-:2
(F4504) 9

Date: August 27, 1984
Subject: Gram/Kerf of Material Vaporization of PWR/BWR Thimble, Instrument and Tie Rods from Laser Disassembly

To: R. E. Watts

General Information

1. Conversation with Dan Racki:

   A. Laser Kerf = 0.030 in (nominal)
   B. Most material vaporizes when cut

2. Material Properties of Zircaloy-2 & 4

   Density = ρ = 6.55 gram/cm^3

3. 2.54 cm = 1 in (Conversion factor)

PWR DISASSEMBLY WORST CASE ANALYSIS - LARGEST WALL THICKNESS

Ce 15 x 15; OD = 1.115 in = 2.8321 cm
ID = 1.035 in = 2.6289 cm
Wall = 0.040 in = 0.1016 cm

Number of tubes to be cut = 5

C = Cut = 0.030 in = 0.0762 cm

A = Area = π (OD^2-ID^2)/4 = π (2.8321^2-2.6289^2)/4 = 0.8715 cm^2

V = Volume = AxC = 0.8715 cm^2 x 0.0762 cm = 0.0664 cm^3

g/cut = V x ρ = 0.0664 cm^3 x 6.55 g/cm^3 = 0.4350 g/cut

@ 5 cuts = 5x0.4350 g/cut = 2.175 g/5 cut

PWR DISASSEMBLY WORST CASE ANALYSIS - MOST THIMBLES AND LARGEST WALL THICKNESS

Westinghouse 17x17 OD = 0.482 in = 1.22428 cm
ID = 0.450 in = 1.143 cm
Wall = 0.016 in = 0.04064 cm

Number of tubes to be cut = 25

C = Cut = 0.030 in = 0.0762 cm

A = Area = π (OD^2-ID^2)/4 = π (1.22428^2-1.143^2)/4 = 0.1511 cm^2

V = Volume = AxC = 0.1511 cm^2 x 0.0762 cm = 0.0115 cm^3

g/cut = VxC = 0.0115 cm^3 x 6.55 g/cm^3 = 0.0754 g/cut

@ 25 cut = 25 x 0.0754 g/cut = 1.886 g/25 cut

BWR DISASSEMBLY WORST CASE ANALYSIS - LARGEST TIE ROD EXTENSION

GE 7x7 OD = 0.570 in = 1.4478 cm

Number to be cut = 8 top
8 bottom
Total = 16

C = Cut = 0.030 in = 0.0762 cm

A = Area = π $d^2/4$ = π x $1.4478^2/4$ = 1.6463 cm^2

V = Volume = AxC = 1.6463 cm^2 x 0.0762 cm = 0.1254 cm^3

g/cut = V x ρ = 0.1254 cm^3 x 6.55 g/cm^3 = 0.8217 g/cut

@ 16 cut = 16x0.8217 g/cut = 13.147 g/16 cut*

*The governing case for most materials vaporized is the GE 7x7 BWR type fuel assembly @ 13.147 g/16 cut. This is due to cutting of solid rods versus PWR tubing.

W. H. Blissell

/mmb

THE RALPH M. PARSONS COMPANY of DELAWARE

MINUTES OF MEETING

Date September 6-7, 1984 MM- 057

Location Ralph M. Parsons Company

Pasadena, CA

SUBJECT Job No. 6440 MRS Facility

Welding and Waste Reduction Equipment Selection

I. Attendees

The following personnel were in attendance during these meetings:

RMP	WEC
S. T. Huang	T. E. Cross
W. L. Santo	R. Watts
C. H. Keehn	R. J. Steffen
S. Y. Mayet*	
R. L. Jarvis*	
A. K. Jowdy	
W. D. Woods	

*September 6 meeting only.

II. Purpose

These meetings were conducted to discuss WEC's designs for canister welding and secondary scrap handling.

III. Discussions

A. Canister Welding

The alternatives and selected method of canister welding were reviewed. A separate report is being prepared which will document the trade-offs and basis for selection. In general, the following systems were evaluated and disadvantages noted:

1. Generic System - Fusion Welding

Welding Systems	Disadvantages
TIG and MIG	Electrode changeout Weld preparation Need to roll canister Past experience at EMAD was not satisfactory.
Plasma and Laser	Need filler metal to complete weld pass.

2. Generic System - Solid State

Welding Systems	Disadvantages
Inertia	Through wall shaft seal needs to be designed for rotation and translation. Expense of special lid design to assure capture during rotation.
Homo-Polar	Advanced state-of-art Bus for penetration and high cost

Based upon the study, WEC has elected to proceed with the homo-polar system. They will contact the manufacturer to arrange for a technical discussion if required.

B. Secondary Waste Reduction

Several methods of waste reduction were investigated. These included cutting, melting, acid digestion, composition and shredding. In addition the location for this reduction system was reviewed. The following system disadvantages were evaluated:

1. Reduction Method - Cutting

Cutting Method	Disadvantages
Torch and Laser	a. Generation of radioactive vapor and splatter b. Manual operation* c. Time to process
Saw or Cutting Wheel	a. Generation of dust b. Manual operation* c. Time to process
Shear	a. Generation of dust b. Manual operation* c. Hydraulics in hot area d. Blade maintenance e. Potential jamming

2. Reduction Method - Compaction

Compactor	a. Generation of dust b. Hydraulics in hot area c. Drum loading device required

3. Reduction Method - Melting

Induction Melter	a. Refractory changeout b. Off-gas treatment c. Advanced state-of-art

Disadvantages

4. Reduction Method - Acid Digestion

Dissolver	a. Off-gas treatment
	b. Dissolver material selection
	c. Additional hazardous material handling
	d. Solid-liquid operation equipment
	e. Liquid complexing
	f. Product/cement interaction
	g. Process time

5. Reduction Method - Shredding

Shredder	a. Special untested design
	b. Blade maintenance
	c. Generation of dust
	d. Material selection
	e. Size of product

*Due to grid spacing variations of the different fuel types and manufacturers, an automated remote system cannot be used.

Other discussions included:

1. WEC has shredded a PWR skeleton using a standard Shred Pax AZ-160 shredder. It was determined that (1) end box compaction was not significant enough to warrant shredding; and (2) pieces as long as 14" passed through the shredder. The longer pieces were passed through a smaller shredder using smaller teeth at a closer spacing which resulted in a product of approximately 6 to 8 inches. A skeleton grid broke a tooth of the smaller shredder. This was due to the shredder operating speed.

   A test report is being prepared by WEC to support this test program and results.

The following preliminary trade-off, Table 1, was conducted to arrive at the selected reduction system. Table 2 presents the trade-off between cell dedicated or central reduction system.

The location of the reduction equipment was investigated. It was determined that the existing cell configuration does not provide sufficient space to accommodate any of the consolidation reduction systems.

A more indepth trade-off is being prepared to support the shredder selection.

G. K. Landy
for
W. D. Woods

WDW:gp
Attachments
Table 1
Table 2

REDUCTION SYSTEM SELECTION

TABLE 1

Consideration	Shear and Compact		Shear		Shredder		Laser	
Design	Custom	(1)	Custom	(1)	Custom	(1)	Custom	(1)
Contamination	Dust	(2)	Dust	(1)	Dust	(1)	Vapor & Splatter	(3)
Product Length	Controlled	(1)	Controlled	(1)	Uncontrolled	(2)	Controlled	(1)
Skeleton/Drum	8	(1)	3	(2.7)	6	(1.6)	3	(2.7)
Maintenance	Highest	(3)	Intermediate	(2)	Intermediate	(2)	Lowest	(1)
Indexing	Yes	(2)	Yes	(2)	No	(1)	Yes	(2)
Cost	Intermediate	(2)	Lowest	(1)	Lowest	(1)	Highest	(3)
Accident Mode	Jam	(4)	Jam	(3)	Jam	(2)	None	(1)
Availability	Lowest	(3)	Intermediate	(2)	Intermediate	(2)	Highest	(1)
Operational Cost (Power)	30 KW	(1)	15 KW	(1)	30 KW	(2)	60 KW	(4)
Rating*		(20)		(16.7)		(15.6)		(19.7)

*Low rating is preferable

NUMBER OF REDUCTION SYSTEMS

TABLE 2

Consideration	Cell Dedicated		Central	
Waste Transfer	Enclosed	(1)	Partly enclosed	(2)
Number of Units	3	(3)	1	(1)
Transfer Maintenance	Drum Cart	(2)	Conveyor	(1)
Lag Storage	Chute	(1)	Conveyor	(1)
Equipment Failure	One cell down	(1)	All cells down	(3)
Sorted Waste Handling	Additional chutes	(1)	Additional chutes & conveyors	(3)
Exposure	Min. amount of waste at equipment	(1)	Max. amount of waste at equipment (conveyor storage)	(2)
Shielding	Same as above	(1)	Same as above	(2)
Accident Recovery	Single Unit Changeout	(1)	Multiple Unit Changeout	(3)
Rating*		(12)		(18)

*Low rating is preferable

THE RALPH M. PARSONS COMPANY of DELAWARE

'NTEROFFICE CORRESPONDENCE

IOC #514

To Those Listed

Date May 14, 1985

From Anita K. Jowdy Phone 3105 Location 459

SUBJECT Job No. 6440 - Monitored Retrievable Storage Facility
Clarification of Previously Issued Document (Ref: MM-057)

Table 1 of the subject minutes of meeting relating to methods of secondary waste reduction has been expanded to include induction melting and acid digestion. These methods were discussed in the body of the document but inadvertently deleted from the table. (Attendees from the original meeting met to evaluate the systems: J. Roll, S. Mayet, C. Keehn, A. Wilcox for S. Huang, W. Santo, W. D. Woods, A. K. Jowdy.)

Consideration	Melter		Dissolve	
Design	Custom	(1)	Custom	(1)
Contamination	Off-gas	(2)	Off-gas	(3)
Product Length	Controlled	(1)	Controlled	(1)
Skeleton/Drum	17	(0.5)**	17	(0.5)**
Maintenance	Highest	(3)	Highest	(3)
Indexing	No.	(1)	No.	(1)
Cost	Highest	(3)***	Highest	(1)***
Accident Mode	Spill	(4)	Vessel Failure	(5)
Availability	Lowest	(3)	Lowest	(3)
Operational Cost (Power)	800 KW	(5)	Negligible	(1)
Rating*		23.5		19.5

* Low rating is preferable
** Restricted by weight (1000#). Value is for PWR.
*** Extra remote handling equipment and off-gas cleanup.

Table 2 remains unchanged since it evaluates location and quantity for the operation of waste reduction and is not drastically affected by the method selected.

A. K. Jowdy

AKJ:kb

See attached distribution

FOREWORD

The Welding System Tradeoff Study underwent client review. Client comments are at the end of this study (Reference MRS 5-5-82, February 20, 1985).

Discussion of the welding system tradeoff study was held as a result of the comments in PNL letter MRS 5.5-82. After initial discussions on general PNL comments, it was determined that it would be better if a consistent set of comparison criteria were developed that everyone present could agree on, and to revise the welding study along those lines.

The following lists the criteria in order of ranking and weight factor:

Rank	Evaluation Criteria	Weight
1	Proven process	22
2	Remote capability	19
3	Inspectability	15
4	Reliability	11
5	Maintainability	11
6	Flexibility	7
7	Simplicity	7
8	Cost	4
9	Time	4
		100%

A definition of these criteria was developed as follows:

Proven process
- Industrial track record
- Reliability
- Qualification of process

Remote capability
- Past hot cell applications
- Ease in adapting to remote operations

Inspectability
- Verification of quality weld
- Verification of process
- Verification of material

Reliability
- In-cell components failure rate
- Out-of-cell components failure rate

Maintainability
- Ease of maintenance and repair
- Time to fix
- Amount of preventive maintenance

Flexibility
- Adaptability to a change in canister design, size, etc.

Simplicity	- Number of equipment components - Number of process variables
Cost	- Capital cost - Operating cost
Time	- Total weld cycle time (setup, weld, inspect)

The basic plan is to identify sources such as AWI, industry, and others, and to obtain data on each welding process. The information would be structured along the lines of the evaluation criteria above and evaluated by a Parsons in-house team according to the established rank and weight listings.

The effort was to become part of Task 3, included in the Task 2B schedule; however, because of schedule and budgetary constraints, this study was not revised for Task 2B.

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Client comments, MRS 5-5-82, dated February 20, 1985

DESIGN STUDY DS-8

WELDING SYSTEM TRADEOFF STUDY

1.0 INTRODUCTION

The Monitored Retrievable Storage (MRS) Facility is being designed and developed to perform a prime objective of receiving, consolidating, packaging, and storing commercial spent nuclear fuel, remote handled transuranic waste (RHTRU), and high-level waste (HLW). The packaging process involves placing spent fuel rods, intact assemblies, or HLW and RHTRU canisters into stainless steel canisters and permanently sealing them by welding a suitable closure onto the canister. A study was performed to investigate the attributes of existing welding systems; compare and rank them for an MRS application; and select a primary system for incorporation into the MRS design. Specifically, this report documents that study, which formed the basis for the selection of the welding process for the MRS Receiving and Handling (R&H) Facility waste packaging operation. The following paragraphs discuss the study approach and describe each of the six welding systems included in this study.

The successful application of a welding system at an MRS facility depends on its compatibility with a number of physical, procedural, and operational interfaces. The following interfaces were identified for this comparative evaluation:

(1) The canister to be welded will be stationary, thereby eliminating "rattling" and possible damage to fuel pins within the canister and the deposition of crud material on the canister walls resulting from rotation.

(2) The axis of the canister will be horizontal, thereby minimizing material-handling operations within the cell.

(3) All canisters will be constructed of standard pipe.

(4) The spent fuel canister will be 12-in.-dia, Schedule 20 pipe (12.75 in. OD with a nominal wall thickness of 0.25 in.).

(5) Defective spent fuel canisters will be overpacked, not repaired. The overpack will be 14-in., Schedule 10 pipe (14.00 in. OD with a nominal wall thickness of 0.25 in.).

(6) The 24-in. canisters of HLW and RHTRU will be overpacked with pipe having an OD of 26 in., with nominal wall thickness of 0.312 in.

(7) The canister and overpack material will be AISI Type 304 stainless steel.

(8) The weld will be a structural weld as well as a seal weld.

(9) The weld must be inspectable by use of an ultrasonic test (UT) method.

(10) The weld is to be performed in a radiation environment of 10^6 R/hr.

(11) Weld preheating or postheating is undesirable.

(12) Minimum weld preparation machining is desirable.

(13) Production rate for the welder is 3 to 5 canisters/cell/day.

For this study, six welding systems were considered. They are listed below, and described in more detail in the succeeding paragraphs and in References 1 through 8.

- Tungsten inert gas (TIG)
- Metal inert gas (MIG)
- Plasma arc welding (PAW)
- Laser beam welding (LBW)
- Inertia welding (INW)
- Resistance-upset welding (RUW)

1.1 TUNGSTEN INERT GAS

The TIG system is a nonautogenous arc welding system that fuses metals by heating the interfacing joint by use of an electric arc and depositing melted filler wire in the weld preparation area. The arc is "struck" between the welding system's tungsten electrode and the metal interfaces to be welded. The system for the MRS application consists of two major pieces: a rotating welding head and a control console. The rotating welding head consists of a clamping assembly (track), an oscillating welding torch, tungsten electrode, and a filler wire spool and drive. For an MRS application, the welding head would be located within the cell and be remotely indexed with respect to the joint to be welded. Electric and gas service lines are routed from the head, out of the cell, to a remote-control console located in an operating gallery. Welding variables are set and controlled from the control console. During the welding operation, an arc is struck between the tungsten electrode (cathode) and the canister (anode), generating the necessary heat for welding. Simultaneously, filler wire is fed into the arc, melts, and is deposited, in an inert gas cover, at the weld interface. The weld head oscillates across the weld preparation area while rotating around the stationary canister. Major welding variables for this process include current, dwell time, arc pulse width, excursion time, oscillator amplitude, wire feed, and arc voltage.

1.2 METAL INERT GAS

The MIG system is a nonautogenous welding system that fuses metals by heating them with an arc, which is transferred between a consumable

electrode (the metal filler wire itself) and the workpiece. The MIG system configuration is analogous to that for TIG. The major difference is that the metal filler wire is the electrode instead of the tungsten electrode.

1.3 PLASMA ARC WELDING

The PAW system is an autogenous welding system that fuses metals by heating them with a constricted arc, which is surrounded by an ionized gas. The arc is transferred between a tungsten electrode and the workpiece. This system is a specialized form of TIG welding and is referred to as a "transferred arc" process. The physical arrangement of a PAW system is similar to the TIG and MIG welding systems, but the process differs. For plasma arc welding, the electrode is housed inside a torch head and is purged by two gas supplies: plasma gas and inert cover gas. Plasma gas exits from an internal orifice, surrounds the arc during the welding process and, through heat conduction, becomes ionized. The ionized gas shields and protects the arc and abets its high temperature by preventing heat loss. The inert cover gas, which exits from a concentric nozzle, surrounds both the arc and plasma gas, and helps prevent oxidization of metal in the heat-affected zone and weld puddle during the process. During the welding operation, the plasma arc creates a "keyhole" that moves along the weld preparation. Solidification of the metal in the wake of the arc fuses the components together. For most of the process, no filler material is needed, but filler material may be required to close the "keyhole." For application in the hot cell, the clamp assembly (track), weld head, and torch are located within the cell, with electric, gas, and cooling service lines routed from the weld head to a remote-control console located in an operating gallery.

1.4 LASER BEAM WELDING

The LBW system is an autogenous welding system that fuses metals with the heat obtained from the application of a concentrated coherent light beam impinging upon the surfaces to be joined. The laser welding system is composed of two major subsystems: a laser generator and an optical delivery system. The laser generator (depending on the welding requirements) is a relatively small (2- x 2- x 8-ft) self-contained power supply that generates the laser beam; the optical delivery system is a configuration of mirrors housed within hollow tubes (transfer tubes), which, through reflection, deliver the beam to the surfaces to be welded. Transfer tubes act as corridors for the beam to travel through and are purged with an inert gas to alleviate thermal blooming of the beam. Near the weld surfaces, a parabolic mirror or lens focuses the beam to an extremely fine point to provide the necessary energy flux at the weld joint interface. For the MRS application, the laser beam would be directed around the canister to make the weld. Since the laser generator and the mirror system are separate systems, and the divergence of the beam is relatively small (1 to 10 mils) over moderate lengths (defined as approximately 50 ft), the laser generator can be located outside the hot cell, and the optical delivery system can be located in the hot cell. The laser, like the plasma arc, welds in the "keyhole" fashion and may require filler material to close the "keyhole" at the end of the weld. An inert cover gas is used with this process, as with the TIG, MIG, and PAW systems.

1.5 INERTIA WELDING

The INW system is a solid-state, upset-welding system that fuses metals by the heat and pressure obtained from mechanically induced sliding motion between faying surfaces of materials to be welded. The inertia welding system is an assembly of equipment that includes hydraulic pumps; a hydraulic drive and drive train to accelerate a large flywheel; a forge press capable of providing, for the MRS application, up to 500,000 lb of force; chuck mechanisms to hold the canister and lid; and forge restraints, capable of resisting axial as well as torsional reactive loads. For this system, a canister is placed in a large stationary chuck and the lid is placed in an opposing chuck, which is connected by a shaft to a flywheel. Hydraulic motors accelerate the lid and flywheel to a predetermined speed, then are disengaged. The forge press is then activated, forcing the rotating lid against the mating surface of the stationary canister. Relative motion between the surfaces generates frictional heat and, under the induced pressure and heat, the material begins to yield. As the flywheel loses its kinetic energy, the rotating wheel and lid decelerate with a continuation of the forge pressure. Once the flywheel rotation has ceased and forge pressure has been removed, a structurally sound weld has been produced. Only three major variables are involved in this welding system: (1) rotational speed, (2) forge pressure, and (3) time. No inert cover gas or filler material is necessary. Except for the chuck mechanisms, force restraints, and the shaft between the flywheel/lid chuck, all equipment required for this process is located exterior to the hot cell. The chuck mechanisms and force restraints are located within the hot cell, with the shaft penetrating the hot-cell wall.

1.6 RESISTANCE-UPSET WELDING

The RUW system is a solid-state, upset-welding system that applies a current pulse, which preferentially heats the interface between two workpieces. As the material temperature increases, a forging operation commences to produce the weld. This system includes hydraulic pumps; a generator or transformer; a forge press capable of providing up to 500,000 lb of force; a hydraulic drive unit; a chuck mechanism to hold the canister; two electrodes; and forge restraints capable of resisting axial reactive loads. For this system, the canister is held in a large chuck and a lid is guided into place between the canister and forging ram. Two electrodes are connected, via large copper bus bars, to a remotely located generator or transformer, and attached separately to the canister and to the end of the forging ram. The forge press is activated before welding to compress the lid against the canister. The interface pressure is initially held at about 5,000 psi. Once alignment and contact pressure have been verified, an ac current pulse of approximately 50,000 A/sq in. of material being welded is discharged through the circuit. The circuit route is from the generator (or transformer) to the electrode (via copper bus bar) on the forging ram, through the lid, across the weld interface, and back out through the electrode in contact with the canister. Significant "I^2R loss" occurs at the weld interface, because of constrictive resistance, heating the local contact area of the materials. Simultaneously, the forging pressure is increased to provide a pressure of

approximately 20,000 psi of material being welded at the weld interface. The press continues to operate until a specified upset distance has been achieved (usually about 0.25 in.). The weld is formed and the press returns to its original position. The operation requires no filler material or inert gas; however, the weld will be performed in an inert gas environment to improve the weld. Except for the chuck mechanism, forge restraints and electrodes, and the shaft between forge press/lid, all equipment required for this process is located exterior to the cell. The chuck mechanism and forge restraints are located within the cell, with the shaft and bus bars penetrating the cell wall.

2.0 COMPARISON CATEGORIES

Each of the six welding systems described above is considered to be a feasible alternative, which could be developed to produce the welds required for the MRS canisters. However, as the previous descriptions show, there are differences among the systems, equipment, and required support systems. This tradeoff evaluates these differences with respect to the requirements, constraints, objectives, and desires of the specific MRS application.

Comparison categories were determined by a six-member panel, using a judgmental method. The intent of the panel was to establish comparison categories that best represent the majority of concerns and interests for the reliable operation of an MRS welding system. The following categories were selected as a basis for this tradeoff:

(1) Technical maturity
(2) Ease of qualification of mockup and testing program
(3) Consistency
(4) Welding system cost
(5) Welding system design impact

Group members then subdivided the primary categories into more detailed subcategories, and so on, until explicit topics were arrived at under each subcategory. Once the subcategories were broken down into detailed topics, weighted factors were assigned. Initially, each group member assigned his own ranking to the topics under each subcategory from "most important, ranked No. 1" to "least important, ranked No. 6." The rankings were then added together to arrive at the weighing factors; the lowest summed ranking represented the most important topic. This process continued until all topics under each subcategory received a weighing factor. Then subcategories were ranked under each primary category, following the same process, and finally the primary categories were ranked. The categories, along with their assigned weight factors (in parentheses), are:

I. TECHNICAL MATURITY (Primary Category) (11)

1. Application and Past Experience (Subcategory) (6)

(Topic)

A. Acceptable and successful demonstration (12)
B. Qualified and used on MRS canister configuration (23)
C. Successfully automated (18)
D. Remote hot cell experience (12)
E. Hot cell production experience (15)

2. Specifying and Obtaining Equipment (Subcategory) (12)

(Topic)

A. Number of specifications and complexity (14)
B. Available vendors (11)
C. Commercial configuration versus MRS configuration (11)

II. EASE OF QUALIFICATION OF MOCKUP AND TESTING PROGRAM (Primary Category) (21)

1. Establishing Qualifications For Mockup Facility (Subcategory) (17)

(Topic)

A. Space requirements (13)
B. Hot cell simulation (6)

2. Specifying Qualification Testing Program (Subcategory) (10)

(Topic)

A. Weld mockup design (16)
B. Number of variables for test (9)
C. Flexibility (11)

3. Weld Process Qualifications (Subcategory) (9)

(Topic)

A. Verification of welds (6)

III. CONSISTENCY (Primary Category)

1. Continuous Operational Reliability (Subcategory) (6)

(Topic)

A. Process parameters and variables (6)
B. Number of dynamic components (14)
C. Contact maintenance components (16)

2. Ease of Maintenance (Subcategory) (12)

(Topic)

A. Number of dynamic components (13)
B. Remote maintenance components (8)
C. Contact maintenance components (15)

IV. WELDING SYSTEM COSTS (Primary Category) (25)

1. Engineering and Development (Subcategory) (13)

2. Mockup and Testing Cost (Subcategory) (13)

3. Capital (Subcategory) (14)

4. Canister Costs (Subcategory) (14)

V. WELDING SYSTEM DESIGN IMPACT (Primary Category) (23)

1. Canister Configuration (Subcategory) (8)

(Topic)

A. Weld preparation (19)
B. Assembly (26)
C. Weld control (10)
D. Flexibility (15)
E. Lid design (20)

2. Programmatic Implementation (Subcategory) (12)

(Topic)

A. In-cell space (6)
B. Out-of-cell space (11)
C. Inventory space (17)

3. Space Requirements (Subcategory) (11)

(Topic)

A. In-cell space (6)
B. Out-of-cell space (11)
C. Inventory space (17)

Once this process was finished, a matrix was constructed that included the categories and their weighing factors. The six welding systems were then compared for each topic (see Figure 2-1). The six systems were ranked 1.0 through 6.0 for each topic, with a ranking of 1.0 representing the most appropriate welding system for the topic of interest. For each topic, the summed rankings of 1.0 through 6.0 equaled 21 total points. If certain welding systems were judged equal, they were all assigned the average value of the rankings that they were ranked across. For example, if the overall ranking for a topic was as follows:

TIG	1.0
MIG	2.0
PAW	
LBW	Equal
INW	
RUW	6.0

TIG was ranked and assigned Number 1.0, MIG was ranked and assigned Number 2.0, RUW was ranked and assigned Number 6.0, but PAW, LBW, and INW were ranked as equal and they occupied the ranking range of 3.0 through 5.0. Since they are equal, however, they were assigned the average value of:

$$\frac{3.0 + 4.0 + 5.0}{3} = 4.0$$

Therefore,

TIG = 4.0
LBW = 4.0
INW = 4.0

When summed, the total assigned values always equal 21.0.

Once the topics were assigned ranking values, they were then multiplied by their immediate weighing factor (total weight).

For example, under the technical maturity category (Figure 2-1), TIG for topic A was ranked 3.0 (or third). This value was multiplied by the weighing factor for Topic A, 12.0, to give TIG a value of 36.00 for this topic. This process continued for each topic (A through E). Then all topics (A through E) were summed and multiplied by the subcategory weighing factor of 6.0 to yield a subtotal value of 1,149.0. This process was then repeated for the three topics in subcategory 2. Finally, the two subtotals were added (1,149.0 + 1,332.0) and multiplied by the overall weighing factor for the primary category (11.0) to yield the total value for TIG in this primary category of 27,291.0. This procedure was followed for all six welding systems and for all five primary categories. The totals for each of the six systems, under each of the

Category	Weight	Sub Cat. Weight		Topic	Weight		TIG		MIG		PAW		LBW		INW		RUW		Total
I	11.0	1.0	6.0	A	12.0	3.0	36.0	3.0	36.0	3.0	36.0	6.0	72.0	3.0	36.0	3.0	36.0	21.0	252.0
Technical Maturity				B	23.0	3.5	80.5	3.5	80.5	5.5	126.5	5.5	126.5	1.5	34.5	1.5	34.5	21.0	483.0
				C	18.0	2.0	36.0	2.0	36.0	2.0	36.0	5.0	90.0	5.0	90.0	5.0	90.0	21.0	378.0
				D	12.0	2.0	24.0	2.0	24.0	2.0	24.0	5.0	60.0	5.0	60.0	5.0	60.0	21.0	252.0
				E	15.0	1.0	15.0	4.0	60.0	4.0	60.0	4.0	60.0	4.0	60.0	4.0	60.0	21.0	315.0
	Subtotal						1,149.0		1,149.0		1,695.0		2,451.0		1,683.0		1,683.0		10,080.0
		2.0	12.0	A	14.0	4.0	56.0	4.0	56.0	4.0	56.0	6.0	84.0	2.0	28.0	1.0	14.0	21.0	294.0
				B	11.0	1.5	16.5	1.5	16.5	3.0	33.0	6.0	66.0	4.5	49.5	4.5	49.5	21.0	231.0
				C	11.0	3.5	38.5	3.5	38.5	3.5	38.5	3.5	38.5	3.5	38.5	3.5	38.5	21.0	231.0
	Subtotal						1,332.0		1,332.0		1,530.0		2,262.0		1,392.0		1,224.0		9,072.0
	Total						27,291.0		30,261.0		35,475.0		51,843.0		33,825.0		31,977.0		210,672.0
II	21.0	1.0	17.0	A	13.0	2.0	26.0	2.0	26.0	2.0	26.0	4.0	52.0	6.0	78.0	5.0	65.0	21.0	273.0
				B	6.0	2.0	12.0	2.0	12.0	2.0	12.0	4.0	24.0	6.0	36.0	5.0	30.0	21.0	126.0
	Subtotal						646.0		646.0		646.0		1,292.0		1,938.0		1,615.0		6,783.0
Ease of Qualifications of Mockup and Testing Program		2.0	10.0	A	16.0	2.0	32.0	2.0	32.0	2.0	32.0	4.0	64.0	6.0	96.0	5.0	80.0	21.0	336.0
				B	9.0	6.0	54.0	5.0	45.0	4.0	36.0	3.0	27.0	1.5	13.5	1.5	13.5	21.0	189.0
				C	11.0	4.5	49.5	4.5	49.5	4.5	49.5	4.5	49.5	2.0	22.0	1.0	11.0	21.0	231.0
	Subtotal						1,355.0		1,265.0		1,175.0		1,405.0		1,315.0		1,045.0		7,560.0
		3.0	9.0	A	6.0	5.5	297.0	5.5	297.0	3.5	189.0	3.5	189.0	1.5	81.0	1.5	81.0	21.0	1,134.0
	Total						48,258.0		46,368.0		32,210.0		60,606.0		70,014.0		57,561.0		325,017.0

Figure 2-1 - Matrix Organization and Layout

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Category Weight		Sub Cat. Weight		Topic Weight			TIG		MIG		PAW		LBW		IMW		RUN		Total
III	10.0	1.0	6.0	A	6.0	5.5	33.0	5.5	33.0	3.5	21.0	3.5	21.0	1.5	9.0	1.5	9.0	21.0	126.0
				B	14.0	5.5	77.0	5.5	77.0	4.0	56.0	2.0	28.0	3.0	42.0	1.0	14.0	21.0	294.0
Consistency				C	16.0	5.5	88.0	5.5	88.0	3.5	56.0	3.5	56.0	1.5	24.0	1.5	24.0	21.0	336.0
	Subtotal						1,188.0		1,188.0		798.0		630.0		450.0		282.0		4,536.0
		2.0	12.0	A	13.0	5.5	71.5	5.5	71.5	4.0	52.0	3.0	39.0	2.0	26.0	1.0	13.0	21.0	273.0
				B	8.0	4.5	36.0	4.5	36.0	4.5	36.0	4.5	36.0	1.5	12.0	1.5	12.0	21.0	168.0
				C	15.0	5.0	75.0	5.0	75.0	5.0	75.0	3.0	45.0	1.5	22.5	1.5	22.5	21.0	315.0
	Subtotal						2,190.0		2,190.0		1,956.0		1,440.0		726.0		570.0		9,072.0
	Total						33,780.0		33,780.0		27,540.0		20,700.0		11,760.0		8,520.0		136,080.0
IV	25.0	1.0	13.0	A	1.0	4.0	52.0	4.0	52.0	4.0	52.0	6.0	78.0	1.5	19.5	1.5	19.5	21.0	273.0
		2.0	13.0	A	1.0	2.0	26.0	2.0	26.0	2.0	26.0	4.0	52.0	6.0	78.0	5.0	65.0	21.0	273.0
Welding		3.0	14.0	A	1.0	1.5	21.0	1.5	21.0	3.0	42.0	4.0	56.0	5.5	77.0	5.5	77.0	21.0	294.0
System		4.0	14.0	A	1.0	4.5	63.0	4.5	63.0	2.5	35.0	2.5	35.0	6.0	84.0	1.0	14.0	21.0	294.0
Costs																			
	Total						4,050.0		4,050.0		3,875.0		5,525.0		6,462.5		4,387.5		28,350.0

Figure 2-1 (Contd)

Category Weight		Sub Cat. Weight		Topic Weight		TIG		MIG		PAW		LBW		IRW		RUW		Total
V	23.0	1.0	8.0	A	19.0	5.5	104.5	5.5	104.5	3.5	66.5	3.5	66.5	1.5	28.5	1.5	28.5	21.0	399.0
				B	26.0	3.5	91.0	3.5	91.0	3.5	91.0	3.5	91.0	3.5	91.0	3.5	91.0	21.0	546.0
Welding				C	10.0	5.5	55.0	5.5	55.0	4.0	40.0	3.0	30.0	1.5	15.0	1.5	15.0	21.0	210.0
System				D	15.0	4.0	60.0	4.0	60.0	4.0	60.0	6.0	90.0	2.0	30.0	1.0	15.0	21.0	315.0
Design				E	20.0	3.0	60.0	3.0	60.0	3.0	60.0	3.0	60.0	6.0	122.0	3.0	60.0	21.0	420.0
Impact																			
	Subtotal						2,964.0		2,964.0		2,540.0		2,700.0		2,276.0		1,676.0		15,120.0
		2.0	12.0	A	6.0	2.0	144.0	2.0	144.0	2.0	144.0	6.0	432.0	4.5	324.0	4.5	324.0	21.0	1,512.0
		3.0	11.0	A	6.0	2.5	15.0	2.5	15.0	2.5	15.0	2.5	15.0	5.5	33.0	5.5	33.0	21.0	126.0
				B	11.0	2.5	27.5	2.5	27.5	2.5	27.5	2.5	27.5	6.0	66.0	5.0	55.0	21.0	231.0
				C	17.0	3.5	59.5	3.5	59.5	3.5	59.5	3.5	59.5	3.5	59.5	3.5	59.5	21.0	357.0
	Subtotal						1,122.0		1,122.0		1,122.0		1,122.0		1,743.5		1,622.5		7,854.0
	Total						97,290.0		97,290.0		87,538.0		97,842.0		99,900.5		83,317.5		563,178.0
Grand Total							210,669.0		211,749.0		196,638.0		236,516.0		221,962.0		185,763.0		1,263,297.0

Figure 2-1 (Contd)

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five primary categories, were then summed to yield a grand total. The system with the least total was deemed the system most appropriate for the MRS Facility welding station. This procedure was chosen because of the enhanced and necessary features of weighing certain criteria greater than others and the bottom-up systems engineering format. This method best rates systems with subjectively assigned weighing factors but objectively derived final rankings.

As illustrated in the matrix, the RUW system received the lowest cumulative total and was, therefore, chosen to be the welding system most appropriate for the MRS application. The PAW system finished second, with TIG third.

The remainder of the report supports the rankings of the individual systems for each of the topics in the matrix, and presents comparisons and reasoning for their rankings.

3.0 COMPARISON OF WELDING SYSTEMS FOR TECHNICAL MATURITY CATEGORY

This category presents a comparison of welding systems with respect to their technical maturity. Technical maturity is concerned with the "nearness" of a system to successful implementation. It is considered to be a function of two major items:

(1) Application and past experience

(2) Specifying and obtaining equipment

The results of this comparison are presented in Table 3-1 and described in more detail in subsequent sections.

3.1 APPLICATION OF PAST EXPERIENCE

This subcategory addresses the extent, applicability, and usefulness of the past operational experience of the alternative welding systems. Those systems that have more directly applicable and usable experience are ranked higher than those that do not, as they are considered to be nearer to successful implementation. The concerns addressed in this subcategory comparison are:

(1) Has the system been acceptably and succesfully demonstrated?

(2) Has the system been qualified and used on canisters having the same diameter, wall thickness, material, or configuration as that envisioned for the MRS Facility?

(3) Has the system been extensively and successfully automated ("good") or used in a remote hot cell application in an "intense" radiation field ("better")?

(4) Has the system been used in a production system?

Table 3-1 - Technical Maturity

1. Application of Past Experience (6)

   A. Acceptable and successful demonstration (12)
   B. Qualified and used on MRS canister configuration (23)
   C. Successfully automated (18)
   D. Remote hot cell experience (12)
   E. Hot cell production experience (15)

2. Specifying and Obtaining Equipment (12)

   A. Number of specifications and complexity (14)
   B. Available vendors (11)
   C. Commercial configuration versus MRS configuration (11)

Category Weight		Sub Cat. Weight		Topic Weight			TIG		MIG		PAW		LBW		INW		RUW		Total
I Technical Maturity	11.0	1.0	6.0	A	12.0	3.0	36.0	3.0	36.0	3.0	36.0	6.0	72.0	3.0	36.0	3.0	36.0	21.0	252.0
				B	23.0	3.5	80.5	3.5	80.5	5.5	126.5	5.5	126.5	1.5	34.5	1.5	34.5	21.0	483.0
				C	18.0	2.0	36.0	2.0	36.0	2.0	36.0	5.0	90.0	5.0	90.0	5.0	90.0	21.0	378.0
				D	12.0	2.0	24.0	2.0	24.0	2.0	24.0	5.0	60.0	5.0	60.0	5.0	60.0	21.0	252.0
				E	15.0	1.0	15.0	4.0	60.0	4.0	60.0	4.0	60.0	4.0	60.0	4.0	60.0	21.0	315.0
	Subtotal						1,149.0		1,149.0		1,695.0		2,451.0		1,683.0		1,683.0		10,080.0
		2.0	12.0	A	14.0	4.0	56.0	4.0	56.0	4.0	56.0	6.0	84.0	2.0	28.0	1.0	14.0	21.0	294.0
				B	11.0	1.5	16.5	1.5	16.5	3.0	33.0	6.0	66.0	4.5	49.5	4.5	49.5	21.0	231.0
				C	11.0	3.5	38.5	3.5	38.5	3.5	38.5	3.5	38.5	3.5	38.5	3.5	38.5	21.0	231.0
	Subtotal						1,332.0		1,332.0		1,530.0		2,262.0		1,392.0		1,224.0		9,072.0
	Total						27,291.0		30,261.0		35,475.0		51,843.0		33,825.0		31,977.0		210,672.0

The TIG welding system was ranked Number 1 in this subcategory because it has had nearly 6 years of proven experience in performing autogenous seal welds between canister lids and bodies at the E-MAD facility located in Nevada and at the B-Plant located in Richland, Washington. At E-MAD, the seal weld is approximately 13.5 in. dia between components of Type 304 stainless steel. The weld produced has a nominal thickness of about 0.1 in. The welder is fully automatic, has operated in a hot cell environment with a radiation environment equal to that expected at the MRS Facility, and has been used to package intact fuel assemblies. To date, approximately 20 canisters have been successfully welded in a prototype packaging operation. At the B-Plant Facility, a TIG system is currently being used to seal stainless steel canisters containing cesium and strontium. The canisters measure approximately 3 in. dia, with a wall thickness of approximately 0.10 in., and are welded with a full-penetration, structurally sound weld. The system operates in a production mode and numerous containers are welded each week. Compared to the required operation at the MRS Facility, the TIG system experience is applicable in most areas. The basic configuration of the E-MAD hot cell equipment (rotating welding head and separate control console), size of canister welded, and the type of fuel being packaged are considered to be compatible with the requirements of the MRS Facility welding station. However, the system used at E-MAD differs in the type of weld (seal versus structural), its canister orientation (vertical versus horizontal), and in the production throughput rate.

The MIG system is quite comparable to the TIG system; however, it does not have the extent of directly applicable hot cell welding operational experience that the TIG system does. It has, however, been evaluated and demonstrated, in a mock hot cell environment, as a candidate remote welding system for nuclear waste packages. This demonstration was conducted at Hanford as part of DOE-sponsored nuclear waste programs. In addition, its similarity to the TIG welding system and its long industrial-use history induce confidence that it can be adapted to an MRS configuration.

The INW system was ranked third because it has no hot cell operational experience, and is not a fully automated system. However, it has been used extensively throughout industry for numerous welding operations, and has been successfully evaluated at Hanford by Pacific Northwest Laboratory as a candidate system for welding stainless steel end caps onto canister bodies filled with vitrified, high-level waste. The system can be oriented in any fashion and will comply with the horizontally oriented canister to be welded at the MRS Facility.

The RUW system, like the INW system, has no hot cell operational experience nor has it been fully automated. However, the system has been evaluated and is being used for welding 5-in.-dia lids onto canisters containing simulated vitrified, high-level waste at the Savannah River Defense Waste Processing Facility. For that operation, ac step-up transformers supply current for the

welding process. A welding verification program has been underway at the site for several years, and stainless steels and numerous other metals have been successfully welded. The system has been refined and is performing welds with acceptable results. This system, like the INW system, can also function properly in any orientation, and is, therefore, ranked equal to the INW system.

In this comparison subcategory, the PAW system was ranked fifth. The PAW system has been used successfully throughout the nuclear industry and in hot cell environments. At the E-MAD Facility in Nevada, an automated PAW system (installed in 1981) has been developed for use to weld 12.75-in., carbon-steel canisters having a nominal wall thickness of 0.25 in. Efforts are currently underway to qualify the process for stainless steel. The welding system has been used within a hot cell environment and is designed for a production-type operation with a rotating welding head and a separate control console. The canister on which these welds were made has its axis vertical, which is not desirable for the MRS application. In addition, difficulty can be expected in performing welds on horizontally oriented pipe because of a tendency of weld pool material to drip onto the electrode at the 5, 6, and 7 o'clock positions of weld.

The LBW system was ranked sixth in this subcategory because it has very limited operational experience within any type of hot cell environment and has not been used to weld pipe under the conditions expected at the MRS Facility. The system is a proven technology, having been used to weld stainless steels and other metals in a nonproduction environment.

3.2 SPECIFYING AND OBTAINING EQUIPMENT

This subcategory addresses the ease of specifying and obtaining the equipment and establishing the qualification configuration (e.g., setting up the equipment in a simulated MRS hot cell environment). The comparisons considered and evaluated three primary areas:

(1) The number of equipment purchasing specifications required and their complexity.

(2) The available vendors to support a competitive bidding process (number of potential suppliers).

(3) The compatibility between what industry normally supplies and what will be required for an MRS system.

The RUW system was ranked first in this subcategory because of the few equipment specifications required, the nature of the company producing the equipment, and the ease with which the qualification setup can be established. Because the items of equipment located in-cell and out-of-cell are relatively simple in design and few in number, the generation of the equipment specifications for their fabrication and procurement is judged to be relatively straightforward. In addition, the industry that supplies the equipment is geared toward providing the features needed (i.e., "custom

equipment can be expected to be normal") and, even though there are not now many vendors to support an extensive competitive bidding process, this is not seen as a major negative factor. Also, because of the few pieces of equipment needed, the qualification setup is viewed as straightforward, being relatively easy to specify. However, the RUW systems available from vendors are not of the MRS configuration; the system will be unique.

The TIG and MIG systems were ranked equal in this subcategory, but behind the RUW system. The specifications for these systems were expected to be more complicated and extensive than those for the RUW system because there are more process-related variables. Both welding systems are commercially automatable, and the industry could supply such systems (although the remotely automatic attachment and detachment operation requirements will make the system "special"). A prominent advantage of the TIG and MIG systems over the RUW system is the availability of numerous vendors to support a competitive bidding process.

The INW system is ranked fourth in this subcategory even though it has many of the same advantages as the RUW, TIG, and MIG systems. It is considered to require relatively simple specifications, although they will be more complicated than those for the RUW system because of the additional mechanical features of the forge restraints and transversing/rotating forge ram. Like the RUW system, it does not have the benefit of an extensive competitive bidding process, but again this is not viewed as a major negative factor. The INW systems supplied by the vendor are not compatible with the MRS configuration; the system will be specifically designed and unique.

The PAW system was ranked fifth in this subcategory. In comparison to the other alternatives, the system requires complex specifications because of the process variables, alignment features, and equipment uniqueness. PAW systems have many variables requiring control and specification; in addition, fully hot cell automated systems are judged to extend slightly the industry state-of-the-art for standard systems. The available vendors are numerous and this should provide for good, cost-competitive bids.

The LBW system is ranked sixth in this subcategory. The laser generator is essentially an off-the-shelf item, available commercially. It is a completely self-contained unit, whose specifications are based essentially on power-output requirements. The other portion of this system, the optical delivery system, complicates almost all considerations of this category of comparison. The optical delivery system will require additional specifications for its process variables and components, and available vendors providing this type of optical system are few. The ranking of the LBW system results from these complications. As with the other systems, vendors do not supply a system that is compatible with the MRS requirements and configuration, and a unique design will be necessary.

4.0 COMPARISON OF WELDING SYSTEMS FOR QUALIFICATION OF MOCKUP AND TESTING PROGRAMS

This category presents a comparison of welding systems with respect to the confidence and ease in accomplishing an equipment and process qualification program. It is considered to be a function of three major items:

(1) Establishing qualification mockup facility
(2) Specifying qualification testing program
(3) Weld process qualification

Welding system and equipment qualification, mockup, and testing are inevitable parts of the development and implementation of any welding system in an application such as the MRS. Inherent differences between the alternative systems being considered here influence the confidence and ease of achieving this qualification. In general terms, this is accomplished through a series of steps that include specifying and obtaining a prototype welding system; planning a development program and sequence; designing and obtaining mockups; simulating the key elements of the actual installation; making, examining, and repeating welds; and defining and refining the equipment, the process, and its variables. The result of these steps is the qualification of the welding system and its equipment.

The results of this comparison are presented in Table 4-1 and described in more detail in subsequent sections.

4.1 ESTABLISHING QUALIFICATION MOCKUP FACILITY

This subcategory addresses the issues to be considered in establishing and setting up a qualification mockup facility that would be used to qualify a welding system for use at the MRS Facility.

The concerns addressed in this subcategory comparison include;

(1) Space requirements
(2) Hot cell simulation

Because the mockup system must represent the actual system that will be used at the MRS Facility, it should resemble it, including the surrounding environment (e.g., walls, floor, door, and lights) to the fullest extent possible. This subcategory, therefore, considers the in-cell and out-of-cell space requirements of each welding system and the ease with which the hot cell environment can be set up for qualifying a system.

For this subcategory, the TIG, MIG, and PAW systems were ranked equal but above the LBW, RUW, and INW systems because of the similar nature of their equipment, their operating processes, and their required hot cell simulation. Each of the three systems will require an equal amount of in-cell space because of their similar design and will require equal amounts of out-of-cell space; for their supporting utility equipment (gas, coolant, electric, etc.). All systems will require modifications and enhanced design

Table 4-1 - Qualification of Mockup and Testing Program

1. Establishing Qualifications for Mockup Facility (17)

   A. Space requirements (13)
   B. Hot cell simulation (6)

2. Specifying Qualification Testing Program (Subcategory) (10)

   A. Weld mockup design (16)
   B. Number of variables for test (9)
   C. Flexibility (11)

3. Weld Process Qualifications (Subcategory) (9)

   A. Verification of welds (6)

Category Weight		Sub Cat. Weight		Topic Weight			TIG		MIG		PAW		LBW		IMW		RUW		Total
II	21.0	1.0	17.0	A	13.0	2.0	26.0	2.0	26.0	2.0	26.0	4.0	52.0	6.0	78.0	5.0	65.0	21.0	273.0
				B	6.0	2.0	12.0	2.0	12.0	2.0	12.0	4.0	24.0	6.0	36.0	5.0	30.0	21.0	126.0
	Subtotal						646.0		646.0		646.0		1,292.0		1,938.0		1,615.0		6,783.0
Ease of Qualifications of Mockup and Testing Program		2.0	10.0	A	16.0	2.0	32.0	2.0	32.0	2.0	32.0	4.0	64.0	6.0	96.0	5.0	80.0	21.0	336.0
				B	9.0	6.0	54.0	5.0	45.0	4.0	36.0	3.0	27.0	1.5	13.5	1.5	13.5	21.0	189.0
				C	11.0	4.5	49.5	4.5	49.5	4.5	49.5	4.5	49.5	2.0	22.0	1.0	11.0	21.0	231.0
	Subtotal						1,355.0		1,265.0		1,175.0		1,405.0		1,315.0		1,045.0		7,560.0
		3.0	9.0	A	6.0	5.5	297.0	5.5	297.0	3.5	189.0	3.5	189.0	1.5	81.0	1.5	81.0	21.0	1,134.0
	Total						48,258.0		46,368.0		32,210.0		60,606.0		70,014.0		57,561.0		325,017.0

features to make them remotely attachable onto and detachable from the canister, and to enhance and simplify the change-out of their electrodes, filler wire (TIG, MIG), and utility lines. However, these modifications will not require any significant additional in-cell space. The systems will require the same type of hot cell simulation, consisting of a rectangular box structure with the system components attached to the roof.

The LBW system was ranked fourth behind the TIG, MIG, and PAW systems because of its greater space requirements and more detail required to simulate a hot cell environment. The physical layout of the transfer tubes and rotating focusing head needed to rotate the beam around the canister will be somewhat sophisticated, and will require more in-cell space. The out-of-cell space, necessary to house the laser generator, is comparable to the support equipment required for the TIG, MIG, and PAW systems. The hot cell simulation will need to simulate the primary shield wall and the transparent window through which the laser will penetrate.

The RUW and INW systems were ranked fifth and sixth, respectively, in this subcategory because of their greater in-and-out-of-cell space requirements and the more extensive nature of simulating the hot cell environment. The two systems are similar in equipment layout and should occupy comparable space within the hot cell. However, the RUW system requires less out-of-cell space. The RUW system out-of-cell equipment consists primarily of either an ac transformer or generator and a forge press with its support equipment. The INW system equipment consists of a flywheel and a forge press with its support equipment. The forge presses of both systems are quite similar in size; however, the flywheel for the INW system (depending on its design characteristics) could be of large diameter, thereby requiring more out-of-cell space. For hot cell simulation, both systems will require more elaborate designs and setups because of the need to simulate the primary shielding wall that the forge rams transverse through and the need to design, build, and install the forge presses and restraints. Of the two systems, the RUW system hot cell simulation is judged to be simpler to perform because of the simOler nature of the forge press and restraints. The RUW system forge press translates through the primary shield wall, whereas the INW system translates and rotates. The simpler translating operation of the RUW system does not require bearings and permits simpler shielding and bellows (seal) designs. The RUW restraint design and simulation are judged to be simpler as it need resist only axial loads, whereas the INW system must resist both axial and torsional loads.

4.2 SPECIFYING QUALIFICATION TESTING PROGRAM

This subcategory addresses the ease of qualifying the mockup and testing program. The major topics considered in this comparison are:

(1) Weld mockup design
(2) Number of variables for test
(3) Flexibility

The RUW system was ranked first in this subcategory because of its few operational variables and its enhanced flexibility compared to the remaining systems. The RUW operation depends on only three variables (current, forge pressure, and time) to perform a proper weld, and it was reasoned that the fewer the number of process variables, the simpler the operation. This feature should facilitate mockup testing and qualification by shortening the qualification time period and reducing the time required to determine the proper variable ranges for successful welds. By controlling the contact arm of a variable transformer or the input field excitation level of a generator, the output current can be controlled to meet the demands of operation. This feature enhances the flexibility of the RUW system in mockup testing and in actual operation, and simplifies the welding of different-diameter canisters. Forge pressure is also easily controlled to provide necessary force to forge different-diameter canisters. However, it should be noted that, when welding different-diameter canisters, for mockup and actual operation, the electrode configuration on the end of the forge ram must be of sufficient size to properly transmit electrical current in a uniform manner near the rim of the end cap. This necessity will require some innovative design of the electrode or the installation of a larger electrode, when required. Another disadvantage of the RUW system for mockup testing is the consumption of a full-scale canister for each test. Full-scale canisters will be required to properly test the welding, forging, and forge-restraint capabilities of the system. This necessity will add additional costs to testing.

The PAW system was ranked second behind the RUW system because, even though the canister mockup design is simpler, the number of operating variables is greater and system flexibility is limited. The PAW system operation is dependent on arc current, arc voltage, plasma pressure and flow, welding head rotation speed, shield gas pressure and flow, and welding head coolant flow. These additional variables complicate the test procedure and the derivation of the variable values necessary for a successful weld. This complication will extend the qualification time and increase the testing program effort. The PAW system must rotate about the canister, thus requiring an alignment/guide track plus a method of preventing short circuiting of the electrode by weld pool material that may drop onto the electrode in the 5 to 7 o'clock position of the weld. The alignment/guide track for the system will complicate the ability of the PAW system to weld different-diameter canisters in both mockup testing and actual operation because the guide tracks are designed to fit a specific size of canisters. For the above reasons, the PAW system flexibility is decreased. An advantage of the PAW system is that it does not require full-scale canister mockups, and numerous welds per mockup can be made.

The MIG system was ranked third in this subcategory because of the great number of operating variables and decreased flexibility compared to the RUW and PAW systems. The system has approximately 14 operating variables: arc current, arc voltage, dwell time, excursion time, filler metal feed rate, rotational speed, etc. These additional variables complicate the test procedures and derivation of the variable values necessary for a successful weld. This complication will extend the qualification time and increase the

testing program effort. The MIG system requires an alignment/guide track and its associated problems, as previously stated for the PAW system, which limits its flexibility to weld different-diameter canisters. An important advantage of the MIG system is that each mockup test can use foreshortened canisters and numerous welds per mockup can be made.

The INW system was ranked fourth because the system has less flexibility than the RUW system and has a more complicated canister mockup design. The INW system must have the capability of welding different-size canisters, which requires specifically designed interlocking chucks to maintain alignment between the mating surfaces of the materials during the welds. A universal chuck that would accept all canister and lid configurations would be a complex design; it may be more feasible to design separate chucks to handle different-size canisters. If the latter design approach is taken, the system flexibility is substantially reduced. The INW system is similar to the RUW system in that it operates through the control of only three variables. Therefore, characterizing and addressing values necessary for making a good weld in the mockup testing program are minimal. The primary testing disadvantage of the INW system is that each mockup test will require the use of a full-scale canister mockup, and only one weld per test can be made. In addition, slipproof end caps must be supplied for testing, thereby decreasing the simplicity of canister mockup requirements.

The TIG system finished fifth in this subcategory because of the large number of variables: arc current, arc voltage, dwell time, excursion time, filler metal feed rate, rotation speed, etc. The disadvantage of the large number of variables is the same as discussed for the PAW and MIG systems. This system requires a dedicated alignment/guide track, restricted to a certain size range of weld specimens, which will limit its flexibility and complicate mockup testing. A testing advantage of the TIG system is that canister mockups can be foreshortened and numerous welds per canister can be made. TIG was ranked below MIG only because TIG requires a filler metal feed wire and an electrode, whereas for MIG the filler metal feed wire is the electrode.

The LBW system was ranked sixth in this subcategory because of its poor flexibility and the number of welding variables. The system is less flexible than the RUW and INW systems because of the difficulty of radially adjusting the rotating focusing mirror to maintain a proper focal point for welding different-size canisters. The proper adjustment of the final focusing mirror is important for a successful weld because it has a specific radius of curvature and, therefore, a specific focal length; this makes proper alignment/positioning very sensitive. The LBW system will also be more difficult to mock up than the other systems because of the nature of its equipment (transfer tube, welding head). To perform a proper weld, the rotational speed, output beam flux, focal length distance, and purge gas flow must be addressed and characterized to determine their optimum magnitudes. An advantage of the LBW system is that the canister mockups can be foreshortened for weld testing and numerous welds can be made on a single mockup.

4.3 WELD PROCESS QUALIFICATION

Under this subcategory, the ease with which the weld process can be qualified is considered. A qualified weld process is one that produces welds that have a high probability of passing both the ultrasonic and helium-leak tests. In addition, because of the restrictive hot cell environment, a qualified weld should be capable of being produced by matching the variable weld parameters to previously established technical variable limits. This offers the possibility of having an accept/reject criterion based on comparison of the monitored parametric values with "graphs" of previously tested welds.

Within this subcategory, the RUW and INW systems were judged to be equal and the easiest to verify among the six systems. This ranking results from the autogenous, solid-state nature of the weld and the few operating variables that control the quality of the weld. Both INW and RUW produce welds with smaller amounts of porosity, inclusions, and discontinuities than nonautogenous processes and with minimal carbide precipitation[1] because of the localized, quicker heating and cooling associated with these processes. These welds are judged to have the greater probability of passing both the ultrasonic and helium-leak tests. The small number of variables that need to be controlled and monitored also simplifies and supports the verification of a good weld through the matching of monitored variables to established technical variable limits.

The PAW and LBW systems were ranked equal for this subcategory, behind the RUW and INW systems, but ahead of the TIG and MIG systems. As compared with the RUW and INW systems, the PAW and LBW systems have a greater number of variables that must be monitored, controlled, and compared to established technical limits to verify that an acceptable weld has been made. Both systems are essentially autogenous welding processes and will produce welds with characteristics similar to the solid-state processes, but not of the same quality (porosity and inclusions). There is a greater probability of carbide precipitation with these processes because of the intense, localized heating. For these reasons, it is believed that welds produced by these systems will not have as great a probability of passing both the ultrasonic and helium-leak tests.

The TIG and MIG systems were ranked last in this subcategory because the welds produced by both systems depend on the greatest number of operating variables; also, a great amount of heat is transferred into the weld zone, making the weld susceptible to carbide precipitation. In addition, these

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[1] A complete discussion of the deleterious effects of carbide precipitation is beyond the scope of this document. Briefly, however, in the "sensitization" temperature range, carbon in the alloy combines with some of the chromium, and this carbide precipitates to the metal grain boundaries. The adjacent grains, now low in chromium, are easily corroded. The material is said to be "sensitized."

welding systems are nonautogenous in nature, thus producing welds with the greatest potential for porosity, discontinuities, and impurities. For these reasons, it is believed that welds produced by these systems will have the greatest probability of failing either the ultrasonic or helium-leak test.

5.0 COMPARISON OF WELDING SYSTEMS FOR CONSISTENCY CATEGORY

This category presents a comparison of welding systems with respect to consistency. Weld consistency is achieved by performing a weld of the same integrity and quality, each and every time, for each and every canister. It is considered to be a function of two major items:

(1) Continuous operational reliability
(2) Ease of maintenance

Results of this comparison are presented in Table 5-1 and described in more detail in subsequent sections.

5.1 CONTINUOUS OPERATIONAL RELIABILITY

This subcategory addresses the operational reliability of the welding systems. Operational reliability is considered to be a direct function of the reliability of the equipment that controls and establishes the parameters of the process, and that produces the weld. (Given that all parameters are within technical limits, sound welds will be produced.) The concerns addressed in this subcategory comparison are:

(1) Process parameters and variables
(2) Number of dynamic components
(3) Number of operational steps

High reliabilities can be designed and built into more complicated systems; however, starting with an inherently simple approach makes achieving reliable performance "easier."

The RUW system has the highest ranking in this subcategory. The RUW system is composed of five primary components and produces welds through the adjustment of three weld variables. The five primary components are the forge press, ac transformer or generator, electrodes, force restraint, and chuck mechanisms. The three weld variables are current, time, and forge pressure. For the process, no filler material, cover gas, or special weld preparation is required. The weld is formed between the canister and lid in a single operational step, and is simple to automate, monitor, and control.

The INW system is ranked second in this subcategory. The INW system is composed of four primary components and produces welds through the adjustment of three weld variables. The four primary components are the forge press, drive train and flywheel, chuck mechanisms, and forge

Table 5-1 - Consistency

1. Continuous Operational Reliability (6)

   A. Process parameters and variables (6)
   B. Number of dynamic components (14)
   C. Number of operational steps (16)

2. Ease of Maintenance (12)

   A. Number of dynamic components (13)
   B. Remote maintenance components (8)
   C. Contact maintenance components (15)

Category Weight		Sub Cat. Weight		Topic Weight		TIG		MIG		PAW		LBW		INW		RUW		Total
III	10.0	1.0	6.0	A	6.0	5.5	33.0	5.5	33.0	3.5	21.0	3.5	21.0	1.5	9.0	1.5	9.0	21.0	126.0
				B	14.0	5.5	77.0	5.5	77.0	4.0	56.0	2.0	28.0	3.0	42.0	1.0	14.0	21.0	294.0
Consistency				C	16.0	5.5	88.0	5.5	88.0	3.5	56.0	3.5	56.0	1.5	24.0	1.5	24.0	21.0	336.0
	Subtotal						1,188.0		1,188.0		798.0		630.0		450.0		282.0		4,536.0
		2.0	12.0	A	13.0	5.5	71.5	5.5	71.5	4.0	52.0	3.0	39.0	2.0	26.0	1.0	13.0	21.0	273.0
				B	8.0	4.5	36.0	4.5	36.0	4.5	36.0	4.5	36.0	1.5	12.0	1.5	12.0	21.0	168.0
				C	15.0	5.0	75.0	5.0	75.5	5.0	75.5	3.0	45.0	1.5	22.5	1.5	22.5	21.0	315.0
	Subtotal						2,190.0		2,190.0		1,956.0		1,440.0		726.0		570.0		9,072.0
	Total						33,780.0		33,780.0		27,540.0		20,700.0		11,760.0		8,520.0		136,080.0

restraints. In this regard, it is similar to the RUW system; however, the INW system requires a more complex forge restraint to resist both axial and torsional loads. In addition, the forge press will require a more complex sealing and shielding arrangement about the translating and rotating shaft at the cell wall penetration. The welding operation is controlled by three variables (rotor speed, forge pressure, and time) and is performed in a single operational step. For this process, no filler metal, cover gas, or special weld preparation is required. These three factors are comparable to those of the RUW system.

The LBW system was ranked third in this subcategory because of the greater number of process variables and the more extensive dynamic nature of the system components. The system rotates about the canister and produces welds based on the head rotation speed, focal point distance and alignment, purge gas flow, and mirror coolant flow. The laser system is composed of a generator and a laser beam transfer and guidance tube. In terms of dynamic components, the generator is a self-contained unit with few if any moving components. However, the beam transfer tube is a specifically configured tube with mirrors mounted at specific orientations. The mirrors optically reflect the laser beam and direct it toward a final focusing mirror, which will focus the beam necessary to produce a weld.

For the MRS application, a portion of this tube system must rotate about the canister, yet maintain the focal point of the beam in an appropriate fashion to weld. It should be noted that the final focal point of the beam is extremely sensitive to the proper alignment of all the mirrors in relationship to each other. The mirrors located along the tube are motor-mounted and will have three-dimensional alignment capability. These motors further complicate the nature of the equipment. The weld operation will be performed in a single pass operation; however, because of the time necessary to produce a weld (5 minutes), the mirrors will need to be cooled to prevent thermal distortion and the transfer tube will need to be nitrogen purged to mitigate thermal blooming. These additional operations and components further complicate the system.

The PAW system ranks fourth for this subcategory because of the higher uncertainty of the process reliability. These uncertainties are caused by the small, yet intricate nature of the equipment, and the larger number of welding variables that control the quality of the weld. If any of the welding variables (arc current, arc voltage, plasma gas flow rate, torch head rotation speed, torch head coolant flow, etc.) is improperly set, the PAW process could initiate weld pool slumping or dripping, or carbide precipitation, which could sensitize the canister material. Weld pool matter, if dropped onto the electrode, could quench the welding arc, interrupting operations. Alignment is critical for the PAW system when compared to some of the alternatives and, if it is improperly aligned, parent material, not located at the welding interface, could be damaged. The dynamic nature of the equipment includes many small drive motors, which are responsible for positioning the torch head and rotating it about the canister. These are undesirable features, and are the reasons for the lower reliability of the PAW system in a production mode within a hot cell

environment. The PAW system welds in a single operational step, but will require "prewrapping" its utility lines before welding. Finally, the PAW system requires two gases to support operations.

The MIG and TIG systems were ranked equal but behind the other four systems for this subcategory because they have the greatest number of operating variables, an intricate design, and require multipass operation. Both systems are dependent on many variables (arc current, arc voltage, plasma gas flow rate, torch head rotation speed, torch head coolant flow, etc.) to produce welds of acceptable quality. These variables complicate and reduce the overall reliability of the system because any one of them can be improperly set or can move from its intended setting during operation. Both systems are small, intricate welding systems, having welding torches positioned by numerous small servomotors. Motors are required for torch head positioning, torch head oscillating, system rotating, and filler wire feeding. The small size of the components and the number of the positioning motors and sensors that control them reduce system reliability. The system functions by depositing weld filler material into a weld-preparation area, and usually requires numerous passes to complete a weld. This multipass mode of operation is undesirable and, along with the other disadvantages of the systems, are the reasons for their low ratings.

5.2 EASE OF MAINTENANCE

This subcategory addresses the maintenance requirements of the alternative welding systems. The concerns addressed in this subcategory are:

(1) Number of dynamic components
(2) Remote maintenance components
(3) Contact maintenance components

The systems were considered from the standpoints of both in-cell and out-of-cell maintenance. Preference was given to those systems considered, inherently, to require the least amount of maintenance. Also considered was the ease with which maintenance could be performed and specifically the ease with which maintenance could be performed remotely.

The RUW system was ranked the highest in this subcategory. This system is constructed of only a few moving parts, all of which are sturdy, rugged, and amenable to overdesign. Because of the large components associated with the system, maintenance is considered to be easier because of the reduced number of handling operations. The components of the RUW system that are the most complex and have the greatest probability of failure (forge press, hydraulic supply system, and transformer or generator) are located outside the cell in an accessible maintenance room. There, hands-on maintenance can be performed in an expedient manner. The components located within the cell (electrodes, chucks, and forge press restraints) are large, rugged components and should rarely need maintenance. If they do, remote handling will be required for removal, replacement, and realignment.

The INW system ranks second because of its more complicated design and its additional dynamic components. Like the RUW system, INW is constructed of large, rugged components that are amenable to overdesign, thereby reducing maintenance requirements. This system consists of large components that will reduce handling during maintenance operations. The maintenance complications of the INW system are within the design and construction of the flywheel and forge press system (notably the bearings, chuck assembly, and the forge press axial and torsional restraints). The flywheel, lid chuck, and shaft assemblies are rigidly attached to the forge press, and must rotate and translate with it. This will require special bearings, bellows, and shielding where the shaft penetrates the cell wall. As in the RUW system, the flywheel and hydraulic supply system will be located out-of-cell in an accessible maintenance room for easy, hands-on maintenance. Torsional as well as axial restraints are also necessary for the INW system. These restraints and chucks will be located within the cell, and will require remote handling. Because of their more complicated design, it is believed that their maintenance will be more frequent than that of the RUW system.

The LBW system is ranked third because of the difficulty of maintaining, aligning, and calibrating the mirror/transfer tube system. The mirror system is dependent on proper alignment and, if misaligned, will probably require hands-on maintenance. It is likely that, if this happens, the entire transfer tube system would be removed from the cell and replaced. For the required MRS weld orientation, the mirror system must direct the beam around the canister, and will be a dynamic, rotating system. Maintenance requirements for a dynamic system versus a static system will be more extensive. The mirror cooling systems and drive assemblies could also complicate maintenance of the mirror system. The laser generator, however, will be mounted in the accessible maintenance room for easy, hands-on maintenance.

The PAW system was ranked fourth because of the greater difficulty of performing remote maintenance, the inability to perform contact maintenance, and the physical design of the system. The PAW system would be almost entirely located within the hot cell. System gas, coolant, and electrical supply units, which have the least probability of failure, will be located in the accessible maintenance room for easy, hands-on maintenance. Because of the system layout, the components with the greatest probability of failure (small servomotors for positioning and rotating the welding torch, electrode, etc.) will be located within the hot cell. The size, number, and location of these motors will require a number of remote handling operations and, in some cases, the entire system may need to be removed from the cell and replaced.

The MIG and TIG systems were ranked equal, but last, because of the complicated nature of remote maintenance performance and the intricate design of the system components. The control and utility supply consoles are reliable pieces of equipment, and would be remote from the cell in the accessible maintenance room for easy, hands-on maintenance. However, the actual welding systems will be located within the cell, and will be designed for remote attachment onto and detachment from the canister. As in the case of the LBW system equipment failure, the entire in-cell unit would be

removed from the cell and replaced with an identical unit. The faulty unit will then be decontaminated and repaired by contact maintenance. Because the in-cell equipment performance is dependent on proper alignment, special fixtures and care in replacement will be required. Routine replenishing of the system's consumables (electrodes, filler material) and calibration also influence the maintenance ranking of these systems.

6.0 COMPARISON OF WELDING SYSTEMS FOR WELDING SYSTEM COST CATEGORY

This category presents a comparison of the costs associated with a welding system that is compatible to the MRS welding operation. It is considered a function of four major items:

(1) Engineering and development
(2) Mockup and testing costs
(3) Capital costs
(4) Canister costs

The results of this comparison are presented in Table 6-1 and described in more detail in subsequent sections.

6.1 ENGINEERING AND DEVELOPMENT COSTS

This subcategory considers the costs that will be associated with modifying an available welding system to meet the requirements of the MRS. Priority was given to systems requiring the least modification and lowest associated costs. No reliable costs have yet been established for any system, so the costs are based solely on subjective estimates.

For this subcategory, the RUW and INW systems were rated equal and above the other four systems. These two systems were judged to have lower engineering and development costs as no major modifications or design changes are envisioned for making either system compatible to the MRS requirements. These systems, upon procurement, will be compatible to their intended environment, and only slight modifications should be necessary.

The PAW, TIG, and MIG systems were ranked equal but below the RUW and INW systems because of the additional engineering and development costs that will be necessary to modify the systems to be fully compatible with the MRS operations. The welding operation at the MRS Facility is to be fully and remotely automated, including the attachment of the welding system to the canister and its detachment. For these three systems, substantial engineering and associated development costs will be incurred to make this operation possible. The principal costs will be associated with designing a robotic type of subsystem to remotely attach the system to a canister and detach it. All three systems will require a similar subsystem.

The LBW system was ranked last because substantial engineering and development costs will be incurred in designing the transfer tube, mirrors, and mirror

Table 6-1 - Welding System Costs

1. Engineering and Development (13)

2. Mockup and Testing Cost (13)

3. Capital (14)

4. Canister Costs (14)

Category Weight		Sub Cat. Weight		Topic Weight			TIG		MIG		PAW		LBW		IBW		RUW		Total
IV	25.0	1.0	13.0	A	1.0	4.0	52.0	4.0	52.0	4.0	52.0	6.0	78.0	1.5	19.5	1.5	19.5	21.0	273.0
		2.0	13.0	A	1.0	2.0	26.0	2.0	26.0	2.0	26.0	4.0	52.0	6.0	78.0	5.0	65.0	21.0	273.0
Welding		3.0	14.0	A	1.0	1.5	21.0	1.5	21.0	3.0	42.0	4.0	56.0	5.5	77.0	5.5	77.0	21.0	294.0
System		4.0	14.0	A	1.0	4.5	63.0	4.5	63.0	2.5	35.0	2.5	35.0	6.0	84.0	1.0	14.0	21.0	294.0
Costs																			
Total							4,050.0		4,050.0		3,875.0		5,525.0		6,462.5		4,387.5		28,350.0

mounts; the rotating/focusing mirror and mirror mounts; and the control system. This type of tube system is unavailable from laser manufacturers as an off-the-shelf item.

6.2 MOCKUP TESTING COSTS

This subcategory considers the costs associated with the mockup testing of any of the welding systems. The least cost obviously was judged most favorable.

For this category, the TIG, MIG, and PAW systems were rated equal but above the other systems because of the simpler mockup requirements for testing these systems. The rationale for LBW, RUW, and INW is fully explained in Section 2.

6.3 CAPITAL COSTS

This subcategory subjectively considers the initial capital expenses that would be incurred in purchasing a welding system. The least cost was judged most desirable.

The TIG and MIG systems require the least initial capital cost because of their size, complexity, number of components, availability, and simplicity of control. These systems, however, will require substantial modifications.

The PAW system was rated third because, even though it is similar to a TIG or MIG welding system, it is less available from manufacturers and would be a special order. This will increase its initial capital cost.

The LBW system is ranked fourth. It ranks behind the PAW system because of the associated costs of its transfer tube system, mirrors, mirror mounts, and mirror-alignment control units. Depending on its size, the laser generator is relatively inexpensive.

The INW and RUW systems require the greatest capital costs because of their size, complexity, and support subsystems. These systems will also be unique; therefore, cost will be increased.

6.4 CANISTER COSTS

This subcategory considers the costs associated with procuring canisters for the welding system. Priority was given to the welding systems that require a canister that does not need excessive weld preparation or special lid configuration.

The RUW system received the top ranking because the canister requires no special weld preparation, and the lid is a simple, circular, flat plate that is readily available.

The PAW and LBW systems were ranked equal but below the RUW system because these welding systems require a flat butt joint to be machined onto the welding surface of the canister and the flat circular lid.

The TIG and MIG systems were ranked equal and below RUW, PAW, and LBW because they require a beveled weld preparation on both the mating surfaces of the canister and the circular, flat lid.

The INW system was ranked last because it requires a slipproof lid design for the welding operation. The lid must be capable of being locked into the chuck of the forging ram, and under no condition can it become detached. This will require additional machining and added costs.

7.0 COMPARISON OF WELDING SYSTEMS FOR SYSTEM IMPACT CATEGORY

This category presents a comparison of welding systems with respect to a variety of impacts or constraints that they could impose on the MRS Facility welding station. It is considered to be a function of three major items:

(1) Canister configuration
(2) Programmatic implementation
(3) Space requirements

The results of this comparison are presented in Table 7-1 and described in more detail in subsequent sections.

7.1 CANISTER CONFIGURATION

This subcategory addresses the impacts and constraints that a welding system imposes on the canister and lid configuration. Areas of impacts and constraint include:

(1) Weld preparation required for canister and lid.
(2) Ease of achieving shape and alignment requirements of weld joint.
(3) Degree of weld control.
(4) Flexibility of system to handle different-size canisters.
(5) Lid design.

The selection of any system is directly related to these five impacts. Rankings were designated according to the systems that have the least impact.

The RUW system was ranked first in this subcategory because it is judged to impose the least constraints. For the RUW system, therefore, a saw cut on the canister end, perpendicular to the pipe axis, will suffice as preparation for this welding process. Little weld preparation is necessary for the pipe ends, and tolerances at the weld interfaces are not stringent. The lid design required for the RUW system is a flat, circular plate, which can be procured at minimum cost. Alignment of the mating pieces is important and will require provisions for maintenance during forging. Some degree of control of the chemistry of the weld can be accomplished through adjustment of the current magnitude and forge pressure. The RUW system requires extremely high current

Table 7-1 - Welding System Design Impact

1. Canister Configuration (8)

   A. Weld preparation (19)
   B. Alignment (26)
   C. Weld control (10)
   D. Flexibility (15)
   E. Lid design (20)

2. Programmatic Implementation (12)

   A. Additional studies (6)

3. Space Requirements (11)

   A. In-cell space (6)
   B. Out-of-cell space (11)
   C. Inventory space (17)

Category Weight		Sub Cat. Weight		Topic Weight			TIG		MIG		PAW		LBW		IMW		RUW		Total
V	23.0	1.0	8.0	A	19.0	5.5	104.5	5.5	104.5	3.5	66.5	3.5	66.5	1.5	28.5	1.5	28.5	21.0	399.0
				B	26.0	3.5	91.0	3.5	91.0	3.5	91.0	3.5	91.0	3.5	91.0	3.5	91.0	21.0	546.0
Welding				C	10.0	5.5	55.0	5.5	55.0	4.0	40.0	3.0	30.0	1.5	15.0	1.5	15.0	21.0	210.0
System				D	15.0	4.0	60.0	4.0	60.0	4.0	60.0	6.0	90.0	2.0	30.0	1.0	15.0	21.0	315.0
Design				E	20.0	3.0	60.0	3.0	60.0	3.0	60.0	3.0	60.0	6.0	122.0	3.0	60.0	21.0	420.0
Impact																			
	Subtotal						2,964.0		2,964.0		2,540.0		2,700.0		2,276.0		1,676.0		15,120.0
		2.0	12.0	A	6.0	2.0	144.0	2.0	144.0	2.0	144.0	6.0	432.0	4.5	324.0	4.5	324.0	21.0	1,512.0
		3.0	11.0	A	6.0	2.5	15.0	2.5	15.0	2.5	15.0	2.5	15.0	5.5	33.0	5.5	33.0	21.0	126.0
				B	11.0	2.5	27.5	2.5	27.5	2.5	27.5	2.5	27.5	6.0	66.0	5.0	55.0	21.0	231.0
				C	17.0	3.5	59.5	3.5	59.5	3.5	59.5	3.5	59.5	3.5	59.5	3.5	59.5	21.0	357.0
	Subtotal						1,122.0		1,122.0		1,122.0		1,122.0		1,743.5		1,622.5		7,854.0
	Total						97,290.0		97,290.0		87,538.0		97,842.0		99,900.5		83,317.5		563,178.0
Grand Total							210,669.0		211,749.0		196,638.0		236,516.0		221,962.0		185,763.0		1,263,297.0

to be capable of welding different-size canisters. The area of the material to be welded is a limiting criterion of the RUW system, but any size of canister can be welded with an RUW system provided that adequate current and forging force are supplied. Forge restraints, however, would have to be upgraded to resist the greater forge forces that are needed as the area of material to be welded increases.

The INW system is second in this subcategory because of additional constraints that are imposed on the canister and lid. This system requires little weld preparation for the pipe ends, and tolerances at the weld interfaces are not stringent. The INW system is dynamic in nature; therefore, it requires a special, slipproof lid configuration to resist the high torsional and axial loads that are imposed on both the canister and lid during welding. Alignment of the two mating pieces is important and will require provisions for maintenance during forging. Weld control is judged to be more difficult because the rotational speed of the flywheel is obtained and released for forging. The INW system is capable of welding a variety of canister sizes, but is limited by the area of material to be welded. As in the RUW system, forge restraints, both torsional and axial, will have to be upgraded to resist the greater imposed loads that are needed as the area of material to be welded increases.

The PAW system was ranked third in this subcategory because of its restricted flexibility and the additional impacts imposed on the canister and lid alignment. The lid design for this system is a flat, circular plate that can be procured at minimum cost. Being an autogenous welding process, the system is sensitive to tolerances at the material interfaces. Alignment is critical and the pieces must be prepared for a butt weld. The system welds without forming a protruding weld joint, and produces an excellent weld configuration. However, because of the heat imparted by the welding process, weld pool slumping and carbide precipitation could occur. This could mandate using Type 304L stainless steel material versus the Type 304 stainless steel that can be used for the previously discussed systems. Using 304L for canisters and lids will cost significantly more over the life of the MRS Facility. As for versatility, the equipment is usually for a specific size of canister, and welding a variety of sizes would require design provisions.

The LBW system was ranked fourth in this subcategory, ahead of TIG and MIG. The system shares nearly all of the characteristics and problems of the PAW system, except that it was judged to have less weld control and flexibility, because it is imperative to maintain proper alignment among the mirrors even while they rotate. Alignment of the mating pieces relative to each other and to the laser beam focal point is also critical.

The TIG and MIG systems were ranked the lowest among the six systems because they impose numerous constraints on the canister and lid configuration; are dependent on mating-surface tolerances; and are usually dedicated systems for welding only a certain range of pipe sizes. However, the maintenance and shape of the weld joint for these systems, although important, is not as

difficult as it is for the RUW or INW system. Weld-preparation machining is mandatory for both processes, and tolerances must be watched closely if a proper weld is to be performed. Capability to accept canisters of different sizes is limited as a function of the welding head guide track. The requirement for a guide track for each size of canister welded is judged more complex than that of the INW and RUW systems, but less complex than that of the LBW system. Both processes impart large amounts of heat into the materials while welding and, if not properly accounted for, could proliferate carbide precipitation at the weld-joint interface and subject the canister to sensitization. Preventing this may require using 304L stainless steel, which would increase operational costs for the MRS Facility. The chemical quality of a weld can be controlled with acceptable results in using either of these two systems; however overheating of material, along with large grain growth and carbide precipitation, must be prevented.

7.2 PROGRAMMATIC IMPLEMENTATION

This subcategory addresses the possible effect of the welding systems on the programmatic implementation of the welding operation. The systems were screened to determine which would require additional studies and analyses to provide a basis for their acceptance as a welding operation within the hot cell, and what impact these studies could have on the program. Priority was given to the systems requiring the fewest additional studies.

The TIG, MIG, and PAW systems were ranked equal but above all other systems for this subcategory because their experience within hot cell environments demonstrates that they can function properly within a cell. Even though engineering design modifications will be necessary to bring the systems into compliance with the MRS requirements, few additional analyses or studies are anticipated.

The RUW and INW systems were ranked equal but behind the TIG, MIG, and PAW systems in this subcategory because of the additional studies required for these systems. Studies will be required for the RUW system to address concerns such as grounding loops, electromagnetically induced field currents, current shorts, electromagnetic noise and its impact on instrumentation, and electrocution prevention. For the INW system, safety studies will be required to verify the safety of the process (spinning lid in a hot cell) and to establish the precautions that must be integrated into the design of the system to preclude accidents. Studies will have to consider what possible mishaps could arise if the lid would detach from the chuck at full speed and become loose in the cell.

The LBW system was ranked the lowest in this subcategory because of the lack of in-cell experience and undocumented reliability of the rotating laser-beam mirror guidance system within a radioactive environment. Numerous studies will be required to define the environmental conditions within a hot cell that may affect the integrity of the rotating system, and to identify the shielding requirements and streaming effects associated with laser-beam penetration through the primary containment wall. Additional studies will be

required to establish the equipment logistics and their effect on beam quality. These studies will require analysis, and probably mockup testing, to establish the overall feasibility of the LBW system.

7.3 SPACE REQUIREMENTS

This subcategory addresses the impact of the welding systems on facility space. Consideration was given to the smallest space requirements necessary for a system and the welding systems requiring the least (and least complicated) inventory of parts. The concerns addressed in this subcategory comparison are:

(1) In-cell space requirements
(2) Out-of-cell space requirements
(3) Spare parts and consumable inventory

Within this subcategory, the TIG, MIG, PAW, and LBW systems were ranked equal but above INW and RUW. These systems will occupy less in-cell space because of the physical size of the components and less out-of-cell space because of the physical size of their utility supply units. Inventory space requirements for spare parts and consumables are considered minimal among all systems.

The RUW system was ranked fifth because of its greater in-cell and out-of-cell space requirements necessary for its bulky components (forge press, restraints, electrodes, hydraulic supply unit, and transformer or generator). Inventory space is judged equal to that of the four preceding systems.

The INW system was ranked last in this subcategory because it requires the greatest overall space requirements. The system's in-cell space requirement is considered equal to the RUW system's, but its out-of-cell space requirement is larger because of the flywheel, forge press, and hydraulic supply units. Inventory space is judged equal to that of all other systems.

8.0 CONCLUSION

The preceding comparison of welding systems was undertaken to subjectively analyze candidate welding systems for MRS application and to determine which system is most compatible with the MRS Facility requirements. Categories and topics were selected based on their importance to MRS Facility requirements, and rankings and weighted factors were applied through group review. Category subtotals were determined, and were summed to arrive at a grand total for each welding system. The final ranking of each system is shown in Table 8-1.

As noted in Table 8-1, the RUW welding system is best suited for the MRS Facility.

Table 8-1 - Welding System Ranking

	Sub Cat. Weight	Topic Weight	TIG	MIG	PAW	LBW	INW	RUW	Total
Grand Total			210,669.0	211,749.0	196,638.0	236,516.0	221,962.0	185,763.0	1,263,297.0
Final Rank			3	4	2	6	5	1	

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Battelle
Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509) 375-2684
Telex 15-2874

MRS 5.5-82

February 20, 1985

Mr. W. D. Woods
MRS Project Manager
Ralph M. Parsons Company
100 West Walnut Street
Pasadena, CA 91124

Dear Mr. Woods:

PROJECT D-360 MONITORED RETRIEVABLE STORAGE (MRS) FACILITY
CONTRACT DE-AC06-84-RL-10436

Welding System Trade-Off Study

Reference: P-PNL-206, dated January 22, 1985, same subject

The Parsons' study requires modification both from the technical mechanics of the weighting process and from the use of incomplete, misleading, or incorrect information during the detailed ranking exercise. The study should be revised to incorporate the information given in this letter. The weighting of the various categories should be revised similar to the discussion below concerning the technical validity of the method.

There are three main areas to be considered in the method of ranking the welding systems:

1) a clear and concise discussion or rationale for the preferred welding system;
2) proper application of the method; and
3) the technical validity of the evaluation method.

With regard to item 1) above, the evaluation method does not have an accompanying discussion of the rationale for the result. The report simply states that "... the RUW system received the lowest cumulative total and was, therefore, chosen to be the welding system most appropriate for the MRS application." (p. 12) No other explanation of the result is provided. This suggests that the numerical results provided the decision. It would be helpful to identify the "trade-offs" involved in selecting one system over another.

With regard to item 2) above, the proper application of the method, PNL does not feel qualified to judge the qualifications of the people involved in the process. (However, in reviewing the criteria there seems to be an

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important factor missing. Although it may be contained in several of the other factors, the flexibility or adaptability of the system to variations in either canister size or canister shape is not apparent. This seems to be an especially important factor since we don't know exactly what the canister configuration will be.)

With regard to item 3) above, the technical validity of the method itself, we generally approve of the use of ordinal ranking information at the very detailed level (attribute scores). However, the approach used to combine the attribute scores (or ranks) with the attribute weights is flawed. For a weighting method to be valid, the criterion, or in this case the category, that is judged most important should have the greatest influence on the final result. For the Parsons' data, consistency and technical maturity should have the greatest influence on the result. In fact, design impact has the greatest influence, per the Parsons' data. This is due to two factors. First, the most important factors are given a "low" value, and second, the number of points within a category depends upon how many subcategories and topics have been defined. Consequently, small differences between systems on design impact have a big influence on the final result since there are so many topics. In general, the weight assigned to a criterion should not depend upon the number of attributes used to describe that criterion. The effect of varying numbers of attributes must be corrected.

The attached table reworks the Parsons' data using a more consistent weighting approach. Category, subcategory, and topic weights are applied in the more traditional sense -- high values mean the factor is more important and will more strongly influence the final result. We have tried to maintain consistency in the relative magnitudes of all of the weights, and, in addition, have forced all weights to sum to 1.0 (also the weights on the subcategories under each category sum to 1.0 and the same at the topic level). For the Parsons' assigned categories I and II, weights of 11 and 21, respectively, were assigned. Category I is almost twice as important as II. Thus, we have assigned weights of .28 and .15, respectively, to the above categories. As a result, the numerical results that are reported are simply the weighted average rankings of the systems. These are expressed in the same units as were the original rankings for the topics. This approach has some intuitive appeal since we can now readily interpret the numerical result and it provides us with a measure of the degree of differentiation of the result -- there isn't much. As can be seen in the attached table, and using the same relative attribute weights, the RUW system is still preferred, with the INW system second. PAW is third, and the others are farther back.

Some general comments on the study follow:

1. The inertia welding process has only two independent variables - not three as noted in the study. The variable, time, is actually a dependent variable which is determined by the

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rotational speed and forge pressure and, therefore, is not an independent welding parameter. Only speed and pressure are preset and verified prior to making an inertia weld.

2. The study refers to "large copper bus bars" and current pulses of "approximately 50,000 A/sq. in. of material being welded." A calculation yields current levels of approximately 500,000 amps for the spent fuel canisters and overpacks and over 1.2 million amps for the larger canisters and overpacks. Even though the amperage requirements are not part of the RUW process per se, there is some concern that these high current levels can be produced for use at the MRS facility. Also, the connection of the electrodes to the canisters was not discussed in the study. This could present a formiable problem for this remote welding process.

3. The inertia welding process was degraded because of the possibility of a spinning end closure coming loose from the chuck in a hot cell. In actual practice, the spinning end closure is positioned in such close proximity to the stationery canister that escape from the rotating chuck is not possible. Outside the hot cell in the welding equipment cell, both RUW and INW process will have equipment with high speed rotating parts; the RUW process will have a high voltage electrical generator and the INW process will have a flywheel.

4. In the qualification test comparison section, the study stated that both the INW and RUW processes would expend full-size canisters for each welding test. In fact, only a short pipe segment would be needed for each test and an end closure could be welded to each end of the short pipe segment.

5. Under the cost comparison section, the RUW lid is specified as a simple flat plate. The canister drawings supplied with the 90% design review showed a thin-walled lip on the end closure mating with the canister wall. This error in the study requires correction.

6. No consideration was given to the fact that the largest welds yet performed by a RUW system are in the range of six-inch diameter pipe. There is no demonstrated evidence that welds can be made on the twelve-inch pipe or on the larger overpack canisters using the RUW method.

7. It appears that with the fuel canister in a horizontal orientation, all methods except RUW and INW would require the canister and lid to be rotated about their cylindrical axis during the welding process to avoid problems with the melted material running down the sides of the canister toward the lowest point

on the package. All experience to date, that we are aware of, uses this canister/welder configuration for this type of weld process. Either the assumptions at the beginning of the study need revision or the canisters would have to be welded while in a vertical orientation for these other welding process methods to be viable contenders. The latter choice would require design modifications of some size and handling methods somewhat more complicated prior to welding.

8. It is not clear why the number of welding variables is heavily weighted in the ranking factors. For a production operation, the variables are set at some established values and the trick is to have adequate allowance for variability. Once fixed in value, the number of process "variables" cease to be of major concern. On the other hand, the degree to which a system has been or can be remotized and automated should be a principle consideration for or against the selection.

Specific comments on the noted sections of the study follow:

2.1.1 Application of Past Experience, p. 14, first paragraph

The extrapolation of the E-MAD facility and B-Plant experiences to qualify the TIG and MIG processes 1 and 2, respectively, seems questionable. The gas tungsten arc system at the E-MAD facility welded a .10-inch penetration weld in the 2F position (vertical). This is not at all comparable to a system making .25-inch penetration weld with filler wire in the 5G position (horizontal). Great difficulties can be anticipated attempting to control the weld puddle on the underside of the MRS canister as mentioned earlier. Extensive problems are also anticipated in trying to achieve weld consistency. The 20 "prototype" canisters welded at the E-MAD facility hardly qualify as extensive experience. The welding system at B-Plant makes an autogenous weld (no filler), operated in the 1G position (canister rotates under the torch) and achieves .10-inch penetration. This system is also very different from that proposed for the MRS facility and, therefore, extrapolation of that experience is questionable.

2.1.2 Specifying and Obtaining Equipment

PNL has difficulty accepting this category as part of a welding system trade-off study. Complexity of specifications should have little or no influence on the process selection; what one needs is something that works rather than a process or equipment with simple specifications. The same comment applies to availability of vendors. None of the evaluated processes can be used in a "commercial configuration." All welding processes will have to be modified for hot cell application.

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3.1.2 Specifying Qualification Testing Program, p. 21, first complete paragraph

This is the only paragraph in this item in which separate chucks for each size of canister is mentioned. Does this indicate that the other processes, and in particular the RUW process, does not require different sized holding mechanisms for each size of canister? Alignment of the parts to be welded is critical in all the processes.

Simple devices can be used to accommodate canister size changes for most of the processes.

4.1.1 Continuous Operational Reliability, p. 23, last two paragraphs

The RUW system has five primary components and three welding parameters. The INW has four primary components and two (not three) welding parameters. On the basis of these two statements, the INW process inherently appears more simple and more reliable. Equipment complexity, however, must also be considered when assessing reliability. Inertia welding machines, many of which are larger and of greater capacity than those that could be used in the MRS facility, have been built and delivered to industry. Therefore, bearing, shaft, and hydraulic design have been well-proven and the reliability has been demonstrated. Design to use this system through a hot cell wall does not require unusual or non-existent technology and, therefore, should not cause more concern than any other hot cell design.

6.1.1 Canister Configuration, p. 31, last two paragraphs

PNL has difficulty accepting the statement: "A saw cut on the canister end, perpendicular to the pipe axis, will suffice as preparation for this welding process." This appears to be contradictory to the machined end closure shown on the canister drawings presented for the 90% design review. The Savannah River process was cited as the reference application for this process. In order to produce a weld of the quality required for MRS application, a joint design similar to that used in the Savannah River process may be required. This joint is not a simple flat cap on a pipe, but a tightly toleranced machined insertion plug configuration.

If the above is true, three of the five process advantages (1, 2, and 5) for RUW disappear, and instead become process liabilities.

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For the present design effort, including Task 2.B., it makes little difference whether the INW or RUW process is considered the design basis process. The required space envelopes are virtually identical and the resulting products are essentially equivalent. Therefore, regardless of which solid state welding process floats to the top as the "best" qualified process for the MRS facility, no change needs to be made to the conceptual design drawings; however, the study should be revised to reflect the comments in this letter.

During the follow-on design verification efforts, PNL will need to have both welding processes demonstrated and sample welds prepared of the appropriate size and shape to determine whether either process can actually weld canisters of the sizes planned for the MRS, and to permit detailed examination and testing of the welds for qualification.

If you have any questions concerning these comments, feel free to contact Roy Gale at (509) 375-2685 or myself.

Very truly yours,

DSJackson

D. S. Jackson
Technical Administrator
A-E Services

DSJ:RMG:gd
Attachment

cc: RB Goranson, DOE-RL
RJ Hall, PNL
RD Izatt, DOE-RL
FA Pace, DOE-RL
GS Rokkan, DOE-RL

			NET WEIGHT	TIG RANK	TIG NET WEIGHT	MIG RANK	MIG NET WEIGHT	PAW RANK	PAW NET WEIGHT	LBW RANK	LBW NET WEIGHT	INW RANK	INW NET WEIGHT	RUW RANK	RUW NET WEIGHT
TECHNICAL MATURITY															
0.28	0.67	0.25	0.047	3	0.141109	3	0.141109	3	0.141109	6	0.282218	3	0.141109	3	0.141109
		0.13	0.025	3.5	0.085892	3.5	0.085892	5.5	0.134973	5.5	0.134973	1.5	0.036811	1.5	0.036811
		0.17	0.031	2	0.062715	2	0.062715	2	0.062715	5	0.156787	5	0.156787	5	0.156787
		0.25	0.047	2	0.094072	2	0.094072	2	0.094072	5	0.235181	5	0.235181	5	0.235181
		0.20	0.038	1	0.037629	4	0.150516	4	0.150516	4	0.150516	4	0.150516	4	0.150516
	0.33	0.28	0.026	4	0.104246	4	0.104246	4	0.104246	6	0.156369	2	0.052123	1	0.026061
		0.36	0.033	1.5	0.049753	1.5	0.049753	3	0.099507	6	0.199015	4.5	0.149261	4.5	0.149261
		0.36	0.033	3.5	0.116092	3.5	0.116092	3.5	0.116092	3.5	0.116092	3.5	0.116092	3.5	0.116092
					0.691510		0.804397		0.903233		1.431154		1.037882		1.011821
EASE OF QUAL.															
0.15	0.21797	0.33	0.011	2	0.021579	2	0.021579	2	0.021579	4	0.043158	6	0.064737	5	0.053947
		0.67	0.022	2	0.043811	2	0.043811	2	0.043811	4	0.087623	6	0.131435	5	0.109529
	0.37046	0.24	0.013	2	0.026259	2	0.026259	2	0.026259	4	0.052518	6	0.078778	5	0.065648
		0.42	0.023	6	0.140049	5	0.116708	4	0.093366	3	0.070024	1.5	0.035012	1.5	0.035012
		0.34	0.019	4.5	0.085939	4.5	0.085939	4.5	0.085939	4.5	0.085939	2	0.038195	1	0.019097
	0.411622	1.00	0.062	5.5	0.339588	5.5	0.339588	3.5	0.216101	3.5	0.216101	1.5	0.092614	1.5	0.092614
					0.657227		0.633886		0.487058		0.555366		0.440773		0.375850
CONSISTENCY															
0.31	0.67	0.55	0.115	5.5	0.633382	5.5	0.633382	3.5	0.403061	3.5	0.403061	1.5	0.172740	1.5	0.172740
		0.24	0.049	5.5	0.271449	5.5	0.271449	4	0.197417	2	0.098708	3	0.148063	1	0.049354
		0.21	0.043	5.5	0.237518	5.5	0.237518	3.5	0.151148	3.5	0.151148	1.5	0.064777	1.5	0.064777
	0.33	0.29	0.029	5.5	0.161140	5.5	0.161140	4	0.117193	3	0.087894	2	0.058596	1	0.029298
		0.47	0.048	4.5	0.214244	4.5	0.214244	4.5	0.214244	4.5	0.214244	1.5	0.071414	1.5	0.071414
		0.25	0.025	5	0.126959	5	0.126959	5	0.126959	3	0.076175	1.5	0.038087	1.5	0.038087
					1.644694		1.644694		1.210024		1.031232		0.553680		0.425673
COSTS															
0.12	1	0.25	0.030	4	0.1216	4	0.1216	4	0.1216	6	0.1824	1.5	0.0456	1.5	0.0456
		0.25	0.030	2	0.0608	2	0.0608	2	0.0608	4	0.1216	6	0.1824	5	0.152
		0.25	0.030	1.5	0.0444	1.5	0.0444	3	0.0888	4	0.1184	5.5	0.1628	5.5	0.1628
		0.25	0.030	4.5	0.1332	4.5	0.1332	2.5	0.074	2.5	0.074	6	0.1776	1	0.0296
					0.36		0.36		0.3452		0.4964		0.5684		0.39
DESIGN IMPACT															
0.13	0.417721	0.17	0.009	5.5	0.051077	5.5	0.051077	3.5	0.032503	3.5	0.032503	1.5	0.013930	1.5	0.013930
		0.12	0.007	3.5	0.023752	3.5	0.023752	3.5	0.023752	3.5	0.023752	3.5	0.023752	3.5	0.023752
		0.32	0.018	5.5	0.097046	5.5	0.097046	4	0.070579	3	0.052934	1.5	0.026467	1.5	0.026467
		0.22	0.012	4	0.047052	4	0.047052	4	0.047052	6	0.070579	2	0.023526	1	0.011763
		0.18	0.009	3	0.026467	3	0.026467	3	0.026467	3	0.026467	6	0.052934	3	0.026467
	0.278481	1.00	0.036	2	0.072405	2	0.072405	2	0.072405	6	0.217215	4.5	0.162911	4.5	0.162911
	0.303797	0.53	0.021	2.5	0.052009	2.5	0.052009	2.5	0.052009	2.5	0.052009	5.5	0.114420	5.5	0.114420
		0.29	0.011	2.5	0.028368	2.5	0.028368	2.5	0.028368	2.5	0.028368	6	0.068084	5	0.056737
		0.19	0.007	3.5	0.025698	3.5	0.025698	3.5	0.025698	3.5	0.025698	3.5	0.025698	3.5	0.025698
					0.423878		0.423878		0.378837		0.529529		0.511726		0.462148
GRAND TOTAL					3.78		3.87		3.32		4.04		3.11		2.67

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SPENT FUEL CONSOLIDATION OPTIMIZATION STUDY

1.0 EXECUTIVE SUMMARY

The objective of this study was to determine a baseline for the conceptual design efforts for the pressurized water reactor (PWR) and boiling water reactor (BWR) spent fuel consolidation equipment to be used in the Monitored Retrievable Storage (MRS) Facility. Two parameters were identified as key to the concept specification: (1) wet versus dry environment, and (2) horizontal versus vertical orientation. To date, all demonstrated systems have been of the vertical, wet type designed for operation in the spent-fuel pools of nuclear power plants. These systems have shown that spent fuel can be consolidated safely, but, based on their production capacity, it was found that more consolidation stations would be required to achieve the same throughput when compared to a horizontal system.

The choice of consolidation methods affects component equipment designs and the layout of the MRS Receiving and Handling (R&H) Building. The major differences between horizontal and vertical operations are in system configuration, methods of fuel rod removal from the spent-fuel assembly, and fuel rod reconfiguration. In vertical operations, the fuel rods are gripped then pulled out of the support structure, and reordered in a transition canister; in horizontal operations, the fuel rods may be gripped, or pushed out of the support structure and reordered in a transition canister, or by using a combination of stationary and movable dies. Pulling horizontally was selected as the reference process based on fuel rod control, production rate, and physical system size.

The fuel consolidation process will be performed remotely in a shielded process cell. No operator entrance is required for normal operations. It is planned that the equipment will be modularized, and designed for remote removal and replacement when maintenance is required.

The operations incorporated into the production line of the fuel consolidation system include: (1) upper and lower end-fitting removal; (2) rod removal; (3) rod reordering and packaging; and (4) secondary waste handling for disposal. Multiple assemblies are processed simultaneously for greater efficiency.

Throughput specifications require a processing capability of 3,600 MTU/yr and the requirement that the facility be capable of accepting all types of fuel for light water reactors (LWRs).

Process and equipment descriptions are provided as a basis for system evaluation. The systems were evaluated according to many different criteria.

These included: (1) production rate; (2) system integration; (3) space requirements; (4) reliability; (5) contamination control; (6) secondary waste handling; (7) maintenance and associated As Low As Reasonably Achievable (ALARA) considerations; (8) off-normal events; and (9) equipment cost considerations.

The concepts presented in this study should be viewed as a starting point for development of a spent fuel assembly consolidation process and design of the system equipment. The system concepts have been described in sufficient detail for identification of critical process interfaces and potential problem areas. All components described for the disassembly and consolidation systems exist, but they must be adapted for production use in the MRS Facility.

Appendix A describes equipment selection of the advanced conceptual design of dry-horizontal consolidation equipment representing current design direction. Pre-reference conceptual design comparisons of consolidation equipment are also presented to provide the basis for equipment comparison and selection.

The studies have led to the conclusion that the requirements for the MRS Facility can best be met by using fuel assembly dismantling and fuel rod consolidation equipment that operates in air (dry) with the fuel assembly axis horizontal.

2.0 INTRODUCTION

On January 7, 1983, President Reagan signed the Nuclear Waste Policy Act of 1982, which commits the federal government to accept commercially generated nuclear waste for disposal in accordance with the schedule specified in the Act. The Act instructs the Department of Energy (DOE) to prepare a detailed study of the need for and feasibility of an MRS Facility. The roles of the MRS facility are to: (1) store spent fuel, high-level waste (HLW), and transuranic wastes (TRU) before disposal in a geologic repository; (2) store spent fuel until it can be reprocessed; and (3) store spent fuel, HLW, and TRU wastes indefinitely. Some of the operations which must be performed at the facility, and that are specifically called out in the MRS Functional Design Criteria (FDC) (Ref. 1), are the disassembly, consolidation, and packaging of fuel assemblies and/or their components. Fuel consolidation is accomplished by reducing the fuel rod center-to-center pitch to a value less than that of the intact fuel assembly. Fuel consolidation is important for maximum use of storage capacity in the MRS Facility or national repositories.

The overall purpose of this study was to establish a technical direction for further development of fuel rod consolidation equipment for an MRS facility. The major issues of concern, consistent with this purpose, were to evaluate and select between wet and dry environments and between vertical and horizontal orientations. Additional issues, comparisons, and selections that will enter into the development of a fuel consolidation system for an MRS Facility include such items as the methods used to extract the fuel rods from their supporting structure; the detailed configuration of the rod-

rearranging devices; and the methods used to remove the upper or lower (or both) end-fittings. A detailed development and evaluation of such methods is included in the scope of this study and is necessary to meet its objective; this study is presented as a starting point for prereference conceptual facility design, and forms the basis for conceptual design.

The wet versus dry comparison was completed on a generic basis. Advantages and disadvantages were defined independently of specific fuel type and operational orientation. The evaluation of vertical versus horizontal orientation for a consolidation system considered the major differences between PWR and BWR spent fuel designs.

In all, four major configurations are addressed in this study: wet-vertical, wet-horizontal, dry-vertical, and dry-horizontal. As discussed above, these were evaluated by comparing wet versus dry and vertical versus horizontal as essentially separate comparisons and as four discrete systems. Wet-vertical systems correspond to those for which industry data, designs, and some experience exist. They are, at least conceptually, adaptable to dry-vertical operations in the remote shielded process cell environment of an MRS Facility. For this reason, the basic elements, functions, and operational sequences that are used in current wet-vertical technology were used as the foundation of a dry-vertical system for this study.

The elements, function, and sequence of a horizontal system (whether wet or dry) had to be defined. This definition, in part, is a logical extension of existing, demonstrated, wet-vertical consolidation technology, but also includes information from the Allied General Nuclear Services (AGNS) demonstration of dry-horizontal consolidation in Table I (Ref. 4).

This study followed the approach outlined below:

(1) Review the existing consolidation equipment and assess its applicability to MRS.

(2) Establish consolidation system considerations, criteria, operations, and fuels to be handled with respect to MRS operating scenarios.

(3) Prepare designs representing the spectrum of major system options; i.e.. wet versus dry environments and horizontal versus vertical operations.

(4) Expand these systems to consider basic differences resulting from the designs of BWR or PWR fuels.

(5) Establish advantages and disadvantages of these systems in light of the previously established considerations, criteria, and operations.

(6) Perform a process time evaluation based on best estimates and operating experience to date.

(7) Perform a first-order trade study.

(8) Generate conclusions and recommendations based on the study findings.

(9) Include an appendix describing the dry-horizontal spent fuel consolidation system equipment selection.

3.0 BACKGROUND

Final specifications for the MRS Facility have not been completed. However, the present criteria (Ref. 1) require that the MRS Facility be designed to receive, disassemble, consolidate, package, seal, monitor, and store a minimum of 3,600 metric tons of uranium (MTU) per year, primarily as spent LWR fuel. This spent fuel is expected to consist of 60 wt% PWR fuel and 40 wt% BWR fuel. There are several fuel assembly designs within each of these reactor types; the effect of this on the MRS Facility will be discussed later.

Current consolidation techniques for spent fuel assemblies have been designed for use at commercial nuclear power plants to increase their spent fuel storage capacity. These techniques, and the hardware to support them, were developed for use in the reactor plant spent fuel storage pools. They perform with the fuel rods vertical, as they are stored in the pools. Thus, existing systems are classified as "wet-vertical," and it was from this perspective that this study started.

3.1 GENERAL FUEL CONSOLIDATION CONCEPT DESCRIPTION

In general terms, spent fuel consolidation consists of: (1) end-fitting severing and removal; (2) reordering fuel rods into a close-packed array; and (3) volume reducing of the remaining nonfuel-bearing structural components for disposal. More specifically, the basic steps leading to fuel consolidation at an MRS Facility are:

(1) Fuel assemblies are removed from reactor-site spent fuel storage pools, placed in reusable shipping casks, and transported to the MRS Facility by rail or highway.

(2) The assemblies are removed from the shipping casks and moved to the consolidation area where the end-fittings(s) are removed.

(3) The fuel rods are removed from the nonfuel-bearing, structural housing.

(4) The fuel rod array is reordered, consolidated, and placed in a storage container.

(5) The container is sealed and transported to a storage location.

(6) The nonfuel-bearing structure of the assembly is volume-reduced and packaged for onsite storage.

3.2 CONSOLIDATION EQUIPMENT DESIGNERS AND MANUFACTURERS

Many companies have demonstrated spent fuel consolidation equipment. The scope of these demonstrations has varied; some included actual radioactive assemblies, and others used simulated "dummy" assemblies. All of these demonstrations have shown the feasibility of the consolidation concepts. Table 1 lists these companies, the basic modes of operation (wet, dry, vertical, horizontal), and relevant comments about the processes. Of the systems listed in Table 1, it should be noted that only two, those of Westinghouse Electric Corporation (Item 3) and Maine Yankee Atomic Power Company (Item 6), have been used to consolidate actual fuel rods; the remainder have been demonstrated on "dummy" rods. In addition, the shredding system (Item 5 in Table 1) is not considered to be a practical concept for the MRS Facility because maintaining the integrity of the fuel rod cladding is mandatory at this time.

Two future consolidation demonstrations, with DOE participation, are planned, as shown in Table 2. One of these will use BWR assemblies; the other will use PWR assemblies.

3.3 CONCLUSIONS ON EXISTING DISASSEMBLY/CONSOLIDATION EQUIPMENT

Most consolidation systems use wet-vertical operations. The major reason is that existing consolidation equipment was designed for onsite use at individual utilities. Hence, the utility environment has dictated the design.

The rationale for vertical consolidation equipment becomes evident when one considers the space limitations in the spent fuel pool. The existing equipment has been designed to a specific utility specification. Consolidation equipment for MRS, however, will not have these constraints. In addition, this equipment must handle many types of fuel on a reliable, production basis.

Extensive modifications to existing equipment and processes must, therefore, be integrated with new design concepts to provide a production consolidation system that is capable of processing all fuel types and arrays. In the following sections, the development and evaluation of equipment and processes are discussed.

4.0 FUEL CONSOLIDATION SYSTEM CONSIDERATIONS AND CRITERIA

Many factors must be considered with respect to MRS fuel consolidation equipment. These include:

- Production rate
- System integration
- Space requirements
- Reliability
- Contamination control
- Secondary waste handling
- Maintenance and ALARA considerations

Table 1 - Designers and Manufacturers of Consolidation Equipment

Designer	Vertical	Wet	Horizontal	Dry	Comments
Nuclear Assurance Corporation (NAC) water basin spent fuel storage using disassembly pin	X	X			NAC has demonstrated consolidation of six different "dummy" PWR assemblies, representing all manufacturers of PWR fuel.
U.S. Tool & Die, Inc.	X	X			Testing was conducted on "dummy" fuel assemblies. In one pulling operation, the fuel rods are funneled into their consolidation container. However, both ends of the container must be sealed after the fuel rods are in the container. A 2:1 consolidation ratio was achieved.
Westinghouse Electric Corporation (WE)	X	X			WE demonstrated the consolidation equipment on four irradiated PWR fuel assemblies at the Oconee Nuclear Station in 1982. The equipment has built-in rod array control after removal. A 2:1 consolidation ratio was achieved.
Allied General Nuclear Services spent fuel consolidation Barnwell Nuclear Fuel Plant (BNFP)			X	X	The demonstration has shown that dry-remote consolidation is possible. Horizontal consolidation equipment requires a larger floor area but less height than vertical equipment. A 2:1 consolidation ratio was achieved with dummy PWR fuel.
Nuclear Power Systems; Boeing Engineering and Construction Corp.			X	X	This system shreds fuel rods and other nonfuel components of the assembly. The shredded material can be compacted into a canister for disposal.
Maine Yankee Atomic Power Company	X	X			In early 1983, Maine Yankee demonstrated fuel consolidation on stainless steel dummy fuel pins. In August 1983, Maine Yankee disassembled one irradiated fuel assembly and stored 172 fuel pins in a spent fuel pin case. A consolidation ratio of 1.6:1 was achieved. This equipment was designed for individual rod removal and insertion into a storage array.

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Table 2 - Future Consolidation Endeavors with DOE Participation

Designer[a]	Vertical	Wet	Horizontal	Dry	Comments
1. Allied General Nuclear Services (AGNS) 2. Nuclear Assurance Corporation (NAC)	X	X			A cooperative agreement between DOE and Tennessee Valley Authority (TVA) will consolidate 12 irradiated BWR fuel assemblies at the Browns Ferry Station. Equipment was built for DOE by AGNS and is based on NAC design specifications. The equipment was delivered to TVA in June 1983.
Combustion Engineering (CE) supported by Electric Power Research Institute and Baltimore Gas and Electric	X	X			The project is planned by Northeast Utilities (NUSCO) at Millstone 2 plant. The demonstration will disassemble 12 irradiated PWR assemblies Commencement is scheduled for 1985 (currently DOE and NUSCO are negotiating a cooperative agreement).

[a]Spent Fuel Storage Seminar sponsored by The Institute of Nuclear Materials Management, January 1984.

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- Off-normal events
- Equipment cost considerations

The following sections describe each of these factors in more detail.

4.1 PRODUCTION RATE

The production rate for the fuel consolidation system is a key element because it forms the basis for overall facility throughput. The MRS Facility must be designed to process 3,600 MTU of spent fuel, initially. At 60% PWR/40% BWR weight split, and using 0.462 MTU/PWR or 0.186 MTU/BWR assembly, this translates to 4,676 PWR assemblies plus 7,740 BWR assemblies per year. The FDC (Ref. 1) further states that the production rate should be based on 3 shifts per day, 7 days per week, year-around operation. The throughput rates required with these operational specifications have been calculated using an overall shielded process cell operating efficiency of 50%. This efficiency rating accounts for the difficulties of shielded process cell operations (tool changing) and for maintenance downtime. On this basis, the approximate calculated production rate for PWR fuel must be 0.94 hr per assembly and, for BWR fuel, 0.57 hr per assembly. Because two cells are operating for each assembly type, the production rate, on a per-cell basis, is 1.87 hr per assembly for PWRs and 1.13 hr per assembly for BWRs.

4.2 SYSTEM INTEGRATION

The fuel consolidation system interfaces with the fuel receiving system, the canister sealing system, and the contamination control system. These interfaces must be simple and reliable.

4.3 SPACE REQUIREMENTS

The space occupied by the consolidation apparatus should be minimized to reduce the hot cell ventilation system, contamination control requirements, and facility costs.

4.4 RELIABILITY

The reliability of a nuclear fuel consolidation system conceptual design may be assessed on the basis of the number of complex operations and the perceived complexity of those operations. This is an inverse relationship because a smaller number of less complex operations results in a more reliable system. Therefore, a fuel assembly consolidation system design must acknowledge and effectively limit the number of complex operations.

4.5 CONTAMINATION CONTROL

Contamination in the form of crud (which clings to spent fuel assembly surfaces), vapor, and fines may become dislodged or airborne during the disassembly and consolidation process. Therefore, a fuel assembly consolidation system design must acknowledge, effectively deal with, and control this contamination.

4.6 SECONDARY WASTE HANDLING

The fuel consolidation process will generate secondary waste, which must be remotely transferred to a volume reduction unit. Secondary waste is defined as any solid component (except for the fuel rods) associated with intact fuel assemblies. This includes the mechanical hardware, grid spacers, lower end-fittings, upper end-fittings, and nonfuel-bearing structural components. This study is directed toward selection and evaluation of spent fuel consolidation equipment and secondary waste volume-reduction interfaces.

4.7 MAINTENANCE AND ALARA CONSIDERATIONS

Ease of maintenance must be addressed by modularization and accessibility to equipment. The maintenance and ALARA considerations are important aspects of the selection process. They are combined in a single category because they are closely related; reduced maintenance will result in lower exposure situations for maintenance personnel. Additionally, increasing the system reliability will result in a decrease in maintenance. Tool changeover must be performed remotely, and should be modular to allow rapid tool changeovers when necessary to accommodate different fuel designs. Support structures should also be modular, incorporating features that allow them to be adapted or changed for each of the different fuel assemblies. Couplings and tool supports must be capable of accepting all tooling used by with the individual system. Complexity of design should be kept to a minimum to allow for high reliability with ease of maintainability.

4.8 OFF-NORMAL EVENTS

This consideration addresses all sequences other than those that are normally carried out on the production line. These events include accident sequences and handling of spent fuel assemblies that have indications of abnormality. Off-normal events also include rod rupture during disassembly and subsequent fuel pellet recovery, rod removal forces greater than the preset limit, loss of rods when in the transfer mode, and bent rods. (All of these events will require secondary tooling for recovery.) The consolidation system must acknowledge these considerations and be capable of effectly dealing with them.

Pyrophoricity is the capability to ignite spontaneously. A fire is an off-normal event. Experience with Zircaloy has shown that fines[1] are pyrophoric, but that heavier sections, such as tubing, are not. Pyrophoricity must be considered if any processes involve machining or grinding.

4.9 EQUIPMENT COST CONSIDERATIONS

The associated costs of spent fuel consolidation equipment should be minimized. This minimization of costs is directly proportional to the reliability of the system. Four cost considerations are identified:

---

[1]Fines refer to metal particles machined or scraped from Zircaloy during disassembly and consolidation. Zircaloy is a high zirconium alloy.

(1) initial capital cost; (2) operational and maintenance cost; (3) facility cost; and (4) support equipment cost. The consolidation equipment must acknowledge these cost considerations and effectively minimize them.

5.0 FUEL DESCRIPTION

As stated in Reference 1, the MRS Facility must be capable of handling all fuel types with lengths up to 15 ft-5.5 in. PWR fuel assemblies within this length are listed in Table 3, and BWR assemblies are listed in Table 4, together with their designers and manufacturers.

Table 3 - PWR Fuel Manufacturers and Array Descriptions

Westinghouse (WE)	Babcock and Wilcox (BW)
14 x 14	14 x 14 (all reprocessed)
15 x 15	15 x 15
17 x 17	17 x 17
17 x 17 LG	

Combustion Engineering (CE)	Exxon Nuclear Corporation (Exxon)
14 x 14	15 x 15 (WE design)
15 x 15	17 x 17 (WE design)
16 x 16	14 x 14 (CE design)
	15 x 15 (CE design)

Table 4 - BWR Fuel Manufacturers and Array Descriptions

General Electric Corporation (GE)	Exxon Nuclear Corporation (Exxon)
6 x 6	7 x 7 (GE design)
7 x 7	8 x 8 (GE design)
8 x 8 (2,3,4,5,6 enrichment types)	10 x 10 (AC design)
9 x 9	

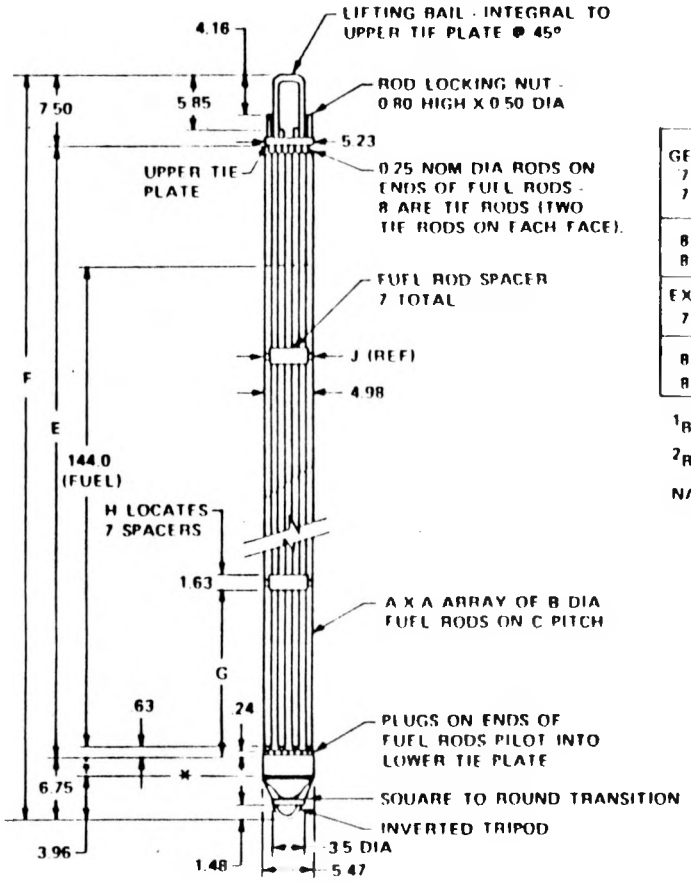
Allis-Chalmers (AC)

10 x 10

As can be seen in these tables, there are four vendors of PWR fuel and three vendors of BWR fuel. On the basis of this information, it is expected that the MRS Facility will handle and consolidate the types of fuels tabulated.

The fuel assemblies illustrated in Figure 1 are typical of BWR assemblies. The assembly is made by fastening (threaded connection) two outside fuel rods on each face of the array to the lower tie plate. Threaded extensions of these rods pass through the upper tie plate, where they are secured with nuts. The

BWR FUEL ASSEMBLY DIMENSIONS – UNIRRADIATED @ 70°F

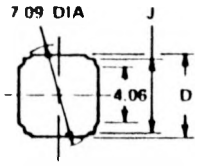


	BWR FUEL ASSEMBLY DIMENSIONS, INCHES, WHERE APPLICABLE									
	A	B	C	D	E	F	G	H	J	NUMBER WATER RODS
GE										
7 X 7 (1966)	7	.563	.738	5.47	157.15	171.4	17.17	19.53	5.25	0
7 X 7 (1968)	7	.570	.738	5.47	157.15	171.4	17.17	19.53	5.25	0
8 X 8 (1973)	8	.493	.640	5.47	161.95	171.4	18.75	20.15	5.26	1
8 X 8 (1977)	8	.483	.640	5.47	161.95	176.2	18.75	20.15	5.26	2
EXXON										
7 X 7	7	.570	.738	5.44	156.1	171.2	NA	NA	5.24	0
8 X 8 (1973)[1]	8	.500	.640	5.44	156.1	171.2	NA	NA	5.24	1
8 X 8 (1977)[2]	8	.493	.640	5.44	156.1	178.5	NA	NA	5.24	2

[1]BWR - 2

[2]BWR - 3, 4, 5, 6

NA - NOT AVAILABLE



*LIMITING CROSS-SECTION

Figure 1 - Typical BWR Fuel Assemblies

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seven fuel rod spacers (grids) are held in position by tabs on the center spacer capture fuel rod. During assembly, this rod is inserted, then rotated 45 deg so the tabs engage the grids. General Electric 8 x 8 fuel assemblies differ from the typical BWR designs because the spacer capture rod does not contain fuel; it is a "water rod."

Figure 2 illustrates typical PWR fuel assemblies. Not all positions in the PWR array contain fuel rods. One rod position near the center of the array is an open-tube instrument thimble. In addition, at several locations throughout the array, additional open tubes serve as control rod guides and grid spacers. The assembly is made by securing the open tubes to the top and bottom nozzles.

6.0 FUEL CONSOLIDATION SYSTEM DESCRIPTIONS

This section describes the consolidation system concepts developed on the basis of the criteria for this consolidation optimization study given in Section 4. Three concepts were developed - one that holds the fuel assemblies vertical and two in which the assemblies are laid horizontally. Variation of these basic concepts allows handling of either BWR or PWR fuel. Conceptually, either system can be operated wet (in a water pit) or dry (in a shielded process cell.) Appendix A contains more detailed information on the rationale for selection and comparison of equipment representing current design of the dry-horizontal consolidation system.

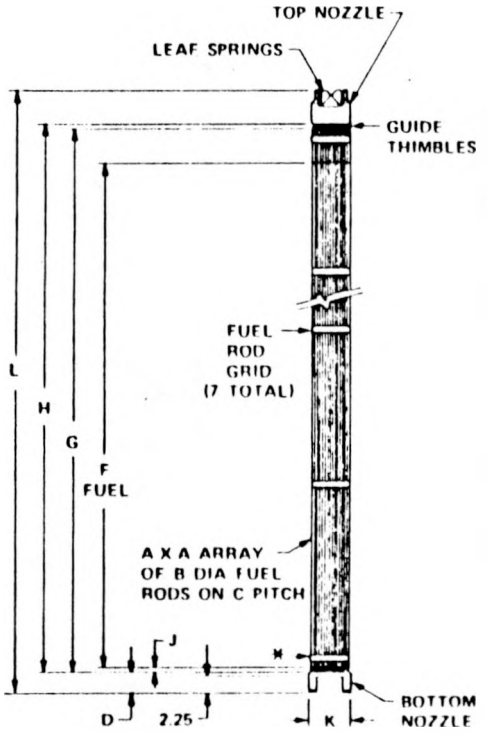
6.1 VERTICAL FUEL CONSOLIDATION SYSTEM

The vertical fuel consolidation system has the same basic components and processes for both PWR and BWR spent fuel assembly operations. The major difference between the two is the end-fitting removal operation. The vertical system is discussed herein, and the PWR and BWR differences are addressed where necessary. The vertical fuel rod consolidation system, shown schematically in Figures 3 and 4, consists of an index table, fuel rod gripper end-effector, fuel assembly support structure, storage container support structure, transition canisters, and transition canister support fixture.

The 6-ft-dia index table supports the main work station fixture, the transition canister fixture, and the storage canister fixture. The index table rotates the spent fuel assemblies, separated top nozzle, skeleton, transition canister, and storage canister into the work station and to the station required to onload or offload the components. Onloading is accomplished by handling equipment not on the table. Offloading is assisted by a push cylinder located on the table.

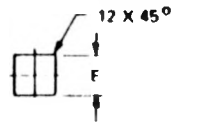
Fuel rod removal, fuel assembly array transition, and fuel assembly consolidation are performed at one location. The tooling, storage container, and transition canisters are rotated to this location, as required. This rotation avoids having to transfer the fuel rods, and increases safety and efficiency.

PWR FUEL ASSEMBLY DIMENSIONS – UNIRRADIATED @ 70°F



	PWR – FUEL ASSEMBLY DIMENSIONS, INCHES WHERE APPLICABLE											
	A	B	C	D	E, SQ	F	G	H	J	K, SQ	L	WEIGHT KG
BABCOCK & WILCOX (BW)												
15 X 15	15	0.430	0.568	4.25	8.536	144	155.4	155.4	0.625	8.536	165.7	689
COMBUSTION ENGINEERING (CE)												
14 X 14	14	0.440	0.580	–	8.11	126 - 132	137	–	–	8.11	157.24	–
15 X 15	15	0.415	0.550	–	8.25	132	–	–	–	8.25	149.1	612
16 X 16	16	0.382	0.506	4.44	8.16	150	162.8	162.8	–	8.16	178.3	657
EXXON												
CE 14 X 14	14	0.440	0.580	2.60	8.11	136.7	146.5	148.0	0.60	8.11	156.7	588
15 X 15	15	0.415	0.550	4.86	8.25	131.8	139.5	145.65	0.58	8.42	148.9	612
WE 15 X 15	15	0.424	0.563	2.72	8.42	144	151.49	151.93	0.60	8.42	159.7	644
17 X 17	17	0.380	0.496	2.74	8.42	144	152.79	153.29	0.50	8.42	159.7	657
WESTINGHOUSE ELECTRIC (WE)												
14 X 14	14	0.422	0.556	–	–	120 - 144	152.96	152.96	–	–	159.8	776
15 X 15	15	0.422	0.563	–	8.426	122 - 144	–	–	–	8.426	159.76	703
17 X 17	17	0.374	0.496	2.74	8.426	144	151.1	155.1	0.688	8.426	161.5	665

– INFORMATION NOT AVAILABLE



*LIMITING CROSS SECTION

Figure 2 - Typical PWR Fuel Assemblies

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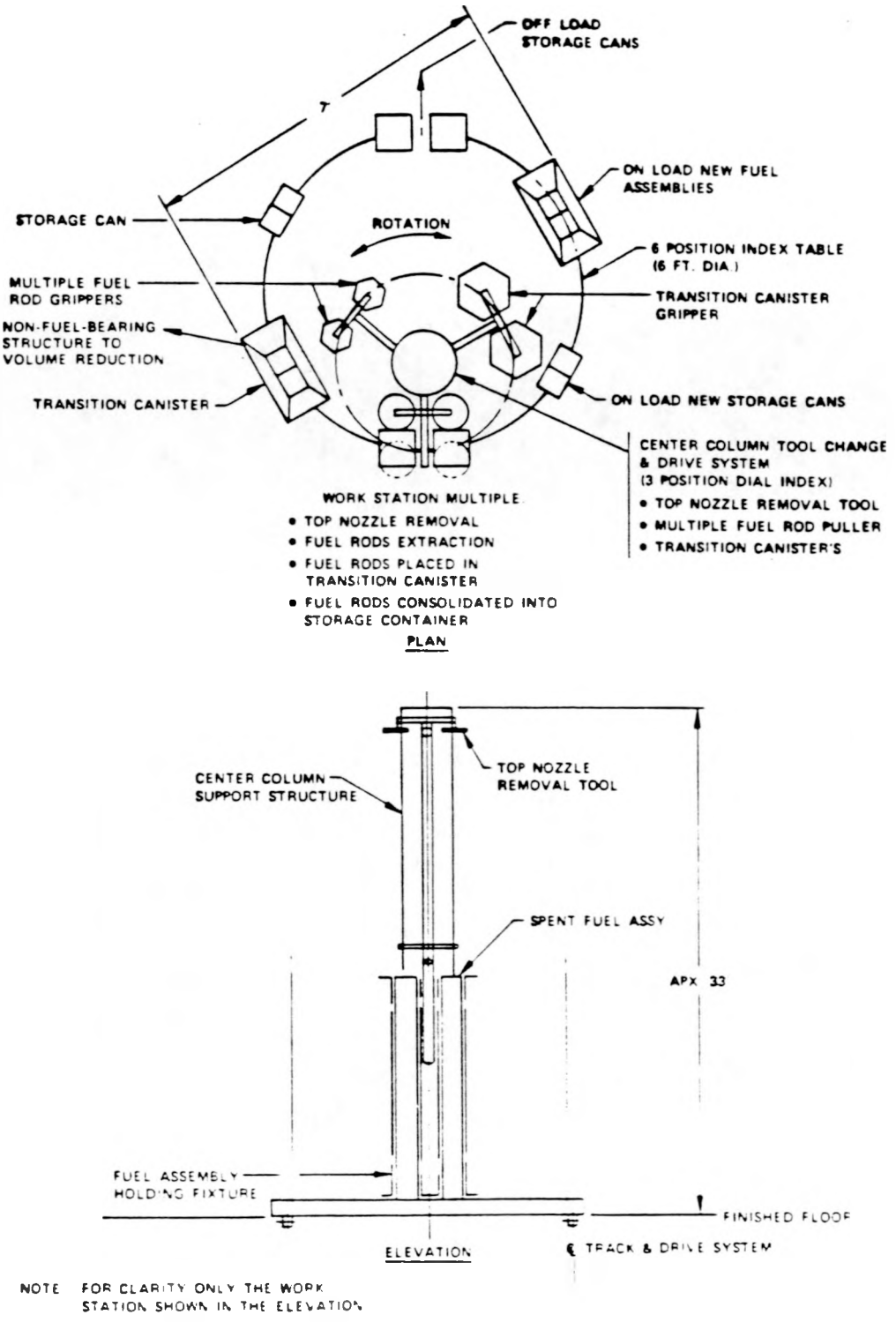


Figure 3 - PWR Vertical Fuel Consolidation Equipment

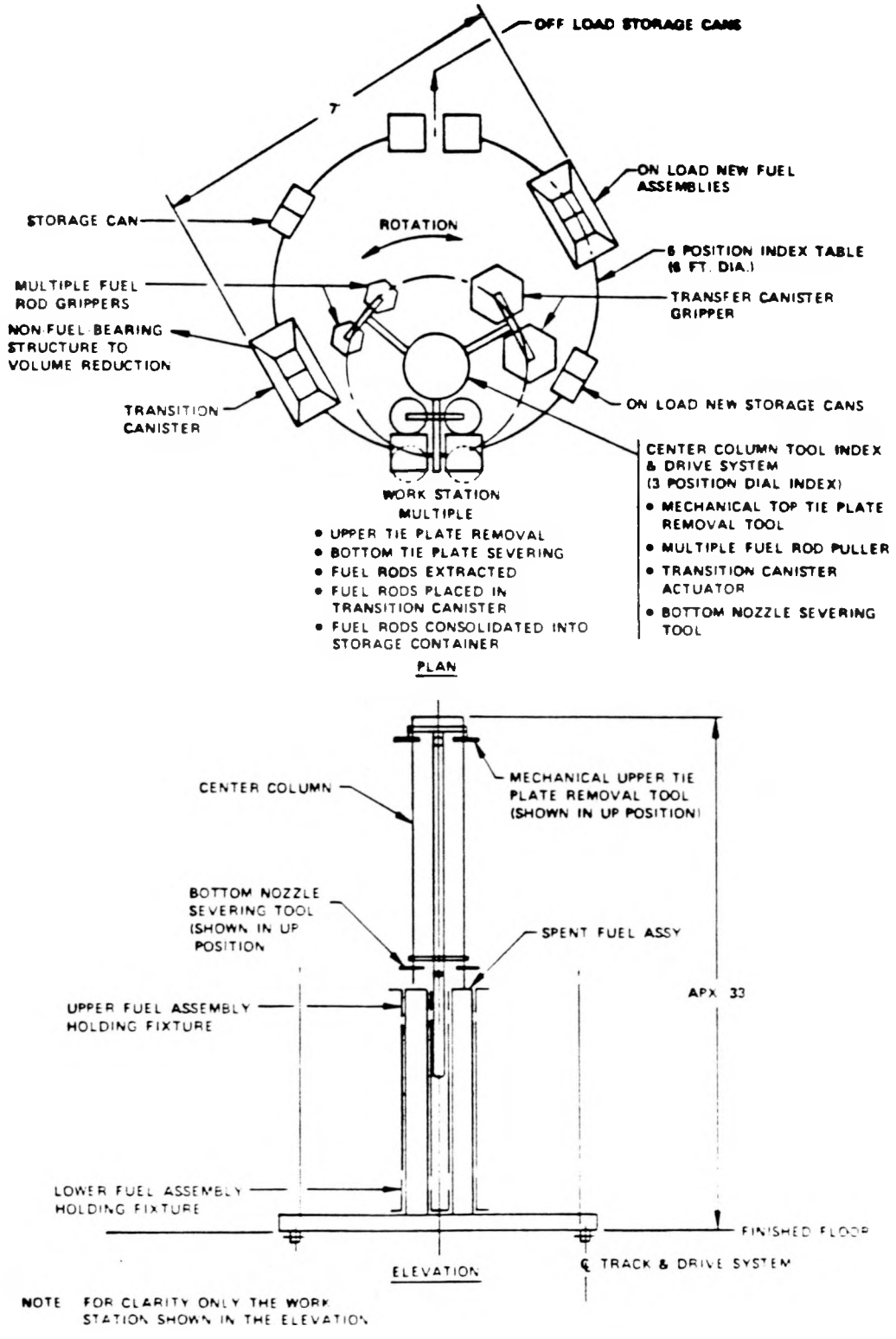


Figure 4 - BWR Vertical Fuel Consolidation Equipment

For both PWR and BWR fuels, fuel rod handling and manipulation are approached from two conceptual directions: (1) 100% fuel rod extraction or (2) rejection of the assembly to an off-normal station. Fuel rod extraction is handled differently for PWR and BWR fuel assemblies. Specifically, for BWR fuel extraction, all rods are removed except the spacer capture rod (if it contains no fuel). If there is no fuel in the spacer capture rod, the rod is treated as secondary waste; the rod and the grid spacers are sent for volume reduction.

Fuel rod manipulation is performed by the center column tool changer. As indicated in Figures 3 and 4, the tool changer provides two axes of motion: (1) a vertical motion perpendicular to the floor and (2) rotation to present tooling or end effectors to the fuel assemblies.

The upper end-fitting removal tools are lowered in the vertical direction, and rotated to the fuel assembly. For PWR fuel, the upper end-fitting is removed by machining the stainless steel instrument thimble tube-to-nozzle welds. In BWR fuel assemblies, the upper end-fitting is removed by machining away the threaded extensions of the fuel rods. The lower end-fitting is severed from the fuel rods by cutting the fuel rod end plugs just above the lower end-fitting. This cut can be made by using a grinding wheel, which will cause the fines to burn as they are made, thus eliminating uncontrolled pyrophoric effects. The end-fittings are treated as secondary waste.

The multiple fuel rod gripper is rotated into position. The gripper is then aligned and engaged with the top of the fuel rods (exposed by removing the upper end-fitting). All fuel rods are extracted and held above the skeleton. The index table then rotates the transition canister to a position under the suspended fuel rods. The fuel rods are lowered into the transition canister. This lowering reorders the fuel rods; it changes their arrangement from an open, square-pitched array to a close-triangular array. The fuel rod gripper is disengaged, and raised out of position. The center column is rotated to position, and engages the transition canister gripper. The transition canister, filled with spent fuel rods, is than raised to its full-up position. The index table rotates the storage container to the location below the transition canister. The transition canister is lowered to engage with the top of the storage container, and a set of powered rollers (spring loaded against the fuel rods) "pull" the fuel rods out of the transition canister into the storage container. The residual nonfuel-bearing structural components are then offloaded to a volume-reduction unit.

6.2 HORIZONTAL FUEL CONSOLIDATION SYSTEMS

The horizontal systems described below represent conceptual designs. A reference horizontal system that accomplishes fuel rod removal by pushing was primarily conceived for comparison with the vertical system. Further design work and evaluation resulted in a change from a push technique to one of pulling. In the conceptual design, the horizontal system pulls the fuel rods from their support structure. This change in technique decreased the overall length of the system by approximately 15 ft. The primary reason for this decrease in length is because the push rods must be the full fuel assembly length for fuel rod removal. Additionally, individual collets can be load

limited to preclude tensile rod rupture during extraction. Both horizontal push and pull systems are described herein. The description includes a rationale for component selection compiled during the conceptual design of the dry-horizontal pull fuel consolidation system.

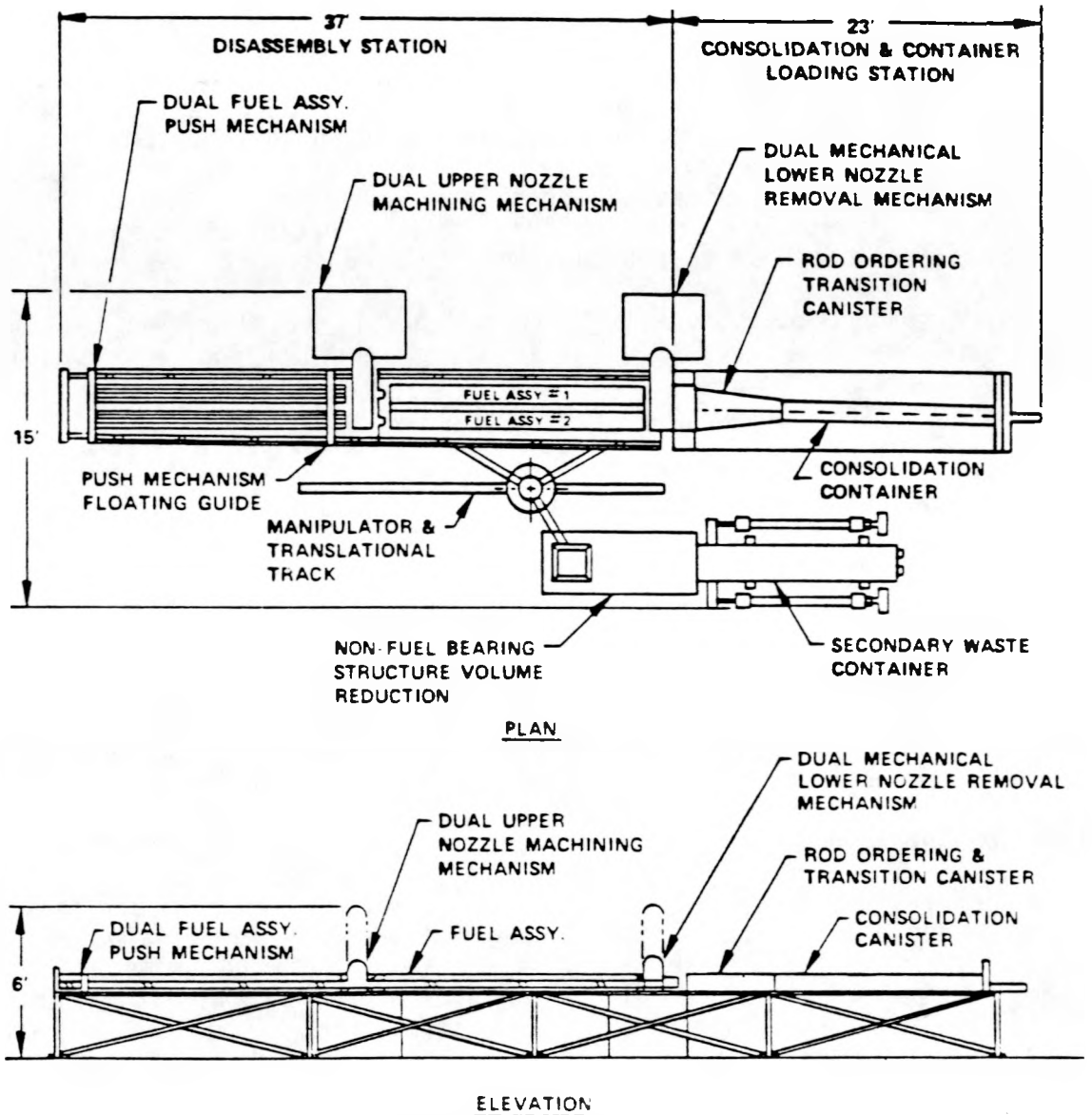
6.2.1 Horizontal-Push Fuel Consolidation Systems

The horizontal-push fuel assembly consolidation systems are shown in Figures 5 and 6 (for PWR and BWR assemblies, respectively). Each system consists of a fuel assembly push mechanism, upper end-fitting machining mechanisms, mechanical lower end-fitting removal mechanism, rod ordering transition canister, robotic manipulator, nonfuel-bearing structure volume reduction unit, and consolidation container. For BWR assemblies, a spacer capture rod rotational tool is also required. The complete system is mounted on a support frame, and is divided into two sections on the basis of the major fuel assembly consolidation subprocesses and their related support equipment.

The two major process sequences of the horizontal consolidation system are (1) removal of the upper and lower end-fittings and (2) fuel rod extraction from the support structure. Rod ordering and container loading are accomplished in the consolidation and container loading station. The consolidation container also can be indexed during downtime for maintenance or in off-normal circumstances. Reference 1 states that either two PWR or five BWR fuel assemblies will be consolidated into a storage container. However, upon subsequent design evaulation, three PWR and seven BWR fuel assemblies will be consolidated into a storage container. The horizontal system can accommodate this quantity of assemblies simultaneously; therefore, it provided the basis for design.

Upper and lower nozzle removal in the horizontal system is achieved by the same processes as those used for the vertical system orientation. The nozzles are considered secondary waste, and are remotely placed into a canister. For BWR assemblies, the spacer capture fuel rod, if it contains fuel, will be rotated to release it from the support grids for subsequent extraction and consolidation operations.

Fuel rod removal is achieved by the fuel assembly push mechanism. The mechanism is designed to be slightly longer than the fuel assemblies. Each push mechanism acts simultaneously with the others. The fuel rods are pushed out of the support structure directly into the rod ordering transition canister. Upon complete insertion of the fuel rods into the transition canister, the push mechanism is retracted so that the nonfuel-bearing structure (thimble tubes and grid spacers), which is secondary waste, can be transferred remotely to the volume-reduction unit. The push mechanism is then indexed forward to transfer the fuel rods through the transition canister into a consolidation container. The completely loaded container is ready for sealing.



FOR CLARITY & SPACE REQUIREMENT CONSIDERATIONS, THE NON-FUEL BEARING STRUCTURE VOLUME REDUCTION UNIT & MANIPULATOR ARE NOT SHOWN IN ELEVATION

Figure 5 - PWR Horizontal-Push Fuel Consolidation Equipment

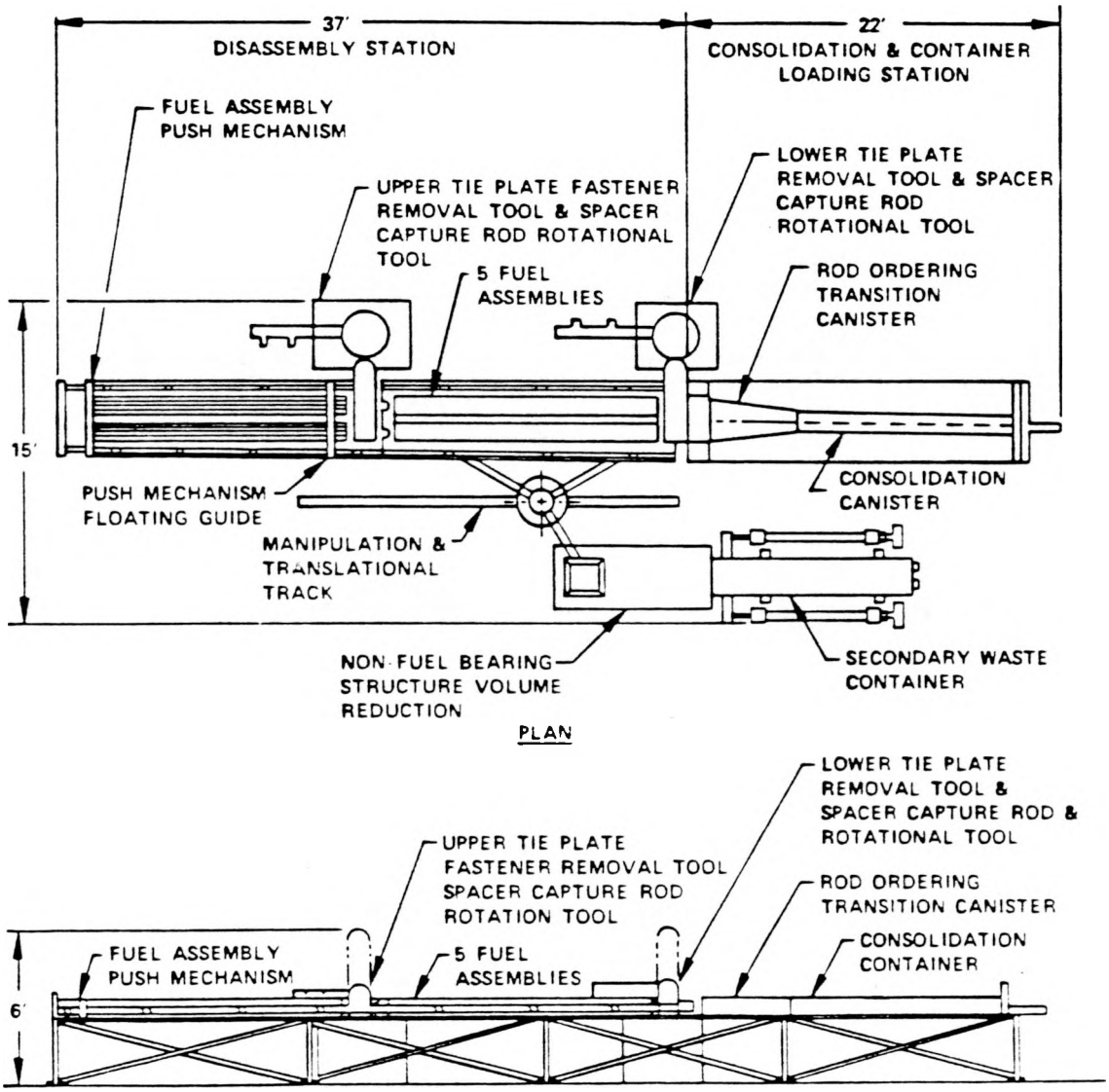


Figure 6 - BWR Horizontal-Push Fuel Consolidation Equipment

Incorporated into the disassembly station is a support frame and clamping assembly to (1) support the thrust loads imposed by the fuel rod push mechanism and (2) retain the fuel assembly in position. Clamping of the fuel assembly occurs only at the grids. A vacuum system below the fuel assemblies collects crud or other debris dislodged during removal of the fuel rods. The transition canister will also employ a vacuum system to collect particulates dislodged during rod ordering. These vacuum systems minimize the airborne contamination caused by the consolidation operations.

6.2.2 Horizontal-Pull Fuel Consolidation Systems

The horizontal-pull fuel assembly consolidation systems are shown in Figures 7 through 9. Figure 9 is a trimetric drawing showing a PWR setup. A BWR system will contain the same basic components, but specific modules peculiar to BWR fuels will replace the PWR modules. The system consists of a fuel assembly clamping module, a laser disassembly subsystem, a downender, a rod extraction and reordering subsystem, and a robotic secondary waste transfer subsystem. The spacer capture fuel rods, containing fuel, on BWR assemblies will be rotated by the robotic subsystem with secondary tooling. The system is mounted on a support frame, and is divided into two sections on the basis of the major fuel assembly consolidation subprocesses and their related support equipment.

The two major process sequences of the system are (1) disassembly of the fuel element and (2) fuel rod extraction and reordering. Disassembly equipment consists of four subsystems: the downender, a fuel assembly clamping module, a laser disassembly subsystem, and a robotic secondary waste transfer subsystem. The function of the disassembly subsystem is to position and secure fuel assemblies for end-fitting severing and to provide a restraint against subsequent rod-extraction forces during disassembly. Residual nonfuel-bearing structural components will be collected and transferred to a secondary waste volume-reduction system. The function of the fuel rod extraction and reordering equipment is to extract and reorder fuel rods (from the existing square-pitched array into a close-packed array) and to insert the consolidated rods into a canister for storage.

The spent fuel reordering equipment consists of five subsystems: a carriage and gripper, horizontal and vertical combs, semicircular rod configuration structure, overhead die, and strap lowering device.

Fuel rod extraction is achieved by the multiple fuel rod gripper. Each collet of the gripper will be load-limited to prevent damage to fuel rods. A full complement of fuel rods from either three PWR or seven BWR assemblies will be extracted simultaneously. The fuel rods are pulled out of the support structure, supported by combs vertically and horizontally along the length of the fuel rods, directly over the semicircular rod configuration structure. The horizontal combs are rotated, horizontally, out of position, allowing a controlled release of the fuel rods onto a spring-tensioned strap lowering device.

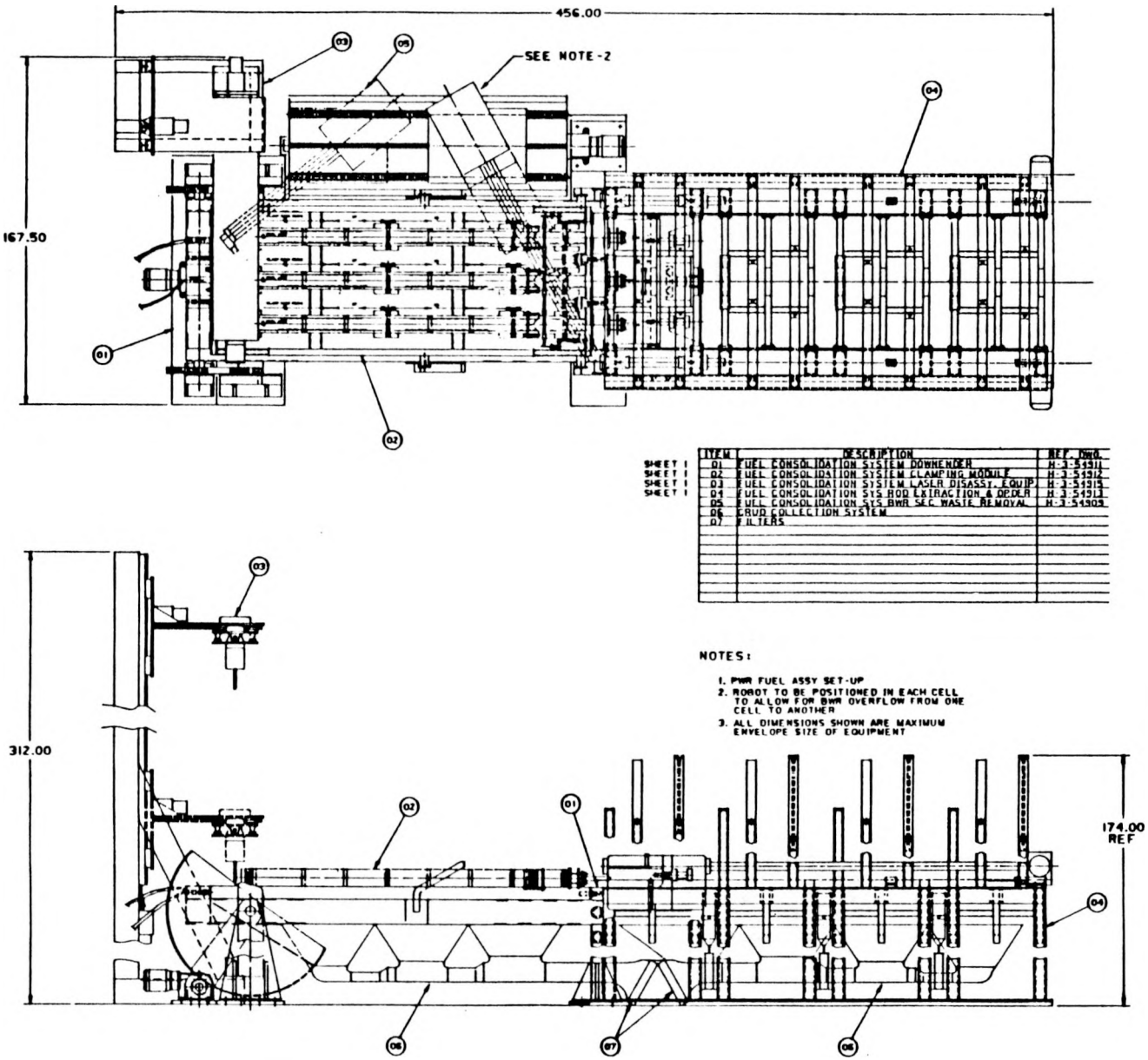


Figure 7 - PWR Horizontal-Pull Fuel Consolidation Equipment

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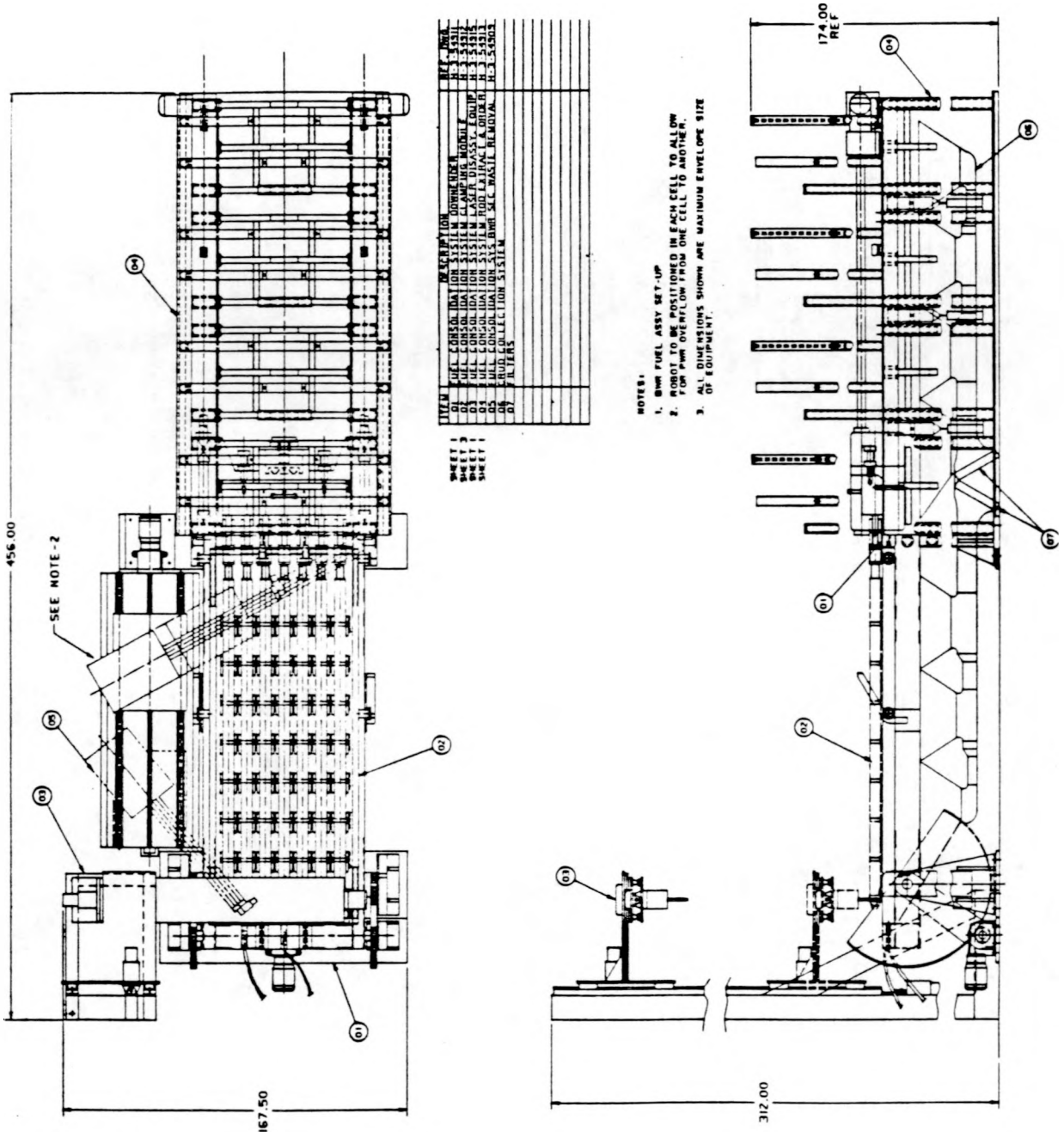

Figure 8 - BWR Horizontal-Pull Fuel Consolidation Equipment

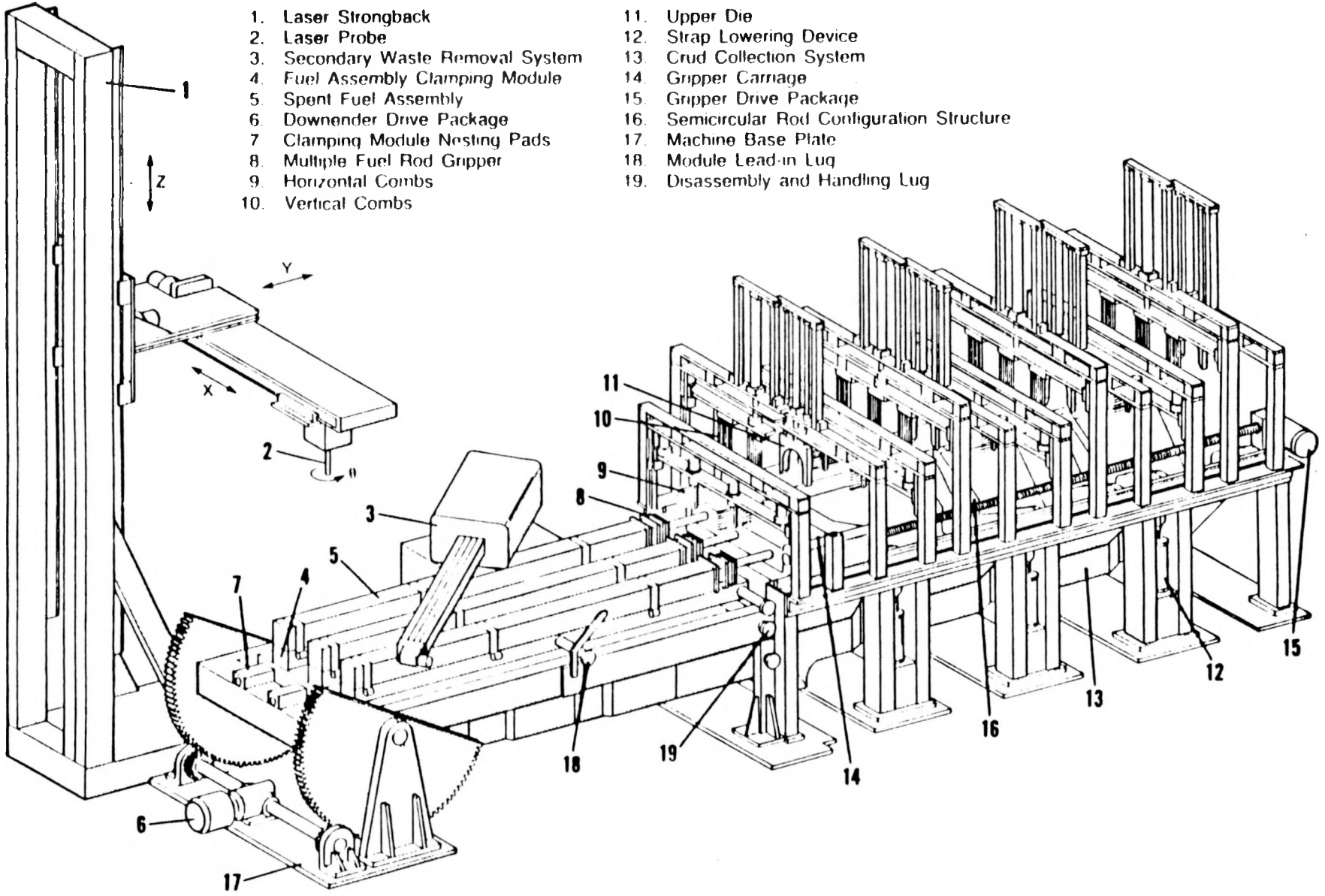

Figure 9 - Spent Fuel Consolidation System - PWR Setup

The upper die is lowered around the fuel rods, forming a circular cross section, to complete the reconfiguration process. The rods are then canistered with the push mechanism on the rear of the gripper carriage. The completely loaded canister is ready for sealing. A vacuum system, located below the fuel assemblies, collects dislodged particles during fuel rod removal.

7.0 PROCESS EVALUATIONS

The previous sections have described the fuel to be processed in the MRS Facility and conceptual designs for the equipment to consolidate them. This section evaluates the processes, as they apply to the different types of fuel, and the effect of the operational medium, wet or dry, on the processes.

7.1 OPERATING ENVIRONMENT

The survey of existing spent fuel consolidation systems (Section 3) indicated that most of the systems are designed for underwater operation. The main reason for this is that commercial development of consolidation equipment has been driven by the need for increased storage capacity at existing nuclear power plants. As a result, the systems have, in general, been designed to fit the limited space available in existing spent fuel storage pools, and have used the pool water to provide contamination control and radiation shielding for the operators. These spent fuel pool configuration constraints do not necessarily apply to consolidation equipment selected for the MRS Facility. The operating environment for consolidation equipment in the MRS Facility can be wet (similar to spent fuel pools) or dry, with radiation shielding provided by the solid materials (such as concrete, steel, and lead) of the hot cell.

The selection process for MRS consolidation equipment included a comparison of the advantages and disadvantages inherent in wet and dry systems. In wet operations, the pool water shields the environment from direct radiation and most particulates. During any machining operations involving zirconium or its alloys, pyrophoricity will be controlled by the wet environment. However, secondary waste, such as machine fines and dislodged crud, will necessitate water-filtration operations. Also, support systems for the pool will require temperature controls, ion exchangers, chemical control, biological growth control, and some decon solutions when tooling is removed from the pool boundary. Dewatering of the consolidated fuel canisters before storage will also be necessary. Dry operations eliminate the need for dewatering before storage. Crud, dislodged during rod removal, can be controlled by using a vacuum system located at the consolidation work stations. Specific advantages and disadvantages of wet and dry operations are listed in Table 5.

Among all of the factors listed in Table 5, two are significant. First, because of subsequent handling operations (such as transporting, welding, and inspection), the use of wet disassembly and consolidation techniques does not reduce the hot cell shield wall thickness requirement. Second, dry operation improves the capability of an operator to observe the process; it can be viewed directly. These factors were among those that led to the selection of a dry disassembly and consolidation system for the MRS Facility.

Table 5 - Comparison of Dry and Wet Fuel Assembly Disassembly and Consolidation Operations

Dry Operations		Wet Operations	
Advantages	Disadvantages	Advantages	Disadvantages
Possibility of generating a contaminated steam cloud by quenching hot, dry fuel assemblies in water is eliminated.	Airborne contamination must be dealt with.	Contaminated particles, such as dislodged crud, will be suspended in water environment.	Fuel assemblies may have to be cooled to prevent a cloud of contaminated steam from being generated when hot, dry fuel assemblies are quenched.
Contamination control is generally simplier in a dry environment.	Provisions not to allow flooding in the cells must be made, so facility must be above flood plane, contain drains, and allow no piping of water through the cells.	Pool water acts as a radiation shield, permitting easy overhead access to equipment by use of long-handled tools.	A water cleaning system will be required.
Operational visibility is better through air than through water. This will reduce operator fatigue, enhance production, decrease maintenance time and ease recovery from off-normal events.	The entire cell volume must be cleaned if a contamination spill occurs.		There is a greater potential for a criticality incident with water present. A neutron poison may be required in the design.
			Visibility through 30 ft of water will be difficult and creates difficulties in off-normal recovery.
There is no need to remove pool water from storage container.			Consolidation containers and secondary waste containers must be dewatered before welding.
Reduced potential for criticality.			A pool boundary failure is a difficult accident from which to recover.
			Entire pool volume must be cleaned if a contamination spill occurs.

7.2 FUEL ASSEMBLY ORIENTATION

The survey of existing and planned spent fuel consolidation systems (Tables 1 and 2) indicated that most of the systems are designed to hold the fuel assembly with its major axis vertical during disassembly and consolidation. The choice of vertical orientation conforms to the physical conditions at the reactor fuel pools: the assemblies are handled and stored with their axes vertical, and the pools are deep enough to provide adequate radiological shielding. For the MRS Facility, consolidation equipment is to be provided on the basis of meeting (among other criteria) production throughput requirements, and it need not be limited by the geometric or operational requirements found in existing spent fuel pools. To develop a reasonable basis for a decision, processing equipment concepts described in Section 6 were developed, and conceptual processing operations for PWR and BWR assemblies in the horizontal and vertical orientations were developed. The conceptual operations are summarized in Table 6 for PWR assemblies and in Table 7 for BWRs assemblies. As noted in these tables, some of the disassembly and consolidation operations are complex. The degree of complexity will depend on the final system design, and has not been assessed in this conceptual study.

Together with considerations relative to secondary waste stream management, hot cell contamination control, visual process monitoring, and throughput rates, reliability considerations must be appraised in making the choice between horizontal and vertical fuel assembly orientation. Those considerations are presented below.

7.2.1 Reliability

As noted above and in Tables 6 and 7, some of the conceptual disassembly and consolidation operations are complex. The degree of complexity may vary, but the process that is the least complex will be the most reliable. As can be seen, fewer operations are judged to be complex with the fuel assemblies horizontal rather than vertical. In addition, unanticipated events occurring with the fuel assemblies horizontal have a reduced potential for damage to the fuel or the apparatus. For example, the aftermath of the rupture of a fuel rod:

(1) In a horizontal system, it is likely that only a few fuel pellets, those near the rupture, would spill; the process interruption would be less severe, and the possibility that a pellet would fall into the apparatus would be remote.

(2) In a vertical system, all of the fuel pellets above the site of the rupture could possibly cascade to the floor of the process cell. This could involve many pellets that could fall into the apparatus, and cause a significant process interruption.

7.2.2 Secondary Waste Stream Management

Three generic secondary waste streams can be identified with respect to the disassembly of fuel assemblies and consolidation of the fuel rods:

Table 6 - Major Conceptual Disassembly and Consolidation Operations

PWR Fuels

Horizontal - Push (See Figure 3)	Horizontal - Pull (See Figure 7)	Vertical (See Figure 5)
1. Rotate assemblies to horizontal and place in disassembly/ consolidation apparatus.	1. Accept assemblies in vertical position and perform parallel operations on loading and nozzle severing.	1. Lower fuel assembly/consolidation apparatus.
2. Remove upper nozzles by cutting control rod thimble tubes or tube/nozzle welds	2. Sever and remove upper nozzles by I.D. tube cutting below first grid and remove nozzles.	2. Remove upper nozzles by cutting control rod thimble tubes or tube/nozzle welds.
3. Remove lower nozzles in manner similar to upper nozzles	3. Rotate to horizontal.	3. Grip all fuel rods in multiple collet head.
4. Push all fuel rods into transi-transition fixture using multiple rod push mechanism.	4. Grip and extract three full complements of fuel rods and begin offloading skeletons once fuel rods are fully. extracted.	4. Pull all fuel rods out of assembly (raise fuel rods to level above skeleton).
5. Retract push mechanism.	5. Insert vertical and horizontal supports while extracting fuel rods.	5. Index turntable to move skeletons out from beneath fuel rods and transition fixture into position.
		5a. Remove skeletons to secondary waste volume-reduction station.
6. Remove skeletons to secondary waste volume reduction station.	6. Rotate horizontal support out of position, allow fuel rods to collect in vertical supports on strap lowering device, and lower into lower die.	6. Lower fuel rods into transition fixture.
7. Index push mechanism.	7. Raise vertical supports, return gripper to a home position, and lower push mechanism.	7. Release fuel rods from multiple collet head.
8. Push fuel rods through transition fixture and into storage canister.	8. Lower overhead die onto fuel rods to end the reconfiguration process.	8. Raise transition fixture so bottom of fixture will clear top of storage canister.
9. Retract push mechanism.	9. Push consolidated bundle into storage canister for subsequent sealing.	9. Index turntable to align storage canister beneath transition fixture.
10. Rotate filled canister to vertical and remove from disassembly/ consolidation.		10. Fraction drive fuel rods out of transition fixture into storage canister.
		11. Lift filled canister out of disassembly/consolidation apparatus.

Table 7 - Major Conceptual Disassembly and Consolidation Operations

BWR Fuels

Horizontal - Push (See Figure 6)	Horizontal - Pull (See Figure 8)	Vertical (See Figure 4)
1. Rotate assemblies to horizontal and place in disassembly/ consolidation apparatus.	1. Accept assemblies in a vertical mode and perform parallel operations of onloading and nozzle severing.	1. Lower fuel assemblies into assembly/consolidation apparatus.
2. Remove upper nozzles by cutting fasteners on 8 tie rods (2 each face).	2. Sever upper nozzles by cutting 8 tie rods below upper nozzle.	2. Remove upper nozzles by cutting fasteners on 8 tie rods.
3. Remove lower nozzles by cutting tie rod ends just above nozzle top faces (rod ends are solid metal - not fuel-bearing).	3. Rotate to horizontal.	3. Release 8 tie rods from lower nozzles by cutting tie rod ends just above nozzle tops.
4. Rotate spacer rods 45 deg to release grids.	4. Remove nozzles and collect compression springs.	4. Rotate spacer rods 45° to release grids.
5. Push all rods into transition fixture using multiple rod push.	5. Rotate spacer capture rod 45 deg to release grids.	5. Grip all fuel rods in multiple collet head.
6. Retract push mechanism.	6. Extract all fuel rods approximately 3 in. except for tie rods integral to lower nozzle.	6. Pull all fuel rods out of grids (raise fuel rods to level above assembly location).
7. Remove spacer grids to secondary waste volume-reduction station.	7. Sever tie rods above lower nozzle.	7. Index turntable to move skeletons out from beneath fuel rods and transition fixture into position.
		7a. Remove skeletons to secondary waste volume-reduction station.

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Table 7 (Contd)

BWR Fuels

Horizontal - Push (See Figure 6)	Horizontal - Pull (See Figure 8)	Vertical (See Figure 4)
8. Index push mechanism.	8. Extract seven fuel complements of fuel rods, insert horizontal and vertical supports, and begin secondary waste collection once extraction is completed.	8. Lower fuel rods into transition fixture.
9. Push fuel rods through transition fixture and into storage canister.	9. Rotate horizontal support out of position and allow fuel rods to collect in vertical supports on strap lowering device.	9. Release fuel rods from multiple collet head.
10. Retract push mechanism.	10. Raise vertical supports, return gripper to a home position, and lower push mechanism.	10. Raise transition fixture so bottom of fixture will clear top of storage canister.
11. Rotate filled canister to vertical and remove from disassembly/ consolidation apparatus.	11. Lower overhead die onto fuel rods to end reconfiguration process.	11. Index turntable to align storage canister beneath transition fixture.
	12. Push consolidated bundle into storage canister for subsequent sealing.	12. Friction-drive fuel rods out of transition fixture into storage canister.
		13. Lift filled canister out of disassembly/consolidation apparatus.

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(1) Debris associated with end-fitting severing operations.

(2) Crud dislodged during fuel rod removal.

(3) Fuel assembly "skeleton" (the nonfuel-bearing structure remaining after the fuel rods have been extracted).

1. Debris Associated with End-Fitting Severing Operations. To extract the fuel rods from a fuel assembly, the upper fuel assembly end-fitting must be removed in all disassembly scenarios conceived to date. (In many cases, the lower end-fitting must be removed, too, but this does not present the difficulties associated with the upper end- fitting, relative to waste stream management.) To remove the upper end-fitting of PWR assemblies, the instrument thimble and control rod guide tubes must be separated from the end-fitting. This can be done by I.D. cutting or by machining through either the weld or the tube. The method of severing the upper end-fitting is in part a function of the method used for fuel rod extraction. However, severing the instrument thimble and control rod guide tubes below the fuel rod elevation will accommodate any fuel rod extraction technique. Therefore, it is planned that upper end-fittings of PWR assemblies will be removed by severing below the fuel rod elevation.

The upper end-fittings of a BWR fuel assembly are fastened, by special nuts, to the threaded extensions of eight fuel rod upper end caps, two on each face of the fuel assembly. Because of the effects of the operating environment on the nut and stud materials, it is expected that the nuts will gall the stud if torque is applied to the nut. The torque would then be transmitted to the fuel tube, which could consequently rupture. Therefore, it is planned that the upper end-fittings of BWR assemblies will be removed by severing the threaded extension.

2. Crud Dislodged During Fuel Rod Removal. Although dislodged crud is secondary waste, it is a greater concern from a contamination control standpoint, as is explained in Section 7.2.3.

3. Fuel Assembly Skeleton Components. Once the fuel rods have been removed from the fuel assembly, the structural, nonfuel-bearing components remain to be managed. From BWR assemblies, these components include the top and bottom end-fittings and the spacer grids; for PWR assemblies, these components are included plus the control rod guides and instrument thimble.

Once some types of BWR assembles have been dismantled, the spacer grids are unsupported. This could pose a more significant fixture problem for vertically oriented assemblies than for horizontal assemblies. The grid clamps, once released would drop the unsupported grids onto the base of the indexing table. The horizontal system would support the grids once the clamps are retracted. PWR assemblies are somewhat more substantial following disassembly, but it is judged that handling of the PWR skeleton will be easier if the skeleton is vertical.

4. Handling and Packaging. The fuel assembly skeletons consist of the relatively massive upper and lower end-fittings plus the spacer grids and, for PWRs, the instrument thimble and the control rod guides. The grids, thimbles, and guides will either be compacted into a canister with dimensions similar to those of the spent fuel canisters or into a remote handled, low-level waste container. The end-fittings may be too massive for efficient compaction; if so, they may be placed directly into similar containers. There does not appear to be an advantage for horizontal or vertical fuel assembly orientation for secondary waste handling and packaging.

7.2.3 Contamination Control

Spent fuel rods, newly removed from an operating reactor, are covered with a highly contaminated layer of various metallic oxides (crud). An evaluation of this crud has shown that the amount of crud on a fuel rod diminishes with time in a fuel storage pool, but the chances of complete removal are small; thus, some crud will be present during disassembly. The residual crud can be dealt with at the disassembly station. During fuel assembly dismantling, crud will be loosened and tend to fall vertically under the influence of gravity. With the assembly vertical, controlling this waste stream is expected to be difficult because the crud collection system must remove the particulates along the vertical axis and through the fuel assembly. With the assembly horizontal, a vacuum system beneath the assembly will assist gravity to pull the loosened crud down, and away from the work station.

7.2.4 Overall Shielded Process Cell Size

The size of the portion of the fuel handling shielded process cell dedicated to the disassembly and consolidation of spent fuel is affected by the orientation of the disassembly and consolidation apparatus. Figures 10 through 14 show plan and elevation views of three conceptual shielded process cells, two with horizontal apparatus and one with vertical apparatus. Figure 14 shows the viewing ports necessary for visual monitoring of the vertical disassembly/consolidation process.

The shielded process cell lengths are 80 ft for the vertical system, 90 ft for the horizontal-"push" system, and 72 ft for the horizontal-pull system. The horizontal-pull system results in an 8-ft (10%) cell length reduction from the vertical system and an 18-ft (20%) reduction from the horizontal-push system. The horizontal-pull consolidation equipment cell layout represents a decrease in length when compared with the other alternatives, and is preferred on the basis of cell size.

7.2.5 Disassembly and Consolidation Time Estimates

The time estimates for the disassembly and consolidation of PWR and BWR fuel assemblies for horizontal-push, -pull, and vertical orientations are given in Tables 8 and 9. As these tables show, for PWRs and BWRs, the horizontal-pull consolidation system provides the minimum process time for both fuel

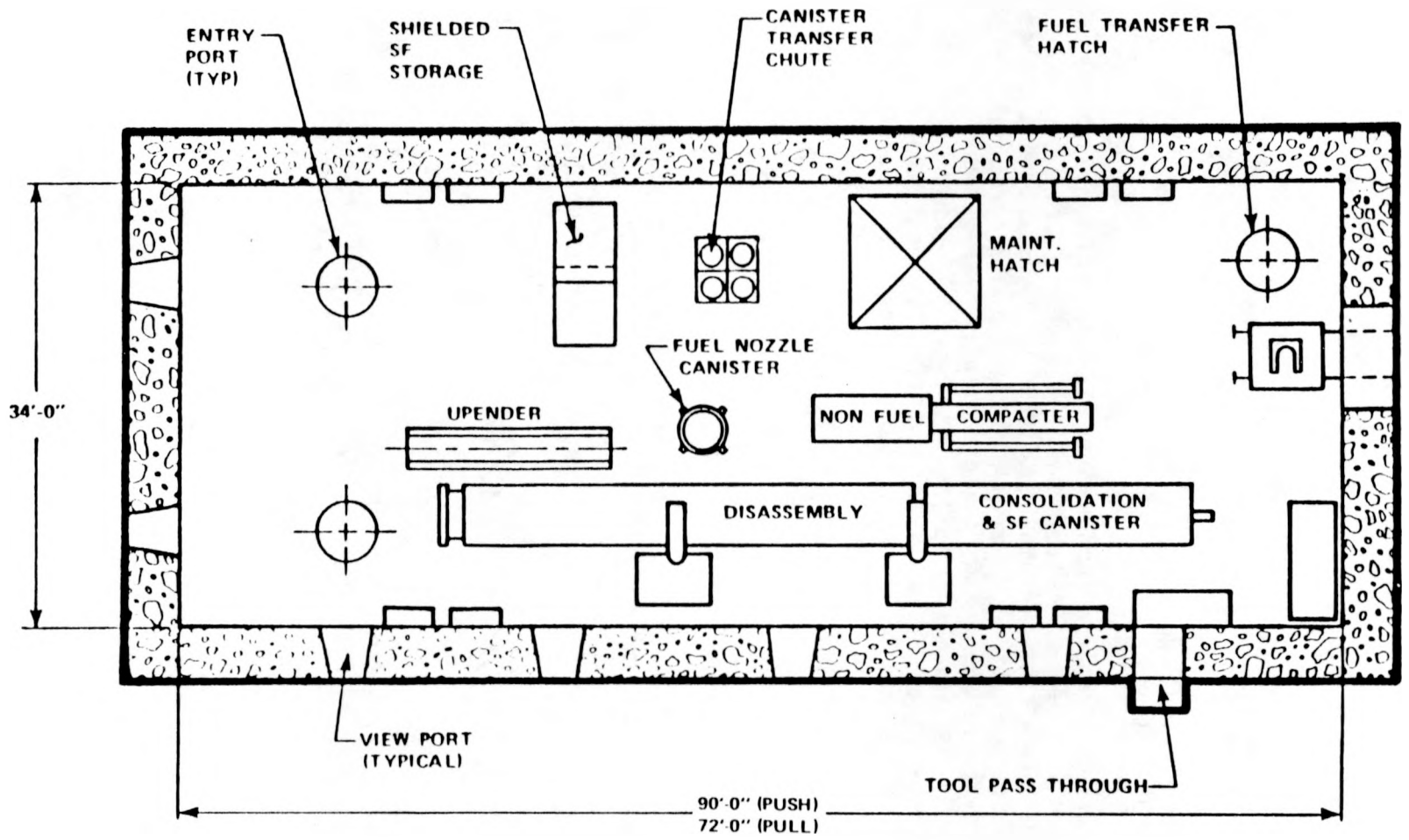

Figure 10 - Plan View of Shielded Process Cell With Horizontal Apparatus

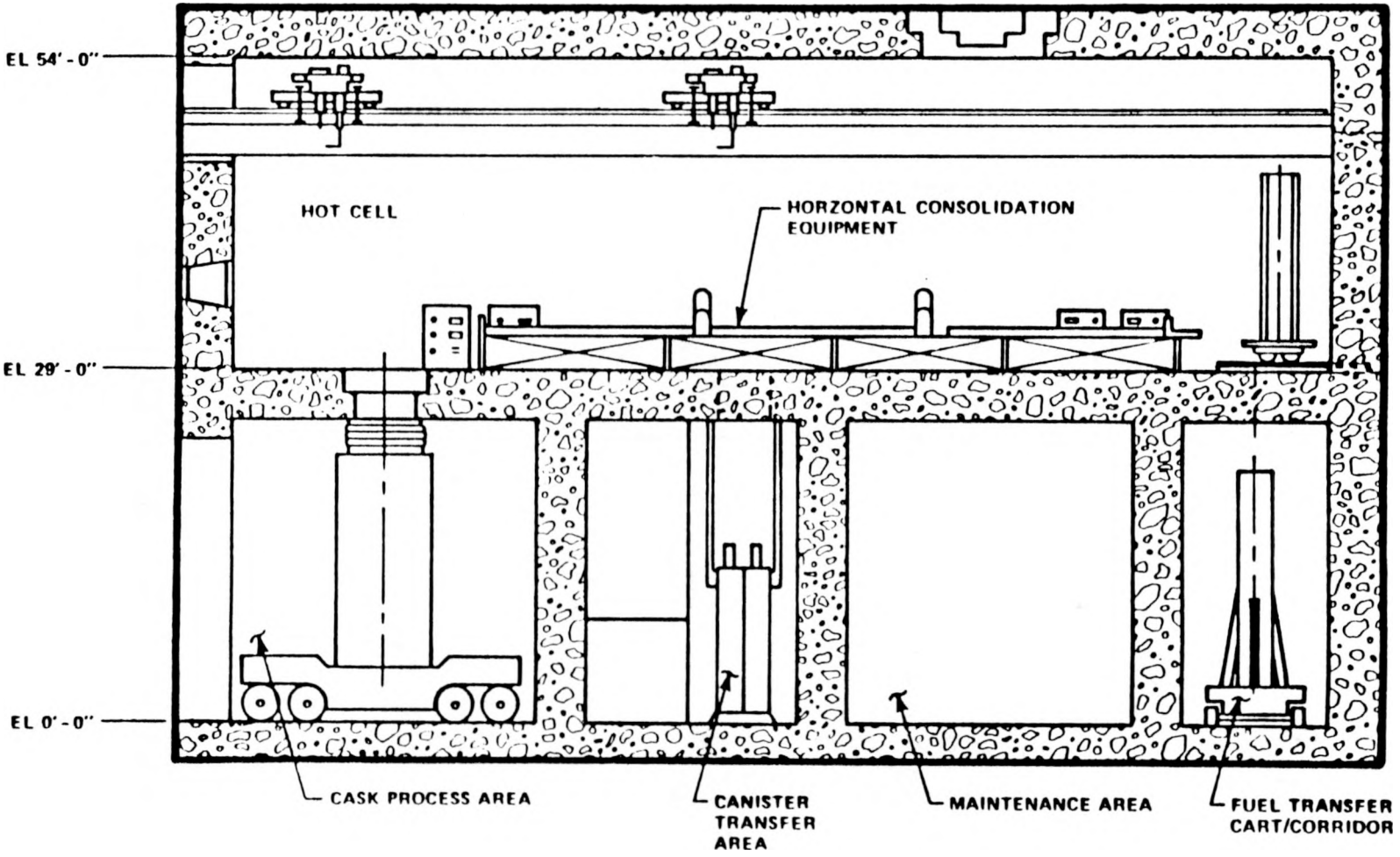

Figure 11 - Elevation View of Shielded Process Cell
With Horizontal Apparatus

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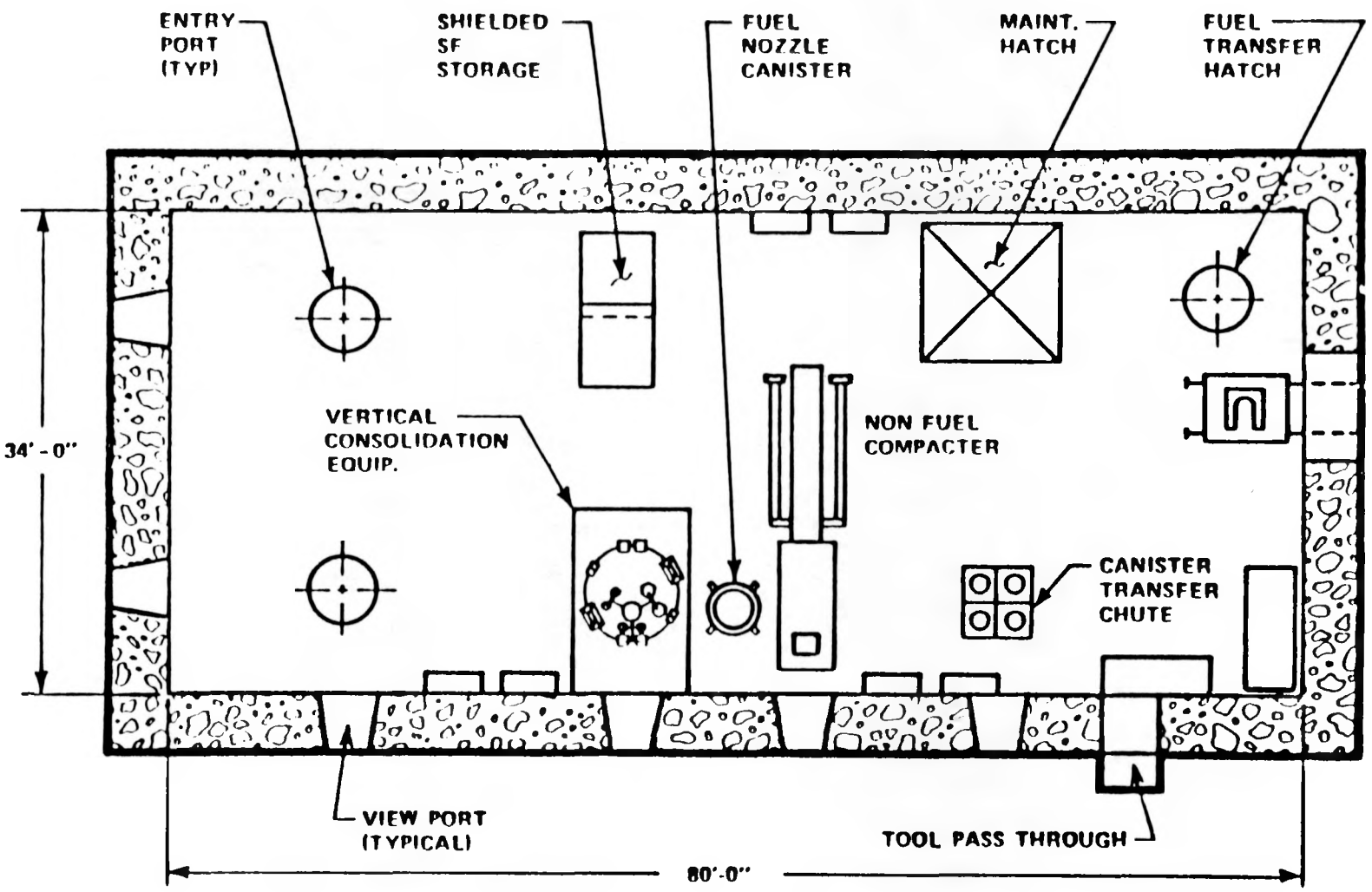

Figure 12 - Plan View of Shielded Process Cell
With Vertical Apparatus

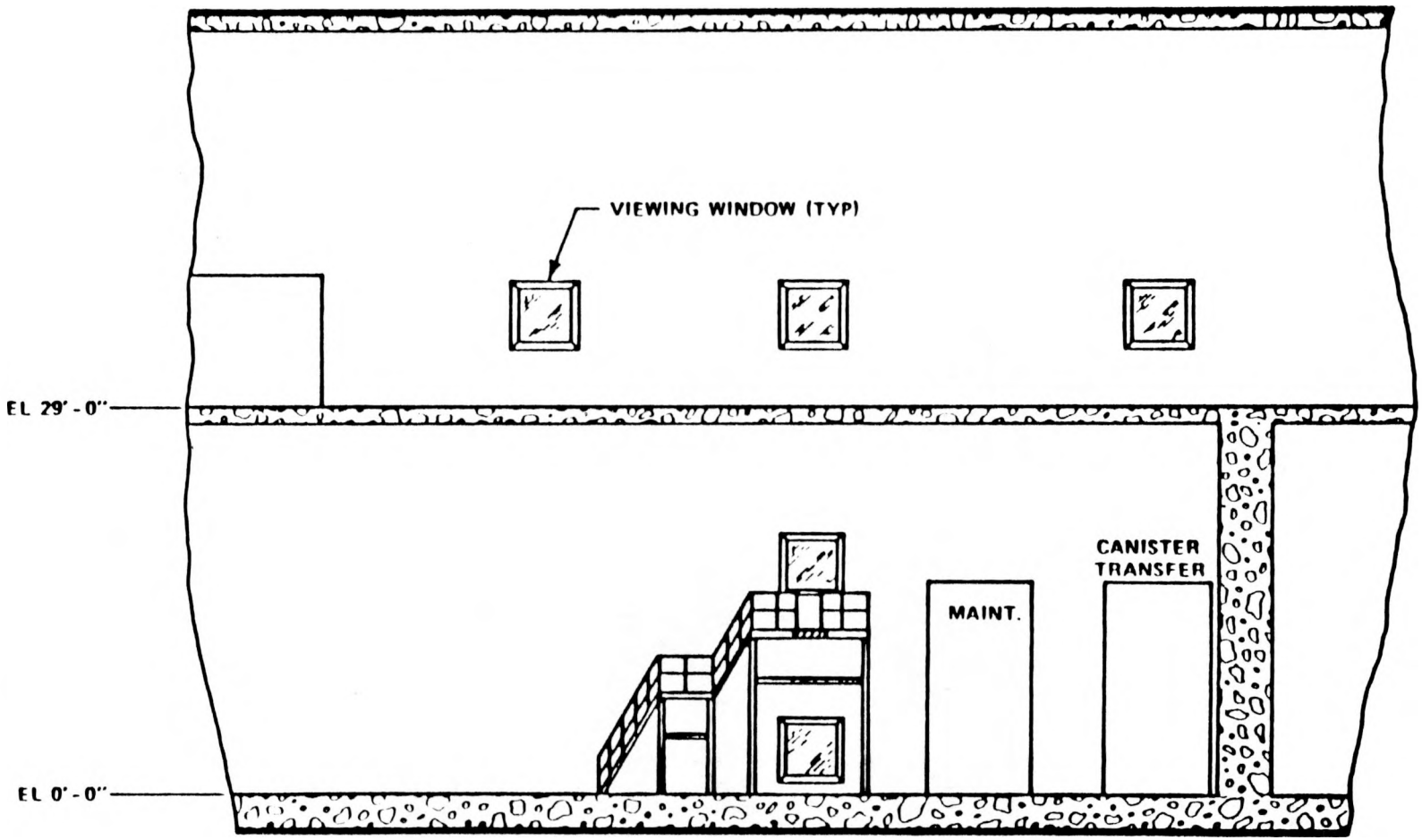

Figure 13 - Elevation of Shielded Process Cell With Vertical Apparatus

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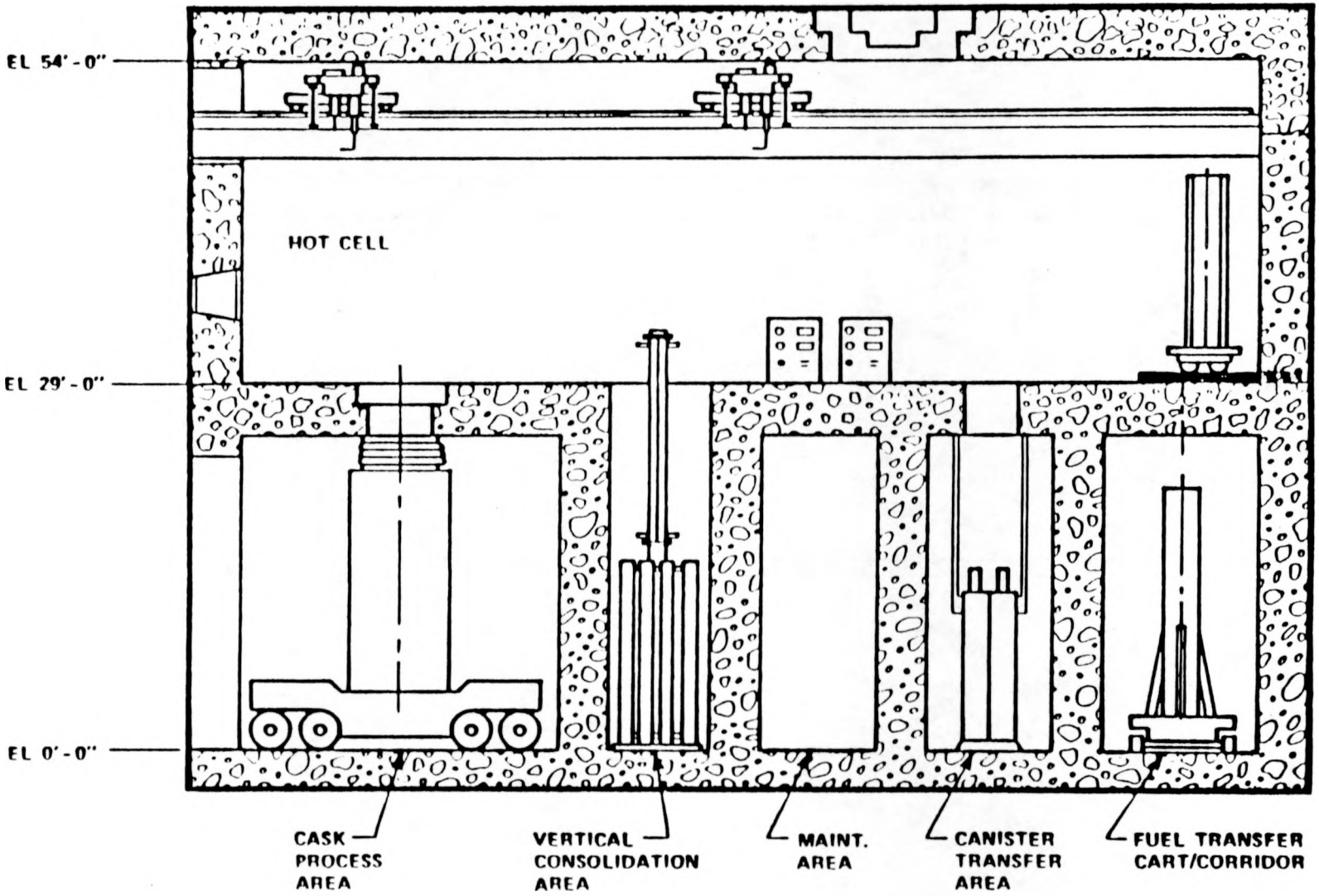

Figure 14 Viewing Port Requirements for Vertical Apparatus

Table 8 - PWR Disassembly and Consolidation Process Time Estimates[a]

HORIZONTAL - PUSH
(Two Assemblies)

A.	Visually examine to verify fuel types.	0.50 hr
B.	Secure assemblies in upender and lay SFA horizontal.	0.50
C.	Remove top and bottom nozzles.	0.50
D.	Push all fuel rods into transition canister (1 push).	0.50
E.	Retract push mechanism.	0.10
F.	Remove skeletons.	0.20
G.	Index push mechanism and push all fuel rods through transition canister into storage canister.	0.40
H.	Upend SF canister and transfer to cart.	0.50
	Total	3.20 hr
	Time per assembly	1.60 hr

HORIZONTAL - PULL
(Three Assemblies)

A.	Visually examine to verify fuel type.	0.50 hr
B.	Secure assemblies on downender.	0.50
C.	Sever top nozzle.	0.20
D.	Repeat steps B and C twice.	1.40
E.	Rotate to horizontal and grip all fuel rods.	0.10
F.	Extract all fuel rods.	0.10
G.	Rotate horizontal combs out of position.	0.10
H.	Lower fuel rods into semicircular rod configuration structure.	0.10
I.	Return carriage.	0.10
J.	Lower upper die.	0.20
K.	Push consolidated bundle into storage canister.	0.25
	Total	3.55 hr
	Time per assembly	1.18 hr

VERTICAL
(Two Assemblies)

A.	Visually examine to verify fuel types.	0.50 hr
B.	Transport to support.	0.50
C.	Cut off and remove top nozzle.	0.50
D.	Pull all rods with multiple collet gripper.	0.50
E.	Place rods in transition canister.	0.50
F.	Raise transition canister over storage canister and secure.	0.50
G.	Deposit consolidated rods into storage canister.	0.50
H.	Index transition canister to initial position.[b]	0.25
	Total	3.75 hr
	Time per assembly	1.875 hr

[a]Calculated required process time to meet throughput: 1.87 hr/assembly
[b]Storage canister is no longer on critical path.

Table 9 - BWR Disassembly and Consolidation Process Time Estimates[a]

HORIZONTAL - PUSH
(Five Assemblies)

A.	Visually examine to verify fuel type.	1.25 hr
B.	Secure assemblies in upender and lay horizontal.	1.25
C.	Remove top and bottom nozzles.	1.00
D.	Rotate capture rods.	0.50
E.	Push all fuel rods into transition canister (1 push).	0.50
F.	Retract push mechanism.	0.10
G.	Remove skeletons.	0.25
H.	Index push mechanism and push all rods through transition canister.	0.40
I.	Upend SF canister and move to cart.	0.50
	Total	5.75 hr
	Time per assembly	1.15 hr

HORIZONTAL - PULL
(Seven Assemblies)

A.	Visually examine to verify fuel type.	1.25 hr
B.	Secure assemblies on downender.	0.50
C.	Sever top nozzle.	0.10
D.	Repeat steps B and C six times.	3.60
E.	Rotate to horizontal and remove top nozzle for disposal.	0.30
F.	Remove and collect springs.	0.20
G.	Rotate capture rod.	0.20
H.	Grip all elements except eight tie rods/assembly.	0.20
I.	Extract rods approximately 3 in.	0.10
J.	Sever lower nozzles.[b]	-
K.	Grip remaining tie rods.	0.20
L.	Extract all fuel rods and insert horizontal and vertical combs.	0.10
M.	Rotate horizontal combs out of position.	0.10
N.	Lower fuel rods into semicircular rod configuration structure.	0.10
O.	Return carriage.	0.10
P.	Lower upper die.	0.20
Q.	Push consolidated bundle into storage canister.	0.25
	Total	7.25 hr
	Time per assembly	1.03 hr

[a]Calculated required process time to meet throughput: 1.13 hr/assembly
[b]Parallel with operational steps E through I.

Table 9 (Contd)

VERTICAL
(Two Assemblies)

A.	Make visual examination to verify fuel type.	1.25 hr
B.	Secure assemblies in stand.	1.25
C.	Cut off and remove top nozzles.	0.50
D.	Secure fuel rods in multi-collet gripper.	0.25
E.	Rotate capture rods.	0.50
F.	Cut off and remove bottom nozzles.	0.50
G.	Pull all rods.	0.50
H.	Place all rods in transition canister.	1.25
I.	Raise transition canister over storage canister.	0.50
J.	Deposit consolidated rods into storage canister.	0.50
K.	Index transition canister to initial position.[c]	0.25
	TOTAL	7.25 hr
	Time per assembly	3.63 hr

[c]Storage canister is no longer on critical path.

types. The horizontal-push system is rated above the vertical system in both PWR and BWR processing categories. This indicates that the horizontal system in general has a higher operating efficiency.

7.2.6 Visual Monitoring

The conceptual layouts (Figures 10 through 14) for facilities with horizontal and vertical dismantling and consolidation equipment were discussed earlier. It can be seen in these figures that both of the horizontal operations can be viewed from one operating gallery. Two operating levels, as shown in Figure 14, are needed for direct visual monitoring of the vertical dismantling and consolidation operations. This is considered to be a disadvange, as this arrangement does not provide direct and effective line-of-sight communication and access between operators. Thus, the horizontal orientation is preferred.

7.3 CONSOLIDATION RATIOS

Consolidation ratios refer to the cross-sectional area (volume equivalent) of the consolidated bundle. Because the fuel rod length is not changed, consolidation from an open, square array to a close-packed array results in a consolidation ratio of approximately 2:1 for all fuel designs and for both vertical and horizontal operations.

7.4 SYSTEM INTEGRATION

The reference spent fuel consolidation system must interface with the fuel receiving and incoming storage of the front-end, and with the canister-seal welding process at the output end. As indicated in the discussion of operating environment, dry processing is more compatible with the MRS Facility environment than is wet processing. From an overall system standpoint, vertical consolidation is somewhat more compatible because assemblies are received with their axes vertical and this orientation is maintained throughout the processing.

7.5 EASE OF MAINTENANCE

Ease of maintenance is somewhat of a misnomer in this application because no maintenance is expected to be performed in the shielded process cell. If maintenance is required, the malfunctioning component must be removed from the system, using remotely operated tools, and then brought out of the shielded process cell for servicing. As a consequence of this, what really must be judged is "accessibility for removal." With a wet environment, most removal operations would require working in both air and water, with the attendant sighting visual difficulties; thus, a dry environment is preferred. Components in a horizontal system are essentially mounted on the same horizontal plane, whereas the components in the vertical system are mounted in a stacked configuration. Therefore, the components in horizontal systems are accessible by use of wall-mounted manipulators and an overhead crane; because the vertical system components are more difficult to reach from the crane, the horizontal system is preferred for accessibility.

Overall, system reliability, both for operations and for maintenance accessibility, favors a horizontal-dry system concept.

7.6 OFF-NORMAL EVENTS

This category includes the unplanned events that can be expected to occur during the operation of the system. To ensure recovery from such events, secondary recovery tooling will be incorporated into the consolidation system. The system design must also provide high visibility for tool use. Because of its arrangement of components, the horizontal system can be viewed from one level. This provision provides a more direct communication link between operators and general ease of recovery tooling use.

7.7 EQUIPMENT COST

Equipment cost considerations for wet-horizontal, wet-vertical, dry-horizontal, and dry-vertical systems are presented herein. Estimated capital cost of equipment is not presented because no existing production consolidation system exists to form a comparison. Rather, the cost considerations involved within each category are discussed.

Equipment costs for dry and wet scenarios (with the exception of motors) are assumed to be about equal. However, support systems for wet and dry consolidators differ vastly. A wet environment will require temperature control, ion exchangers, liquid filtration, chemistry control, biological growth control, HVAC filtration and control, and decon solutions. A dry environment will require HEPA filtration and control, prefilters, and decon liquids. It is grossly estimated that the support systems and associated building space for a wet consolidation system will cost about twice as much as those for a dry consolidation system.

The equipment cost considerations between the vertical and horizontal consolidation equipment are presented herein. Three key parameters were identified as a basis for the comparison between horizontal and vertical cost considerations: initial capital cost, operational cost (including efficiency), and overall facility costs. It is assumed the operational costs will be greater for the vertical system because of the operation and maintenance of additional cells. The initial capital cost of vertical or horizontal equipment is assumed to be the same, based on performing similar functions and essentially requiring the same tooling to perform the consolidation operations.

Overall facility costs can be assessed on the basis of efficiency of the equipment to process 3,600 MTU/yr of spent nuclear fuel. The quantity of shielded process cells required to process the fuel is directly proportional to system efficiency. Six cells will be required to process 3,600 MTU/yr of spent fuel assemblies with the vertical system presented in this study. However, four cells will be required for processing fuel with the horizontal-pull consolidation system. On this basis, a 56% reduction in facility cost is achieved with a horizontal-pull system. Additionally, cell

support equipment would be increased by approximately 56% with a vertical system, including increased initial capital and operating costs. Therefore, from a cost consideration standpoint, the horizontal-pull consolidation system is preferred.

Vertical consolidation systems, using a transition canister for fuel rod reordering are limited to the quantity of assemblies that may be processed. This is caused by the deflections of the fuel rods while in transition from the existing square-pitched array to a close-packed, triangular array. On a conceptual basis, two assemblies (PWR or BWR) can be processed simultaneously with a vertical system. However, three PWR or seven BWR assemblies can be processed with the horizontal-pull system. The main reason for this increase is that the horizontal system does not have the constraints of a transition canister; rather, stationary and translating dies reconfigure the fuel rods, eliminating fuel rod deflections. In all cases, the horizontal-pull consolidation system requires less operating time per assembly, thereby providing a decrease in operational costs.

7.8 PROCESS EVALUATION SUMMARY

A rating of the process evaluation, based on the foregoing discussions, is given in Table 10. The table shows the rating of each of the six possible consolidation systems in each of the evaluation categories. Ratings are on a scale of good, fair, and poor.

The considerations were ranked on a scale of 1 to 3, with 3 being the most important. A similar scale was used for the poor-good rating. Using these ratings, weighted scores were tallied for each system. As shown in Table 10, the horizontal, dry-pull system ratings are substantially above the others on the basis of these evaluations.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The results of this conceptual study and the analysis of the systems indicate that dry-horizontal-pull consolidation is preferred for production spent fuel assembly consolidation in the MRS Facility. The horizontal consolidation concept minimizes the fuel rod handling and transfer operations, thus minimizing the process time for fuel assembly consolidation. In addition, it improves the system's ability to satisfy the initial production specification of 3,600 MTU/yr. The pull approach minimizes overall cell size and storage space for lengthy push mechanisms and transition canisters.

Developmental testing of the dry-horizontal-pulling consolidation system should precede implementation into the MRS Facility. The pulling approach satisfies the FDC requirements of processing 3,600 MTU/yr, and reduces the number of cells required to process fuel from four to three, resulting in a 56% facility savings.

Appendix A contains the conceptual design rationale for individual component selection for the dry-horizontal-pull spent fuel consolidation system.

Table 10 - Process Evaluation Summary

Consideration Category	Relative Importance	Horizontal-Push Wet	Horizontal-Push Dry	Horizontal-Pull Wet	Horizontal-Pull Dry	Vertical Wet	Vertical Dry
Production rate	3	P	F	P	G	P	F
System integration	1	P	F	P	F	P	P
Space considerations	1	F	F	F	G	F	G
Reliability	3	F	F	F	F	F	F
Secondary waste	2	F	G	F	G	F	F
Ease of maintenance	2	F	G	G	G	F	F
Off-normal conditions	3	G	G	G	G	F	F
Equipment cost	2	P	F	P	G	P	F
Weighted score		31	41	33	47	28	34

Rating: Good 3
Fair 2
Poor 1

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REFERENCES

1. "Functional Design Criteria for Monitored Retrievable Storage (MRS) Facility," Project D-360, Battelle Pacific Northwest Laboratory.

2. "Water Basin Spent Fuel Storage Using Pin Disassembly (Pin Storage)," SRO-1051-8, NAC-C-7850, Volume V, Nuclear Assurance Corporation.

3. "Status of Equipment Development for Fuel Disassembly and Rod Consolidation," U.S. Tool & Die, Inc., presented to Institute of Nuclear Materials Management.

4. "Spent Fuel Consolidation at the Barnwell Nuclear Fuel Plant," AGNS-35900-1.2-104, Allied General Nuclear Services 1980.

5. "Segmentation of Spent Fuel by Shredding," Boeing Engineering and Construction Company.

6. "Modified Spent Fuel Pin Storage," Maine Yankee Atomic Power Company.

APPENDIX

DRY-HORIZONTAL SPENT FUEL CONSOLIDATION SYSTEM EQUIPMENT SELECTION AND CONSIDERATIONS

Evaluations of existing consolidation equipment and various modes of operations led to the selection of a dry-horizontal spent fuel consolidation system. The following sections present the results of this evaluation.

The dry-horizontal spent fuel consolidation system consists primarily of two groups of equipment: disassembly equipment and consolidation equipment. The function of the disassembly equipment is to prepare fuel assemblies for subsequent fuel rod removal. The function of the the consolidation equipment is to reorder fuel rods from their existing square-pitched array to a triangular, close-pitched array. Three PWR or seven BWR fuel assemblies are processed simultaneously. This quantity of assemblies was based on: (1) thermal heat load considerations, (2) integer quantity of assemblies per canister, and (3) storage canister geometry. This combination reduces space requirements within the facility and minimizes process time per assembly.

A.1 DISASSEMBLY EQUIPMENT

Selection of the disassembly equipment considered the following:

- End-fitting severing methods
- Secondary waste material transfer methods

The following sections discuss each of these in more detail.

A.1.1 END-FITTING SEVERING METHODS

The following methods of severing end-fittings on PWR and BWR fuel assemblies were considered:

(1) Laser
(2) Stone saw
(3) Multiple-inner-diameter tube cutters
(4) Milling

The evaluation of severing methods was influenced by a number of physical, procedural, and operational conditions. The following listed conditions were defined for this evaluation:

(1) The severing method must be capable of severing both upper and lower end-fittings on similar fuel assemblies without tooling changeouts.

(2) The severing means (e.g., tube cutter, stone saw blade, laser probe, or milling cutter) must be modular to accommodate variations in fuel types.

(3) The location of the cut must be below the top of the fuel rods to allow adequate clearance to engage the collets on the fuel rods.

(4) The kerf must be clean to prevent burrs and provide minimal distortion during the severing operation.

(5) The severing system must be capable of being moved out of the way while onloading intact assemblies.

The selection of the laser for disassembly of end-fittings is consistent with the above conditions. The basis for this selection and the description of the four severing methods are included herein.

A.1.1.A. Laser

System studies were accomplished in two discrete tasks - a detailed literature search (including investigation of related fuel reprocessing and laser programs) and observation of existing laser facilities.

Information for the literature search came from the following sources:

(1) Westinghouse Research and Development Center
(2) United Technologies Research Center
(3) AVCO Everett Metalworking Lasers
(4) SPAWR Optical Research, Inc.
(5) II-VI Incorporated

The results of the search served as the basis for both recommending laser system equipment and evaluating system design requirements. In addition to the literature search, visits were made to the Westinghouse Research and Development Center to observe and discuss laser facilities, laser auxiliary equipment, and laser operation. These visits provided first-hand knowledge of current laser operation and design technology.

The laser provides PWR/BWR interchangeability through modular cutter probe changeouts. A fuel-specific, PWR probe is inserted within a thimble or instrument tube to sever below the first grid, thereby providing acceptable collet clearance to grip and extract the fuel rods. Once the rod extraction process is completed, the laser probe translates down to sever the bottom end-fittings in preparation for secondary waste volume-reduction processes. The laser can, therefore, provide both upper and lower end-fitting removal with a single tool.

A fuel-specific BWR probe is inserted within the laser head, and begins the severing process with one modular tooling change. The eight tie rods used to structurally secure the assembly must be severed and the upper end-fitting removed to gain access to the fuel rods. The upper portion of the tie rods

is severed slightly below the upper end-fitting, providing gripper access to the fuel rods for extraction. The lower portion of the tie rods is severed above the lower tie plate, freeing the remaining eight fuel rods for extraction. No equipment modification or secondary tooling is required to sever the lower portion of the tie rods.

Burrs, common to mechanical severing techniques, will be at a minimum. Interchangeability through single modular probes for PWR/BWR end-fitting severing of both upper and lower end-fittings with one tool (approximately a 30-mil kerf, single-base unit, with multifunctional capabilities) provides the basis for selection of the laser method.

The following end-fitting severing methods were considered, but not selected for the dry-horizontal spent fuel consolidation system:

(1) Stone saw
(2) Multiple-inner-diameter tube cutter
(3) Milling

A.1.1.B. Stone Saw

The stone-saw method would pass a stone wheel through a cutting plane below the upper end-fitting and above the lower end-fitting, providing access for fuel-rod extraction and preparation for secondary waste volume-reduction operations.

PWR upper end-fitting severing would require an approximately 18-in.-dia stone cutting wheel to pass through the thimble and instrument tubes, thereby providing access to fuel rods after upper end-fitting removal. The stone saw cannot sever below the upper elevation of fuel rods without compromising fuel rod integrity. The stone-saw technique, therefore, is not compatible with using collets to withdraw the fuel rods. An example of "gap" clearance on a Westinghouse fuel assembly is approximately 0.095 in., decreasing the collet's wall thickness to a structurally unacceptable level. Lower end-fitting severing can easily be accomplished with a stone saw, provided that fuel rods have not dropped because of grid relaxation in pool storage or during transportation and handling at the MRS Facility.

BWR upper end-fitting severing would require an approximately 2-in.-dia stone cutting wheel to pass through the eight tie-rod nuts, providing access to the fuel rods after end-fitting removal. Consequently, the stone-saw method of severing does not combine interchangeability among variations in PWR/BWR fuels. Contamination control of particles from both the stone saw and the part being severed would require secondary collection systems. Repeatability in cutting quality possibly would be difficult to control, on a production basis, from a remote standpoint.

A.1.1.C. Multiple-Inner-Diameter Tube Cutters

PWR spent-fuel assemblies must be cut below the first grid to allow access and clearance for fuel rod gripper collets. On a production basis, a

multiple-inner-diameter tube cutter can provide the required thimble and instrument severing below the first grid; however, lower end-fitting severing would require additional tooling. A stone saw would provide a feasible scenario for lower end-fitting severing. Inner-diameter tube cutters do not provide interchangeability between upper and lower end-fitting severing. Also, BWR tie rods are solid right cylinders, allowing no use of an inner-diameter tube cutter. For these reasons, a multiple-inner-diameter tube cutter was not selected.

A.1.1.D. Milling

PWR joining techniques of thimble tubes to upper end-fittings consist of a welded joint, which can be milled away and provide access to fuel rods after nozzle removal. Additionally, the head on cap screws used to fasten the lower end-fitting to thimble tubes can be machined to free the lower end-fitting. During the milling operation, stainless steel chips would be generated, and a chip-collection system, local to the milling cutter, must be employed, requiring additional support equipment to perform the nozzle-severing operations. The milling cutter will not provide severing below the first grid to allow sufficient clearances for fuel rod gripper collets. For BWR assemblies, a milling technique is not compatible with severing either the upper or lower end-fittings. For these reasons, a milling method of end-fitting severing was not selected.

A.1.2 MATERIAL TRANSFER OF SECONDARY WASTE METHODS

During the disassembly of spent fuel elements, secondary waste (consisting of upper and lower end-fittings, grids, thimbles, instrument tubes, water rods, and associated mechanical hardware) must be removed from the disassembly equipment and transferred to be volume-reduced.

The following sections briefly describe the methods considered. Selection of a dedicated robot and overhead crane with manipulator was based on the following rationale for secondary waste material transfer.

A.1.2.A. Dedicated Robot

The main reason for the selection of a dedicated robot is that the secondary waste removal operation is an on-line process in the consolidation operation. Use of the dedicated robot would increase the overall system efficiency by (1) not requiring support equipment, such as the overhead crane or wall-mounted manipulator, to perform additional functions; (2) allowing operations to be programmed; and (3) permitting high control of accuracy and repeatability. In addition to material transfer of secondary waste, the robot can perform capture-rod rotation on BWR assemblies. The combination of multifunctional, repetitive on-line functions and precision programmability led to the selection of a robot for secondary waste material transfer.

The following methods of secondary waste material transfer were considered, but not selected:

(1) Wall-mounted manipulator
(2) Overhead crane with manipulator

A.1.2.B. Wall-Mounted Manipulator

The primary function of the wall-mounted manipulator is to perform maintenance and modular component changeout operations on the fuel consolidation system. The wall-mounted manipulator can be used to perform off-normal functions if the dedicated robotic system is down. Placing both on-line and recovery operations in one system will decrease the overall reliability of the consolidation process. On this basis, the wall-mounted manipulator was not selected.

A.1.2.C. Overhead Crane with Manipulator

The overhead crane with a fuel grapple will transfer PWR upper end-fittings. A PWR fuel assembly will be loaded onto the upender; parallel operations between part-loading, severing of the upper end-fitting, and end-fitting removal can then be performed.

Because time estimates between part-loading and nozzle severing are similar, the parallelism of operations provides an increased overall system efficiency. The increased efficiency from use of the same fuel grapple for end-fitting transfer led to the selection of the overhead crane for end-fitting removal of PWR assemblies.

A.2 CONSOLIDATION EQUIPMENT

Selection of consolidation equipment considered the following:

(1) Spent fuel rod extraction methods
(2) Rod reconfiguration methods

The following sections present the fuel rod extraction and reconfiguration techniques selected for the consolidation process and those considered during the advanced conceptual design process.

A.2.1 SPENT FUEL ROD EXTRACTION METHODS

Spent fuel rod extraction methods that were considered include:

(1) Multiple-full-complement fuel rod pulling gripper
(2) Push rods
(3) Reciprocating gripper

The selection of a multiple-full-complement fuel rod pulling gripper was based on the following.

A.2.1.A. Multiple-Full-Complement Fuel Rod Pulling Gripper

Multiple fuel rod removal will provide the highest efficiency of the rod-removal techniques described. The operation will use individual collets corresponding to fuel rod locations on three PWR or seven BWR assemblies. The gripper will pull fuel rods from the "skeleton" directly over the reconfiguration station. Employing a pull will enable load limiting on fuel rods during extraction. Off-normal recovery of stuck rods can be approached by retracting the gripping head and regripping the stuck rod(s) at a higher gripping force. The system overall length is greatly reduced from full-length pushing operations by approximately the length of a fuel assembly. This decrease in length represents a substantial cost saving from a facility overview. Modularization of grippers (which interface with a generic carriage) provides interchangeability among all variations of PWR/BWR fuel types. The combination of cost effectiveness, extraction load limiting, use of interchangeable modules, and off-normal recovery capabilities was among the priority capabilities inherent in the selection of a multiple-"pull" gripper. Additionally, a PWR multicollect fuel rod gripper for pulling fuel rods from a skeleton has been tested and functionally demonstrated on irradiated fuel rods.

The following spent fuel rod extraction methods were considered, but not selected for the dry-horizontal fuel consolidation system:

(1) Push rods
(2) Reciprocating gripper

A.2.1.B. Push Rods

Multiple rods in a simulated fuel assembly array, which are slightly longer than a fuel assembly, would push fuel rods from the grid structure into a reordering station. Use of push rods would require an effective increase in system size equal to the fuel-assembly length. A mechanical interface is not required between a push rod and a fuel rod. Force limitations on individual fuel rods would be difficult to control (because of the slenderness of push rods) during the extraction process.

On the basis of additional system length and control of forces on fuel rods, the push method of rod extraction was not selected.

A.2.1.C. Reciprocating Gripper

A mechanism that would grip and pull a full complement of fuel rods, release, return to a start position, regrip, and extract was eliminated on the basis of its violating a "once-gripped-do-not-release" (until an operation is completed) philosophy.

A.2.2 ROD RECONFIGURATION METHODS

Fuel rod reconfiguration methods that were considered include:

(1) Die, strap, and comb combination
(2) Transition canister

The selection of a die, strap, and comb combination for fuel rod reconfiguration was based on the following.

A.2.2.A. Die, Strap, and Comb Combination

During fuel rod extraction, horizontal and vertical combs are sequentially and simultaneously inserted into the extracted fuel rod array. Horizontal combs provide fuel rod support from gravity-induced deflections. Vertical combs provide alignment and guidance during lowering once the horizontal combs are rotated out of position. Horizontal and vertical combs are a design-specific module particular to a fuel type, and need replacement when different fuel assemblies are processed. The combs provide controlled guidance, support, and limit deflections of the extracted fuel bundle.

Translating upper and stationary lower semicircular dies provide the reconfiguration process to the extracted fuel rods. The dies are generic in design, and are independent of fuel type. They do not require changeover when processing variations in fuel type.

Straps that are spring-loaded provide the transfer ability of the extracted fuel bundle into the lower stationary dies. Additionally, the spring feature will absorb any impact loads imposed on fuel rods during the lowering process.

A generic design that requires minimal changeouts, provides guidance of fuel rods during reordering, and limits deflections to a minimum are key parameters in selecting the die, strap, and comb combination as the preferred rod reconfiguration method.

A.2.2.B. Transition Canister

Reordering spent fuel rods from a square-pitched array into a close-packed, triangular array can be accomplished by a transition canister. A transition canister contains metallic separators and guides that, throughout the length, converge the rods together. During the reordering process, the fuel rods must bow and deflect. Multiple groups of fuel assemblies will require lengthy transitions to limit compound deflections resulting from fuel rod convergence.

Transition canisters can use a friction-type drive to transport fuel rods into a storage canister. Another approach would be to use long push rods to transfer the fuel rods into a canister. The transition canister must be design-specific to a particular fuel type, requiring modular changes with variations in fuel. A friction drive requires that all fuel rods be extracted to transfer the consolidated bundle into a storage canister or the system fails. In the case of stuck rods in the skeleton, the operation would require insertion of a "dummy" rod into the bundle, using a friction drive.

It should be noted that the transition concept has been tested and functionally demonstrated, but not on multiple fuel assemblies. Based on fuel-specific modules, rod deflection, and possible rod rupture when processing multiple assemblies, as well as problems encountered during recovery operations, the transition canister method was not selected.

A.3 GENERAL DESIGN FEATURES

The following describe the general design features of the dry-horizontal spent fuel consolidation system:

(1) Structural stainless steel box beam members were selected and used to the maximum extent for clean design and elimination of crud traps.

(2) Components that are design-specific to a particular fuel type were designed to be remotely removable and replaceable, using bails, trunnions, capture bolt mechanical fasteners, and manifold connections.

(3) Electrical and pneumatic drives were selected in place of potentially "leaky" hydraulic drives.

(4) Consolidation equipment was selected on the basis of minimizing overall space envelopes.

(5) Use of existing technology was incorporated into the design. Examples include the laser system, gripper, and combs.

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REPOSITORY OVERPACK CLOSURE WELD PROCESS

1.0 INTRODUCTION

Waste forms processed in the shielded process cells of the R&H Building are packed into canisters of various sizes. Some of these canisters are then transported to the shielded canyon cell, where they are overpacked into large cylindrical vessels called repository overpacks. After an overpack is loaded with canisters, it is sealed by placing a lid on top of it and welding the lid to the main body of the overpack. The weld that attaches the lid to the body is called the closure weld; because the contents of the repository overpack are radioactive, this weld is performed remotely. The purpose of this study is to determine the welding process that is conducive to performing the closure weld remotely and with optimum ease. The following sections discuss the five welding processes considered for this application, followed by the selection of the optimum process.

2.0 WELDING SYSTEM REQUIREMENTS

Certain physical, procedural and operational requirements shall apply to the closure weld process. These are enumerated below in two categories: (1) function and performance requirements, and (2) space and environmental limitations.

2.1 FUNCTION AND PERFORMANCE REQUIREMENTS

The overpack, its closure weld, and the welding process must meet the following functional and performance requirements:

2.1.1 Overpack and Weld

(1) The overpack will accommodate canisters of processed radioactive waste. Its enveloping dimensions will not exceed those depicted in Figure 2-1.

(2) In the shielded canyon cell, the overpack will be stationary and will rest in a vertical orientation inside a pit. The top of the overpack must protrude at least 12 in. above the pit to allow a welding apparatus to perform the closure weld.

(3) After transportation out of the MRS Facility, the overpack will be stored in a repository, where corrosive elements such as salt and basalt will abound. The rate of the corrosion of steel in this environment by brine is estimated to be about 2.5 cm/1,000 yr (Ref. 1, Figure 5-3, p. 62). The design life of the overpack is 1,000 yr. Thus, the overpack (and hence the closure weld) must have enough

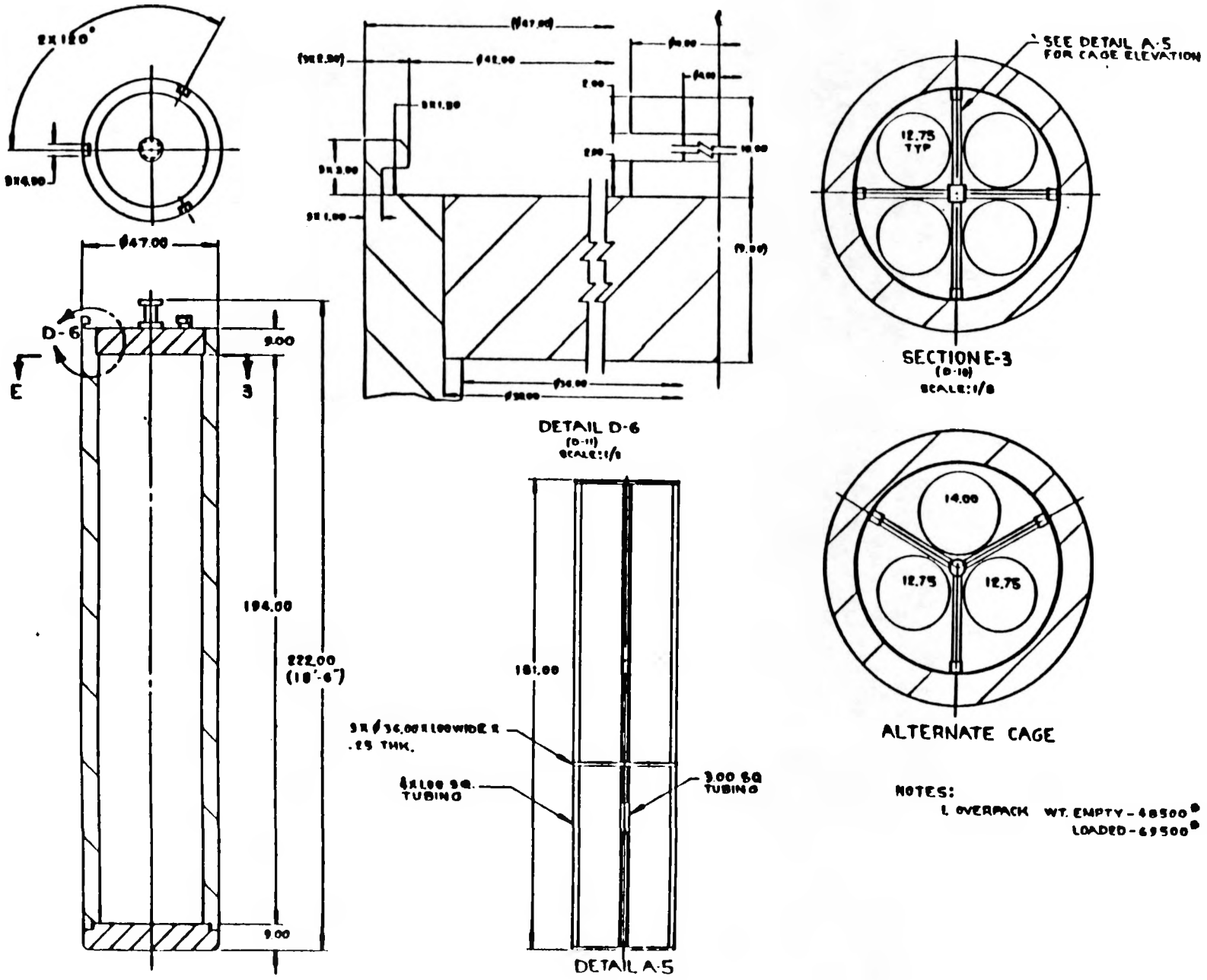

Figure 2-1 - Repository Overpack

bulk to be able to withstand this corrosion and maintain their structural integrity throughout this period. Based on the above rate of corrosion, it can be calculated that the depth of the closure weld must be at least 2 in., which includes a safety margin of approximately 1,000 yr.

(4) Galvanic corrosion is also expected in the salt repository. To prevent galvanic corrosion, the closure weld filler metal must have a composition as similar to the base metal as possible.

(5) In addition to resisting the above corrosive environment, the overpack and its closure weld must also be able to withstand, for 1,000 yr, the lithostatic pressures expected to be prevalent in a salt repository. The design base lithostatic pressure is 15.4 MPa (2,234 lb/sq in.) (Ref. 1, Appendix G, p. 245).

(6) The overpack material must be a steel pipe of maximum carbon content 0.25% and effective carbon content less than 0.40%. The composition of the overpack steel must approximate most closely to the chemistry of AISI 1018, but its mechanical properties must be equivalent to those of AISI 1021. This requirement stems from requirement (3), above (Ref. 1, Appendix G, p. 243).

(7) From Figure 2-1, it is clear that the lid of the overpack will sit on a ledge machined into the overpack. Because of this design feature, external loads impressed upon the lid will be transferred to the overpack. Therefore, the purpose of the overpack closure weld will only be to seal the overpack effectively for 1,000 yr. A visual examination of the closure weld will ensure that the weld meets the sealing requirement, so the weld must pass this examination. Note, however, that for purposes of adding a safety margin to the weld design, requirement (5), above, is still valid.

(8) The weld shall be of sound enough quality to pass the following tests: a visual examination and nondestructive testing for cracks. The weld shall pass these tests regardless of its shape, size, and type.

2.1.2 Welding Process

(1) None of the weld preheating, cooling, stress-relieving, or postweld heat-treatment processes are desirable because they will have to be performed remotely. In general, the welding system must require a minimum of remote operations.

(2) Minimum weld preparation is desired.

(3) To satisfy the desired throughput rate of the MRS Facility, the welding process must perform the closure weld within 4 hr to meet the throughput rate of producing one repository overpack per shielded canyon cell per day. These rates are based on a 50% cell

processing efficiency. (Note that there are two shielded canyon cells in the MRS Facility.)

(4) It is not recommended that the welding system be stationary and the overpack be rotated to perform the closure weld. Mechanical rotation mechanisms, because of their inherent tendency to vibrate, will not be able to rotate a mass as large as the overpack without effecting unpredictable displacements of the weld groove from the set path. A more efficient method will be to keep the overpack (and hence the groove) stationary, and move the welding system around the groove, guided by a groove-follower mechanism. The welding system must be conducive to such a setup.

(5) Because the closure weld will be performed remotely, the welding apparatus for the process chosen must provide a visual view, through closed-circuit television (CCTV), of the welding in progress.

(6) The welding apparatus must be as simple to operate and maintain as possible.

2.2 SPACE AND ENVIRONMENTAL LIMITATIONS

The repository overpack will rest in a pit located in the shielded canyon cell, where the welding will be performed. This section lists the space requirements, radiation levels, maintenance restrictions, thermal environment, masses involved, and mechanical handling systems existing in the shielded canyon cell in the immediate vicinity of the repository overpack pit.

2.2.1 Space Available

Figure 2-2 shows the layout of that end of the shielded canyon cell where the overpack is located.

It is clear from the figure that space on one side of the pit is limited by the canister upender. The upender is shown in two positions, one along its rails and the other turned to a right-angle position. It is the latter position that the welding apparatus must avoid. Although the upender is not expected to move away from the wall while in its right-angle position, for the purpose of ascertaining the space available for the welding system, it is assumed that it will.

The welding system must be in view of the operator looking through the window, as shown in the figure opposite the pit. The window centerline will be approximately 5 ft-6 in. off the floor outside the cell, and window dimensions are assumed to be 3 ft square.

A discharge port plug is located on the opposite side of the overpack pit, away from the upender. The plug is a single-piece, cylindrical radiation shield plug, 108 in dia and 24 in. thick. This plug will be lifted by the overhead crane in the cell and put aside to allow the repository overpack to enter or exit the cell. During entry, the overpack will be lifted through

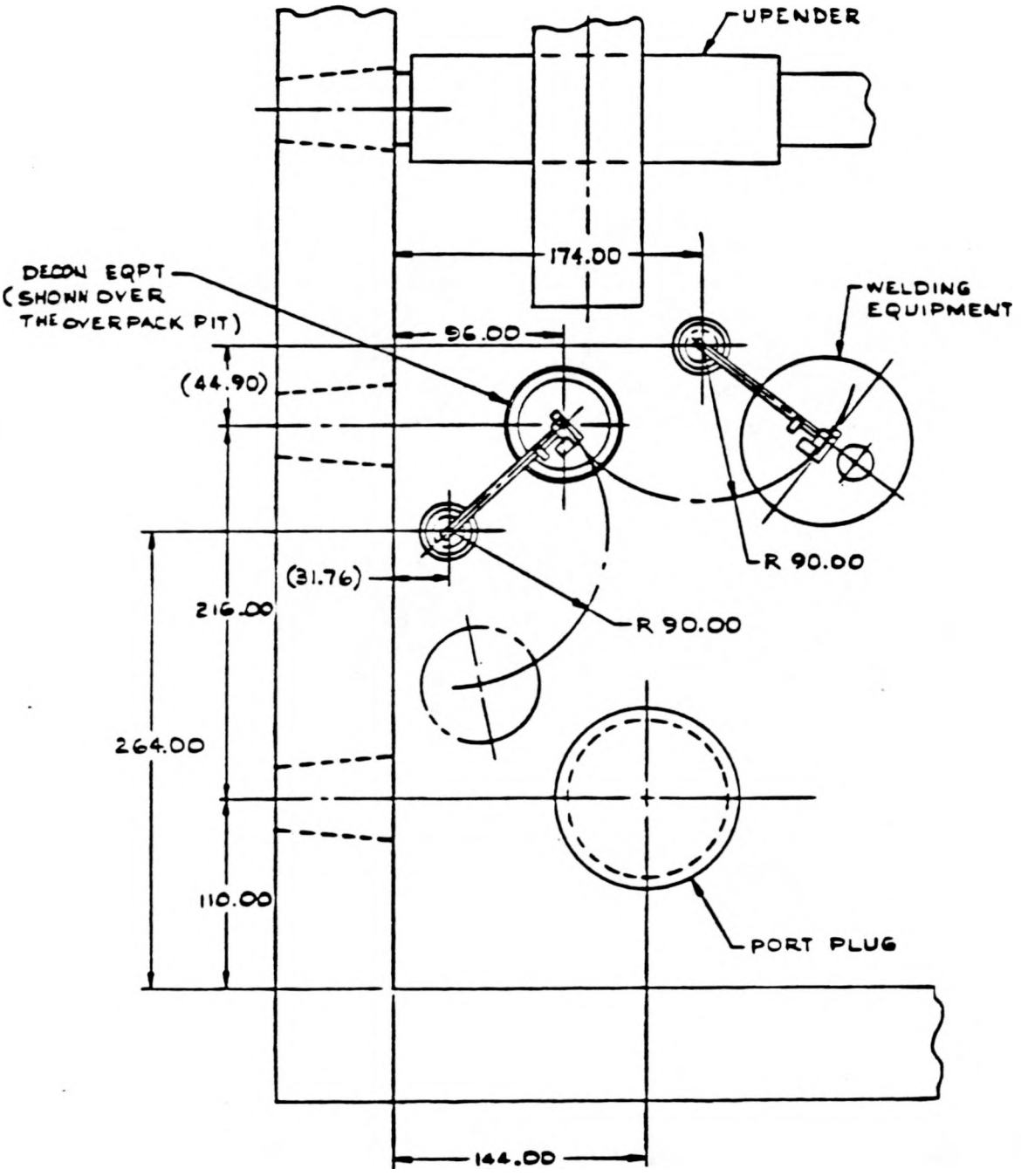

Figure 2-2 - Repository Overpack Area

the port by the same overhead crane, carried parallel to the wall toward the overpack pit, then toward the wall, and lowered into the pit. The motion of the overpack will thus be in a straight line parallel to the wall, and then at right angles toward the wall. The welding apparatus must be able to clear this path for the crane to maneuver unhindered.

Finally, the welding apparatus must not interfere with the operations of the decontamination equipment shown in the figure. This equipment is designed to swing out of the way for the crane and the welding apparatus.

2.2.2 Radiation Levels

The welding process must be able to function in a radioactive environment. For the intensity of the radiation levels prevalent in the shielded canyon cell, refer to Section 30, Table 30-8, of the MRS Facility Conceptual Design Report, Volume I, Book III, Report No. MRS-11, Contract No. DE-AC06-84RL10436, The Ralph M. Parsons Company of Delaware, Westinghouse Electric Corporation, and Golder Associates.

2.2.3 Maintenance Restrictions

Every design in the shielded canyon cell is modular, with the modules easily and remotely removable, so that, if a module needs maintenance, it can be easily removed from the cell and lowered into the maintenance bay of the MRS Facility. Manned access into the shielded canyon cells shall not be assumed for maintaining the welding system. The welding system must also be modular in design, and the modules must be easily and remotely removable, without requiring major dismantling. As for minor maintenance, the design of the system should permit this to be performed in the shielded canyon cell through a remotely operated manipulator arm attached to the overhead crane of the cell.

2.2.4 Thermal Environment

The maximum average of the temperature distribution in the shielded canyon cell will not exceed 140°F.

2.2.5 Mass of Overpack

It is estimated that the overpacks designed for the worst-case repository environment stated in Section 2.1.1 will weigh 48,500 lb when empty, and a maximum of 70,000 lb when loaded.

2.2.6 Mechanical Handling Systems

The mechanical handling systems existing in the shielded canyon cell, in the vicinity of the overpack, are the canister upender, overpack decontamination equipment, overhead crane and its motion, and the discharge port plug. Limitations imposed by these systems on the space available for the welding system are stated in Section 2.2.1.

In addition to these systems, handling equipment will be required for handling the overpack welding system. This equipment will be designed to carry the welding system and enable the welding system to meet the following requirements:

(1) It must be in full view of the viewing window in the cell wall.

(2) It must be able to move out of the path of the overhead crane so that the crane can freely maneuver the overpack in and out of the pit and to and from the discharge port.

In addition to the above, the handling equipment must meet the following requirements:

(1) All machinery on the handling equipment shall be modular for the same reasons as those cited in Section 2.2.3; other maintenance restrictions stated in this section shall also apply.

(2) The handling equipment must provide, through limit switches or CCTV cameras, information to the operator at every stage of its operation. Typically, the information desired is the current position of the equipment; prior warning of an operation about to be completed; and provisions to automatically cancel a command impossible to execute at the current position.

3.0 WELDING SYSTEM DESCRIPTIONS

For the repository overpack closure weld application, the following five welding processes were considered:

(1) Electroslag welding (ESW)

(2) Submerged arc welding (SAW)

(3) Laser beam welding (LBW)

(4) Electron beam welding (EBW)

(5) Gas metal arc welding (GMAW)

Two more processes, resistance welding and inertial welding, were also considered, but were not regarded as suitable for the repository overpack closure weld application because of the large physical dimensions of the overpack (see Figure 2-1) and its weight. These physical characteristics of the overpack would require resistance and inertial equipment of enormous size and complexity; furthermore, there is no experience in either process available that comes even close to the overpack application. Therefore, these two processes have been excluded from further discussion in this study. Each of the above five welding processes is described below, its general attributes first, and then its attributes pertaining to its application to the repository overpack closure weld.

3.1 ELECTROSLAG WELDING (ESW)

Welding by the ESW process is achieved by the coalescence of the base metals with a molten slag, which melts the filler metal and the surfaces of the base metals. The process is initiated by an electric arc that heats the flux and melts it to form the molten slag bath. The arc is then cut off, and the slag is maintained in its molten state through its resistance to the electric current passing between the electrode and the work. The ESW process is a machine welding process that, once started, continues to completion. Because no arc exists after process initiation, the welding is done without spatter. Extremely high weld-deposition rates can be achieved by this process, with minimal distortion of the welded pieces.

There are two types of ESW processes: the conventional method and the consumable guide method.

In the conventional method, one or more electrodes are fed into the joint, depending on the thickness of the groove or the desired weld-deposition rate. The electrodes are held a certain critical distance above the molten flux by nonconsumable wire guides. To maintain the distance between the electrodes and the flux, the electrodes are moved upward at a rate proportional to the weld deposition. This movement may be either automatic or manually controlled by the operator. Flux is added either through separate mechanical means or by using flux-cored electrodes. Cooling of the weld area is required.

In the consumable guide method, both the electrode and the guide that positions the electrode in the weld area are consumable. Flux is normally fabricated into the guide or the electrode or both. Because the electrode and the guide are progressively consumed as the weld deposition progresses, this method does not require the upward movement of the welding apparatus that the conventional method does. (The consumable guide provides about 5 to 10% of the filler metal.) Like the conventional method, this method requires cooling of the weld area.

The basic equipment required by either ESW method is as follows:

(1) Power source, one for each electrode.

(2) Wire feeder.

(3) Electrode guide tube.

(4) Welding control consoles.

(5) Travel carriage (required by the conventional method).

In addition, the ESW process normally requires retaining shoes (dams). Dams are water-cooled barriers that contain the weld pool between the surfaces being welded. In the repository overpack application, however, the circular walls of the groove between the overpack inner diameter and the lid outer diameter will become the dams that will contain the weld pool.

The ESW process is best suited for butt-welding two plates, especially where the wall-to-wall width of the joint is wide and requires filling up with weld metal. A single electrode may be made to oscillate, if the width is too great, or multiple, nonoscillating electrodes may be used. In the application of the repository overpack closure weld, the weld may be considered a butt weld. The length of the weld, in this case, is equal to the entire circumference of the weld groove, as no dams can be provided at regular intervals around the circumference. In the closure weld application, provision of oscillating electrodes is not desirable because of the complexity of the machinery involved for remote operations. Therefore, nonoscillating electrodes must suffice. Table 3-1 summarizes the various parameters associated with ESW. These quantities are valid for both the conventional and consumable guide methods, unless specified otherwise in the table footnotes.

The equivalent quantities for both ESW methods can be derived from the quantities cited in Table 3-1 when applied to the repository overpack closure weld. Table 3-2 summarizes this application.

3.2 SUBMERGED ARC WELDING (SAW)

In the SAW process, an electric arc is established between the electrode and the work. Weld metal is provided by the electrode and by a blanket of granular and fusible flux material, in which the welding area is submerged. The feature of complete submersion of the arc is what distinguishes this process from ESW. Upon arc initiation, the bare-wire electrode, the flux, and the base metal in the immediate vicinity melt to form the weld pool. The electrode is advanced in the direction of welding, and fed into the arc while flux is steadily added. The unmelted, nonconductive blanket of flux provides an effective air and radiation shield, and influences the stability, temperature, and heat distribution of the plasma. The molten slag underneath provides slow cooling and prevents atmospheric contamination of the weld metal as it cools. The weld thus produced is of superior quality, uniformity, and density, and high-deposition rates can also be achieved by this process. Corrosion resistance of the weld can be enhanced by proper selection of the electrode and flux characteristics. This selection, combined with correct procedures derived from empirical tests, can render a weld with mechanical properties equal to the base metal.

Cooling of the weld area is not required by the SAW process; however, complete slag removal between each pass is important in this process. (By a proper selection of the electrode and flux materials, the slag can be rendered self-peeling.) Interpass grinding and vacuuming implements are required for the complete removal of slag. Undercutting must be avoided because it entraps slag.

Table 3-3 defines the parameters associated with SAW. These quantities are valid for the machine-welding form of SAW, in which the equipment performs the complete welding operation, but with constant monitoring by a welding operator. This equipment does not include the interpass cleaning apparatus required by this process.

Table 3-1 - Common ESW Parameters

Parameter	Quantity
Rate of weld deposition of one nonoscillating electrode	25 lb/hr[a]
Width of groove over which one electrode deposits weld	2.5 in.[b]
Flux consumed per 100 lb of weld deposit	5 lb[c]

[a]The rate of deposition varies from 25 to 45 lb/hr. The figure quoted assumes the worst case of 25 lb/hr (Ref. 2, p. 227).

[b]This figure is essentially for the consumable guide method; however, one oscillating electrode in both methods deposits weld over 5 in.; therefore, it was assumed that the deposition rendered by one nonoscillating electrode will also be the same for both methods (Ref. 2, pp. 227-228).

[c]This applies to the conventional method. The consumable guide method does not require the addition of flux from independent machinery because the flux is contained in the electrode and the consumable guide (Ref. 2, Chapter 7).

Table 3-2 - ESW Parameters Applicable to Closure Weld

Parameter	Quantity
Total number of electrodes required	48[a]
Time to complete weld	1.5 hr[b]
Flux consumed per weld	2 lb[c]
Consumable guides consumed per weld (weight equivalent)	4 lb[d]

[a]This quantity is based on the width of the groove, which in this application equals the entire circumference of the groove. From Figure 2-1, Detail D-6, the circumference of the weld groove in the repository overpack can be calculated to be 119 in.

[b]This assumes that the weld depth is 2 in. and the weld diametral width is 0.5 in. (The latter dimension is about the safe minimum for the remote nature of the closure weld application to avoid short-circuiting of the welding system by an accidental touch of the electrode to the lid or the overpack.) Thus, the volume of weld to be deposited is calculated to be 118 cu in. Specific weight of steel is 0.284 lb/cu in.; therefore, the weight of weld metal to be deposited is 34 lb. Table 3-1 establishes the rate of weld deposition to be 25 lb/hr.

[c]This quantity is derived from the calculations in footnote b, above, and the rate of flux consumption established in Table 3-1. Note that this quantity applies to the conventional method only; for the consumable guide method, the amount of flux consumed is reflected by the number of guides consumed.

[d]This applies to the consumable guide method only. A consumable guide normally provides 5 to 10% of the weld metal (Ref. 2, p. 228). Assume the worst case of 10% consumption.

Table 3-3 - Common SAW Parameters

Parameter	Quantity
Width of weld deposition	0.75 in.[a]
Rate of weld deposition	48 lb/hr[b]
Flux consumption	50%[c]
Electrode consumption	50%[d]

[a]This is the width rendered by two electrodes placed between 3 and 5 in. apart along the length of the weld (Ref. 2, pp. 190 and 193).

[b]This is based on the assumption that the current supplied by the power source (each electrode requires an independent power source) is 1,000 A, and that each electrode is 3/32 to 5/32 in. dia, supplied with parallel dc power (Ref. 2, Figure 6.2, p. 192).

[c]These are average estimates of the percent of weld metal coming from the electrodes and the share provided by the flux. Actual figures will depend on the flux and electrode compositions chosen.

* * * * * * * * * * * *

The equivalent quantities for the SAW process can be derived from these quantities when applied to the repository overpack closure weld. Table 3-4 summarizes this application.

3.3 LASER BEAM WELDING (LBW)

The LBW process is an autogenous welding process that fuses metals with the heat obtained from the application of a concentrated coherent light beam impinging on either the surfaces to be welded or a powdered flux sprinkled in the groove between them. The LBW system is composed of two major subsystems: a laser generator and an optical delivery system. The generator is a self-contained power supply that generates the laser beam. The optical delivery system is composed of a configuration of mirrors housed in transfer tubes that, through successive reflections, deliver the beam to the point of welding. Transfer tubes act as corridors for the beam to travel through and are purged with inert gas to suppress thermal blooming of the beam. The final mirror in the array of mirrors is parabolic to focus the beam into concentrated energy at the point of welding. Movement of the mirrors in conjunction with each other moves the beam in a circular path around the weld groove. Thermal blooming of the beam can be restricted between 1 and 10 mils over approximately 50 ft. For these reasons and because the generator and delivery systems are two independent entities, the generator can be remotely located from the workpiece. Cooling of the weld area is not necessary. The weld produced is distortion-free.

Table 3-4 - SAW Parmeters Applicable to Closure Weld

Parameter	Quantity
Number of electrodes required	2[a]
Time to complete weld	45 min[b]
Flux consumed per weld	17 lb[c]
Electrode consumed per weld (weight equivalent)	17 lb[d]

[a]The electrodes used may be wire electrodes or plate electrodes, the latter contoured to fit the curvature of the closure weld groove. Note that the larger the surface area of the plate electrode, the higher its power requirements.

[b]Assumptions on which this quantity is based are the same as in footnote b to Table 3-2. Note that this estimate does not include the time required for interpass cleaning. For the closure weld application, more than one pass will not be required.

[c]These quantities follow the assumption of footnote c to Table 3-3. In practice, the base metal provides a part of the weld pool; its contribution, and hence the saving of the flux and electrodes, will have to be derived from qualifying empirical tests.

* * * * * * * * * *

An inherent limitation of the LBW process is its inability to penetrate deep grooves. Higher power input to the generator increases the resultant beam's penetration. The maximum penetration that can be attained with a laser is a function of beam power, power density, and focusing characteristics. As an example of penetration compared with power, a 20-kW CO-2 system penetrates about 0.80 in. (Ref. 3, Figure 9, p. 653). Laser systems with powers higher than about 10 kW are essentially research tools, and have not found much commercial use. Therefore, for the overpack closure weld application, the 10-kW laser system is the maximum reliable unit available. At this beam power, the weld groove of the overpack will have to be filled with a powder filler (usually Ni 88 or Ni 92, plasma weld grade) for the laser to melt and form the weld metal. If the beam is 5 in. dia at the source, the parabolic mirror for this application will be 7 in. dia, placed directly above the overpack pit, and mounted on a mechanism that moves it in a circular path congruent to the weld groove. Assuming that the nominal groove width is no more than 0.375 in., at least three passes will be required to complete the closure weld. Time taken to complete the weld will be approximately 30 minutes. Filler material can be added between each pass or the filler equipment can continuously precede the laser beam, adding the filler as the welding proceeds. As is clear from Figure 2-2, the distance from the outer edge of the wall to the center of the overpack pit is approximately 14 ft; the beam is not expected to diverge appreciably over this distance, thus making it possible to locate the laser generator outside the shielded canyon cell. Additional space will be required for the power supply of the generator.

3.4 ELECTRON BEAM WELDING (EBW)

The EBW process is a high-energy density fusion process that is achieved by bombarding the weld groove with a sharply (electromagnetically) focused beam of accelerated electrons. Electron velocity may reach as high as 0.7 times the speed of light at 200 kV (Ref. 3, p. 609). The instantaneous conversion of the kinetic energy of the accelerated electrons into thermal energy upon their impact with the workpiece causes the workpiece to melt and form the weld joint. Beam power density can reach as high as 1 million W/sq cm (Ref. 3, p. 609), which is significantly higher than lasers or any known continuous beam, thus making the EBW process suitable for deep-penetration welding.

The electron beam is basically generated by a heated (approximately 4,500°F; Ref. 3, p. 609) tungsten or tantalum cathode (commonly called filament) maintained at some high negative potential. The anode is a ground-potential electrode through which the beam passes in a collimated form. By varying the negative potential of the filament or, in some EBW designs, by varying the operating temperature of the filament, the stream of electrons can be easily and precisely gated on or off, or ramped up and down, thus affording a precise control of the welding process. The versatility of control that this process offers is further evident in that, besides the electromagnetic beam-focusing lens, an electromagnetic deflection coil can be built into the system to bend the beam, thus making it easy to fine-tune the aim of the beam with great precision.

The EBW process requires a vacuum for operation. The electron gun itself is maintained in a vacuum of the order of 1E-04 torr (1 torr = 0.019 lb/sq in.), vacuum in the gun being necessary to prevent contamination and oxidation of the filament, and also to prevent possible high-pressure short circuiting between electrodes charged to different voltages. The welding chamber may be vented to atmosphere before and after the welding operation is complete; during welding, however, the chamber, too, needs evacuation to minimize the scattering of electrons in the beam, thereby maintaining the beam's high-energy density. Depending on the degree of evacuation necessary in the welding chamber, there are three types of EBW systems: high-vacuum; medium-vacuum, where the evacuation may be "soft" or "partial"; and nonvacuum, or atmospheric EBW. Cooling of the weld area is not required with either process. In all processes, the vacuum in the gun is maintained at 1E-04 torr.

Deep penetrations can be achieved by the EBW process, without making the groove as wide as is required to make deep arc welds, and without the high heat input necessary in arc welding. The ability to render a high weld depth-to-width ratio eliminates the need for multiple passes on deep welds. Moreover, the lower heat input affects only a narrow zone, thus minimizing the thermal effects detrimental to the workpiece. Finally, in the vacuum EBW processes, the weld is generally free of impurities, such as oxides and nitrides. These factors, taken together, render a weld of composition and mechanical characteristics nearly the same as those of the base metal.

Table 3-5 summarizes the parameters associated with the EBW process.

Table 3-5 - Common EBW Parameters

Parameter	Quantity
Vacuum requirements:	
High-vacuum EBW	1E-06 to 1E-03 torr[a]
Medium-vacuum EBW	1E-03 to 25 torr[a]
Electron gun	1E-04 torr[a]
Energy conversion efficiency	65%[b]
Maximum concentrated beam travel distance for nonvacuum or atmospheric EBW (approx)	1.375 in.[c]
Mean time between filament replacements	40 hr[d]

[a]Reference 3, p. 610. One torr = 0.019 lb/sq in.

[b]This is slightly higher than, for example, arc welding processes, and significantly higher than the efficiency of other high-energy-density beam welding processes, such as the LBW process (Ref. 3, p. 610).

[c]Also called "standoff," this is the distance from the bottom of the electron beam column to the top of the workpiece (Ref. 3, p. 611).

[d]After a period of use, the filament of an electron gun needs replacement. The period of 40 hr is beam-on time, and it is gleaned from discussions with electron-gun manufacturing companies mentioned below.

* * * * * * * * * *

From Figure 2-1, it can be seen that three lifting lugs are machined on top of the repository overpack. These lugs interface with the grapple attached to the overhead crane. Each lug is 3 in. high. Because the EBW gun will have to move around the overpack to perform the closure weld, it is thus obvious that the distance from the bottom of the gun to the surface of the lid will have to be a minimum of 3 in. Thus, from Table 3-5, the applicability of the nonvacuum process of EBW to the overpack closure weld is ruled out because the gun-to-overpack distance will exceed the limiting 1.375 in. for this process. Of the vacuum processes, the high-vacuum method, though suited to perform the closure weld, is not advised because of its requirement for a high vacuum, which entails higher equipment costs. The medium-vacuum method is the optimum, as commercial experience accumulated by three leading EBW gun-manufacturing companies (Steigerwald, Leybold-Heraeus, and Sciaky Brothers) suggests that the beam will not lose its density over 3 in. of travel in a soft vacuum. Therefore, the medium-vacuum process of EBW is best suited for application to the repository overpack closure weld.

The weld-groove geometry suitable for the EBW process becomes more constricted. The groove width must not exceed 0.015 in. for the electron

beam to be effective. To get an idea of the time taken for the EBW process to perform a deep-penetration weld of this width, consider the results of tests conducted by Sciaky-Vitry in France for ASEA Atom, in which a 100-kV, 850-mA (85-kW) gun was used to butt-weld two 100-mm (4-in.) thick, pure-copper pieces. The thickness was completely penetrated, and the welding speed achieved was 25.5 cm/min (10 in./min). The depth of the weld required in the overpack closure weld is only 2 in., and the material is as stated in Section 2.1.1. Field experience accumulated by the above-mentioned gun manufacturers indicates that, for the closure weld application, a 60-kW electron gun will suffice. Derived from the same experience, the estimated time taken for completing the overpack closure weld by a 60-kW gun is 16 min. This is based on a speed of 7.5 in./min, which includes a conservative safety margin for error in estimation. Actual speed for the overpack closure weld application will range from 7.5 to 10 in./min.

Table 3-6 summarizes the parameters associated with the EBW process as applied to the repository overpack.

Table 3-6 - EBW Parameters Applicable to the Closure Weld

Parameter	Quantity
Vacuum requirement:	
Medium-vacuum EBW	1E-03 to 25 torr
Gun power	60 W
Maximum groove width (approx)	0.015 in.
Estimated weld completion time	16 min

* * * * * * * * * *

3.5 GAS METAL ARC WELDING (GMAW)

The GMAW process is an electric arc welding process that establishes an arc directly between the electrode and the workpiece. The electrode itself provides the weld filler metal, and the arc and the molten weld pool are shielded by an external supply of gas. Depending on the method of transfer of filler metal from the electrode to the weld pool, there are three types of GMAW processes: short-circuiting transfer, globular transfer, and spray transfer.

The short-circuiting GMAW process is a low-current, low-heat process that produces a small, fast-freezing weld pool. Metal transfer occurs during the period when the electrode is in contact with the weld pool, and the frequency at which this contact is established ranges from 20 to 200 times per second (Ref. 2, p. 115). As the electrode touches the weld pool, the current increases and continues to increase until an arc (short circuit) is generated, which melts the electrode tip, and metal transfer takes place. Rigid control of the rate of increase in current is essential because the current must not increase so fast as to disintegrate the transferring drop of filler metal and cause spatter. Because the metal is transferred only

during short circuiting, the shielding gas contributes little to the transfer. Finally, because this process uses low current, and hence generates less heat, it is best suited for welding only thin sections, as the lower heat produces fewer distortions in thin sections.

In the globular GMAW process, discrete drops of filler metal detach from the electrode and fall across the arc into the weld pool under the influence of gravity. The size of the drop is greater than the diameter of the electrode. The arc length, in this process, must be maintained long enough to allow the drop to detach completely from the electrode before the drop contacts the weld pool. If the electrode is made positive, metal transfer results at relatively low currents, regardless of the type of shielding gas. The shielding gas, however, greatly influences the nature of the transfer, which is of two types: axial and nonaxial. Axial transfer is colineal with the electrode's longitudinal axis, and can be achieved in a substantially inert gas shield without significant spatter; however, the weld rendered by axial transfer is likely to be unacceptable because of lack of fusion and insufficient penetration. Nonaxial transfer yields a weld of superior quality, and this type of transfer is always rendered when carbon dioxide is used as the shielding gas (Ref. 2, p. 115). In nonaxial transfer, the molten drop grows until it detaches by short circuiting or gravity; while the drop is forming, however, the arc tends to move over the area between the drop and the workpiece, thereby significantly increasing the possibility of severe spatter.

If the gas shield is inerted by at least 80% argon or helium (Ref. 2, p. 116), and if the current is increased to a certain minimum for a given electrode size, then metal transfer changes from globular to spray. As an example, for mild-steel electrodes of 0.030 in. dia, the globular-to-spray transition current threshold, with a shielding gas composition of 98% argon and 2% oxygen, is 150 A (Ref. 2, Table 4.2, p. 118). In spray transfer, metal is transferred in fine droplets, which are either equal to or less than the diameter of the electrode. The spray is axial. The rate at which droplets are generated is a function of the electrode feed rate. Spray transfer is best suited for welding relatively thick parts because of the high currents associated with the process.

Other GMAW variations are pulsed spray, arc spot welding, and electrogas welding. The pulsed spray is an adaptation of the high-current, high-heat spray method, adapted to weld thin sections; arc spot welding is analogous to resistance spot welding and riveting; and electrogas welding is GMAW adapted for welding vertical joints. It is thus clear that none of these variations is applicable to the overpack closure weld.

From the above process descriptions, it is also clear that the only GMAW process suitable for welding the thick section of the repository overpack closure weld, without a significant possibility of weld spatter, is the spray transfer process. Short-circuiting transfer is best suited for thin sections only. Axial globular transfer generally produces unreliable welds, and this tendency may increase for a weld as deep as 2 in. Nonaxial globular

transfer is spatter-prone, and spatter is not desirable in the overpack closure weld application. This leaves spray transfer as the only suitable GMAW process for this application.

Finally, it should be noted that this process of GMAW requires cooling of the electrodes. Also, interpass cleaning is required because the cooled weld surface tends to form layers of a silicate contaminant that need to be chipped off, and the chips vacuumed away.

Table 3-7 summarizes the common spray-type GMAW process parameters.

Applied to the repository overpack closure weld, the parameters of Table 3-7 become those listed in Table 3-8.

4.0 CONCLUSION

The selection of a welding process for the repository overpack closure weld application is based upon comparing each process for the following attributes:

(1) Construction cost differences (cost of system and cost of facility modifications).

(2) Operating experience and history of process, particularly in applications similar to the overpack closure weld application.

(3) Reliability and maintainability.

(4) Cycle times.

(5) Major operating differences (manpower, utilities, and supplies).

Finally, a weld-groove geometry is designed to suit the selected welding process.

4.1 CONSTRUCTION COST DIFFERENCES

The cost of each welding system is compared in this section. Costs are divided into two categories: cost of the system and cost of installation in the shielded canyon cell.

4.1.1 System Cost

Based on the discussions and parameters established for each welding process in Section 3, Tables 4-1 through 4-5 list the minimum equipment required for each system, as applied to the repository overpack closure weld, and the costs associated with the system. Costs cited are estimates of the standard systems available for each process. Any special modifications made to the systems will entail additional costs. It should also be noted that the estimates do not include the cost of the handling equipment that handles the welding system; that is, the equipment that carries the welding system to

Table 3-7 - Common GMAW Parameters

Parameter	Quantity
Minimum spray arc current	150 A[a]
Shielding gas composition	98% Ar, 2% O-2[a]
Electrode polarity	+ve[b]
Rate of weld deposition	10 lb/hr[c]

[a]This is based on the example cited above; i.e., for a mild-steel electrode of 0.030 in. dia and shielding gas composition as noted.

[b]This is called reverse polarity. With this polarity, the rate of weld deposition is lower than it is with straight polarity (electrode negative), but the arc produced by straight polarity is unstable and erratic (Ref. 2, p. 114).

[c]This rate was obtained from tests conducted at Babcock & Wilcox and at Westinghouse with a Babcock-Hitachi narrow-groove GMAW welding machine. The groove in these tests was of approximately the same diameter and depth, but was machined to make both its walls taper outward toward the top, giving the groove a 0.375-in. width at the bottom and a 0.40-in. width at the top. This was done because a GMAW weld tends to pull the groove walls together. The diameter of electrodes used in both tests was 0.047 in.; it is assumed in the table that the weld-deposition rate will be the same if the feed rate of the 0.030-in.-dia electrode is increased slightly. Note further that, in both tests, two similar electrodes were used, both independently powered, and, in the Babcock & Wilcox test, interpass cleaning was achieved by applying a needle-chipper. The chipper, manufactured by Dresser Industries, is a steel shaft with protruding needles that chip the silicate contaminants off the welded surfaces. The chipper, along with a vacuuming system, was located diametrically opposite the electrodes so that interpass cleaning was accomplished at the same time that the welding was in progress. Time taken for one pass was about 11 minutes.

Table 3-8 - GMAW Parameters Applicable to Closure Weld

Parameter	Quantity
Time per weld	45 min[a]
Number of passes required	5[b]

[a]This assumes a nominal groove width of 0.375 in. Weight of weld metal to be deposited is thus calculated to be 7 lb (refer to footnote c to Table 3-7).

[b]This follows from the time taken per weld and the time taken per pass, the latter stated in footnote c to Table 3-7.

Table 4-1 - ESW Equipment and Costs[a]

Equipment	Quantity	Unit Cost ($)	Total Cost ($)
Electrode feeders	48	11,000	528,000
Power supply	48	4,000	192,000
Cooling apparatus	1	50,000	50,000
Electrodes' carrier	1	150,000	150,000
		Total	920,000

[a]The above costs are for the consumable guide method of ESW. Estimates obtained from Hobart, Ohio, and Westinghouse Engineering.

Table 4-2 - SAW Equipment and Costs[a]

Equipment	Quantity	Unit Cost ($)	Total Cost ($)
Electrode head with traversing mechanism	1	210,000	210,000
Electrode feeding mechanism	1	20,000	20,000
Flux feeding mechanism	1	50,000	50,000
Interpass cleaning and vacuuming apparatus	1	100,000	100,000
Control equipment	1	20,000	20,000
		Total	400,000

[a]Estimates obtained from Hobart, Ohio, and Westinghouse Engineering.

Table 4-3 - LBW Equipment and Costs[a]

Equipment	Quantity	Unit Cost ($)	Total Cost ($)
Laser generator, including all associated equipment (10-kW power)	1	800,000	800,000
Optical delivery system, including mechanism to move beam around closure weld groove	1	150,000	150,000
Powder filler feed mechanism, including mechanism to move it around closure weld groove	1	50,000	50,000
		Total	1,000,000

[a]Estimates obtained from Combustion Engineering-Avco, Massachusetts, and Westinghouse Engineering.

Table 4-4 - EBW Equipment and Costs[a]

Equipment	Quantity	Unit Cost ($)	Total Cost ($)
Electron gun, power supply, and controls	1	520,000	520,000
Vacuum chamber, including equipment to move gun around weld groove	1	74,300	74,300
Evacuating equipment	1	10,700	10,700
Computer equipment	1	95,000	95,000
		Total	700,000

[a]Estimates obtained from Steigerwald, Wisconsin, and Joy Compressors.

Table 4-5 - GMAW Equipment and Costs[a]

Equipment	Quantity	Unit Cost ($)	Total Cost ($)
Wire feeder, tractor drive, water-cooled torch, computer controls	1	200,000	200,000
Interpass cleaning and vacuuming system	1	100,000	100,000
		Total	300,000

aEstimates obtained from CRC Corporation, Texas, and Westinghouse Engineering.

the overpack and then moves the system aside to clear the way for overhead crane operations. Cost of the handling equipment is assumed to be the same for each welding system; therefore, it is omitted for comparison purposes. Finally, it should be noted that there are two shielded canyon cells in the MRS Facility, both of which will have to be equipped with identical welding systems; however, costs cited below are for one cell only.

4.1.2 Cost of Facility Modifications

No equipment already existing in the shielded canyon cell shall be moved from its existing location to accommodate the overpack closure welding system. Cost estimates cited in this section concern the cost of modifying the cell boundaries to accommodate equipment installation.

The ESW, SAW, and GMAW processes are all electrode wire processes. Electrode wire supplies will, therefore, have to be replenished remotely, and fed into the systems as and when the supplies in the cell are exhausted. An alternative to this remote operation is feeding the wires through the walls of the cell (Ref. 4). Wire passages through the walls will have to be zigzagged to prevent radiation from streaming out through the holes; also, a suitable method will have to be developed to attach the trailing end of one wire to the leading edge of the fresh supply without creating deformities in the wire that will later trip the system.

The laser generator and its power supply are located outside the cell for ease of maintenance. This entails installing mirrors in the cell walls to direct the beam into the cell. The height of the beam above the cell floor will have to be as close to the ceiling as possible so that the final array of mirrors can be attached to the ceiling, thus leaving the area below clear for the overhead crane operations. The generator and power supply together will have a footprint about 12 by 10 ft. This room is not available in either Gallery 2040, which is 8 ft wide, or Gallery 2034, which is 14 ft wide. The former gallery will be completely blocked even if the generator is placed lengthwise along it, and operating space in the latter gallery will be sharply reduced. Therefore, these galleries will have to be redesigned for the LBW process.

The EBW process will not require any redesigning of the facility depicted in Reference 4.

4.2 OPERATING EXPERIENCE AND HISTORY

The ESW, SAW, EBW, and GMAW processes have no known operating experience under conditions of either remote operations or radioactivity. Furthermore, there is no known operating experience for the ESW process applied to a circular weld groove, although theoretically it is possible to apply it to the overpack closure weld. The LBW is the only process for which some operating experience exists, at Oak Ridge, but the masses of items welded there are much smaller and beam penetration requirements are less stringent.

Development work will be required, therefore, to adapt the selected process to the overpack closure weld application.

Heat input control by itself, however, is not sufficient to assess the reliability of a process. Other factors, such as maintainability and cycle time, are also important. These factors are discussed in the following paragraphs.

4.3 RELIABILITY AND MAINTAINABILITY

Reliability of any welding process to render the same weld quality for each overpack welded is a function of efficient heat-input control. Controlling heat input in the arc welding processes entails controlling the quality of the arc; in the high-energy density beam processes, heat-input control entails controlling the quality of the beams. Electric arcs cannot be controlled as efficiently as the high-energy density beams can. Therefore, reliability is highest in the LBW and EBW processes. Of these two, the simplest and most efficient control of the beam is afforded by the EBW process, wherein easily controllable electrical parameters govern the quality of the beam. From the point of view of reliability, therefore, the EBW process is the most desirable process for the overpack closure weld application.

Maintainability is a function of the number of wear parts in the welding system. Note that locating the equipment outside the cell makes its maintenance easier, but it is emphasized that locating the equipment outside the cell does not necessarily help simplify the welding process inside the cell. Weightage must, therefore, be given to those subsystems that can be located outside the cell without making the overall welding process more complex. Below are listed the items that will require maintenance:

ESW Wire feeders; cooling apparatus; controls; and electrodes' carrier mechanism.

SAW Wire feeders; electrode moving mechanism; flux feeding mechanism; interpass cleaning mechanism; interpass vacuuming mechanism; control equipment.

LBW Laser generator; power supply; optical delivery system, which includes the inert gas purge mechanism and the mirrors; mirror moving mechanisms; powder filler feeding mechanism.

EBW Gun filament; controls; gun moving mechanisms (including enclosure); vacuum system; vacuum seal.

GMAW Wire feeders; cooling system; welding head moving mechanism (tractor drive); controls; interpass cleaning mechanism; interpass vacuuming mechanism.

In regard to the ESW process, its wire feeders, cooling apparatus, and controls can all be located outside the cell, thus making their maintenance easier, and hence making the ESW process more attractive. However, locating the above equipment outside does not relieve, and in fact probably aggravates, the necessity of feeding no less than 48 electrode wires into the welding process. These wires will now have to be fed through the wall,

which in itself is not a complex process, but all these wires will have to converge down to the workpiece, and all these wires will have to be fed, all at once, at a precisely controlled rate, into the groove as the welding progresses. Achieving this precise movement with all 48 electrodes simultaneously will not prove a simple task. It will make the welding process inside the cell more complicated and hence more prone to error. The advantage thus gained by locating some of the equipment outside will be lost by the problems more than likely to be encountered during welding.

For the SAW process, the electrodes can, once again, be fed from outside the cell, and for the SAW process only two electrodes will have to be fed, thus making the feeding process far simpler than that for the ESW. The flux-feeding mechanism can also be located outside the cell, and so can the control apparatus, but the interpass cleaning will have to be located inside the cell, though the flux vacuuming system can be located outside again. Because of the far fewer number of electrodes being used in the SAW than in the ESW, the SAW process has a higher overall maintainability advantage than that of the ESW.

All major mechanisms of the LBW process requiring close inspections and maintenance can be located outside the cell. The mechanisms inside the cell, such as the mirror-moving mechanism and the powder-filler-feeding mechanism, are relatively simple mechanical systems. The powder to fill the feeder can be supplied from outside the cell. Thus, the LBW has the highest maintainability advantage among the processes considered so far.

Except for the controls and the vacuum system, all the equipment for the EBW process will have to be located inside the cell, thus giving the EBW the lowest maintainability advantage so far.

In regard to the GMAW process, once again the electrode wires can be fed from outside the cell, as can the coolant, but the cooling system -- a part of it, at least -- will have to be inside the cell. The welding head and its moving mechanisms will also have to be inside the cell, as well as the interpass cleaning apparatus. The interpass vacuuming apparatus may be located outside the cell. The GMAW process thus has a maintainability advantage somewhat below the LBW process, but above the SAW.

In descending order of preference, then, this is how the processes rate in maintainability: LBW, GMAW, SAW, ESW, EBW.

From the above, it is clear that the EBW process will require the least maintenance. The gun filament will require replacement after every 40 hr of beam-on time, during which period 150 overpacks will be welded. The filament is normally housed in a small cartridge assembly. Only the filament needs to be replaced, not the whole cartridge. For the overpack closure weld application, it is recommended that the entire spent cartridge be replaced with a new one. A filament costs about $5; the whole cartridge costs up to $150. The cartridge replacement in, for example, the Steigerwald electron gun, can be done remotely with a single tool attached to a manipulator arm. It is imperative that the gun chosen for the overpack closure weld application does not require beam alignment after every replacement of the cartridge or filament, as some of the guns available in the market require.

4.4 CYCLE TIME

Cycle time is the time required to render the welding system reusable after each use. Cycle time for the arc welding processes will be the longest because of the replenishments that will be required for the various feeding mechanisms associated with the processes. Of the two beam processes, cycle time for the EBW process will be the shortest because it has no feeding mechanisms to be replenished. Therefore, the EBW process is, again, the best suited for application to the repository overpack closure weld.

4.5 MAJOR OPERATING DIFFERENCES

This section considers the manpower, utility, and supply requirements for each process.

4.5.1 Manpower

All arc welding processes require frequent electrode replenishment; most also require frequent flux replenishment, which is also the case with the LBW process. Also, the SAW and GMAW processes require interpass cleaning and vacuuming. Because of these attributes, and also because of the higher maintenance required by these processes, greater manpower will be required for the ESW, SAW, LBW, and GMAW processes. No frequent replenishment of either an electrode or flux will be required for the EBW process because their use is not necessary in the process. Also, the simplicity with which the beam can be controlled in the EBW process further alleviates the need for high manpower requirements. In the context of manpower requirements, therefore, the EBW process is the best suited for the overpack closure weld application.

4.5.2 Utilities

All arc welding processes are inherently high-current processes. Although the wattage of the LBW process is lower than that of the EBW process, the current requirements of the former are higher than those of the latter. For a 10-kW LBW system, the current required will be 800 A at 440 volts; the current required by an 85-kW EBW welding system to penetrate 4 in. of pure copper is only 850 mA at 100 kV. Therefore, the EBW process has the least taxing utility requirements of all the processes considered for the repository overpack closure weld.

4.5.3 Supplies

From the above sections, it is clear that the EBW process will require the smallest inventory of supplies, as it has only one replacement item: the filament or cartridge.

4.6 PROCESS SELECTION

Based on the preceding discussions, each process is rated in Table 4-6 on a scale of 1 to 5 for the various attributes listed.

Table 4-6 - Ratings of Welding Processes

Parameter	ESW	SAW	LBW	EBW	GMAW
System cost	2	4	1	3	5
Facility modifications	2	3	1	5	4
Reliability	1	2	4	5	3
Maintainability	2	3	5	1	4
Cycle time	1	2	4	5	3
Manpower	1	2	4	5	3
Utilities	1	3	4	5	2
Supplies	1	2	4	5	3
Total score	11	21	27	34	27

The EBW scores highest in almost every category. This score, coupled with the sheer mechanical and operating simplicity of the EBW apparatus, more than offsets the difference in cost between the EBW and the SAW and GMAW processes, the latter two being the only processes cheaper than the former for the overpack closure weld application. For this application, therefore, the EBW process is the optimum process.

4.7 WELD GEOMETRY

The optimum process having been selected, it is now possible to define the weld geometry that must be machined on the repository overpack and its lid. For the EBW process, the width between the walls of the weld groove must not exceed 0.015 in., as also stated in Section 3.4. Section 2.1.1 established the depth of the weld to be 2 in. The groove may be vertical, at an angle to the vertical, or even horizontal. Its orientation will be governed by the design of the welding system handling equipment.

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DESIGN STUDY DS-11

SHIELDED PROCESS CELL OVERHEAD CRANE ELECTRICAL CABLE MANAGEMENT SYSTEM

1.0 INTRODUCTION

The means of carrying electrical cables from the crane control consoles to the cranes in the shielded process cells and shielded canyon cells was studied to determine the most suitable system. This study documents the rationale used to support the system chosen, and provides some of the reasons that alternative systems were rejected.

The shielded canyon cell and process cell overhead bridge cranes are designed to operate through the full length of the cells, approximately 70 ft in Cells 1, 2, 3, and 4 and almost 300 ft in cells 5 and 6. They must also be capable of moving into separately shielded maintenance bays at the ends of the process cells. Generally, for cranes having long operating traverses, one of three types of systems are used in the crane industry to carry electrical cables between the stationary supply points and the moving crane bridge; they are: (1) cable reels, (2) festoons, and (3) power tracks. The number of conductors (wires) to be carried, the mission of the individual conductors, and the crane travel distance, all enter into the selection of the cable carrier. For the shielded process and canyon cell overhead cranes, it is expected that there will be two power cables with 40 individual conductors, one CCTV cable with 36 individual conductors plus a coaxial cable, and 28 instrument cables containing a total of 93 conductors; this yields a total of 31 cables with 169 individual conductors to be provided for by the cable management system. It is also important to recognize that it is desirable to maintain some physical separation between power and instrument cables, in order to reduce the likelihood of spurious signals in the instrumentation circuits.

The shielded canyon cells and shielded process cells contain shielded maintenance bays. These shielded maintenance bays are designed explicitly for crane servicing, and each is isolated from the shielded canyon cell or shielded process cell that it serves by massive shield doors. The shield doors are closed at all times except when actually moving the crane into or out of the shielded maintenance bay. This results in a requirement that the crane cable management system must not inhibit either crane or shield door movement.

2.0 CABLE CARRYING SYSTEM DESCRIPTIONS

2.1 CABLE REELS

These devices are frequently used in cable management systems designed for situations where it is undesirable to have temporarily unused lengths of

cable exposed. The cable is wound onto the reel and paid out or retrieved as needed to accommodate crane movement. The reel is usually mounted on the crane to preclude dragging the cables as the crane moves. The interface between the stationary wiring and the rotating wires, carried on the reel, is performed through slip-rings and brushes. Figure-1-1 shows a typical cable reel, carrying a single cable, with the slip-ring cover removed for servicing.

It is expected that use of a cable reel would provide a simple way to bridge the gap when moving a crane between the process cell and the adjacent crane maintenance bay, but that advantage is offset by three very distinct disadvantages:

- The necessity of taking instrument and control signals (including CCTV) across slip rings and brushes is judged to be unacceptable.

- The number of individual slip-rings/brushes needed to accommodate the crane wiring is prohibitive.

- Any contamination on the cables will be carried into the cable reel when the cables retract, and will build up in the reel; this is highly unacceptable.

For the reasons noted above, the use of cable reels for the cable management system in the shielded process cell cranes was not explored further prior to considering the other systems available.

2.2 FESTOONS

Festoon arrangements are frequently used as cable management systems for bridge cranes. A typical cable festoon is shown in Figure 2-1. These systems employ a number of cable carriers, which are carried on an auxiliary track, usually just below the crane rails. The crane cables are attached to the cable carriers at regular intervals of cable length; the interval depends to some extent on the length of loop that is acceptable below the cable carrier rail when the crane and cable carriers are at a position nearest the cable anchor point. This is the location where the cable carriers are fully packed against each other, and the loops hang lowest. A second consideration of cable carrier interval is the allowable distance between cable carriers when the cable is extended; this determines the minimum number of cable carriers that can be used.

Festoon arrangements are frequently used, as noted above, and are therefore well known and understood by crane service technicians. They are simple, having only a few moving parts, the rollers on the cable carriers. In addition, the ends of the cables may be "hard-wired" to their terminals. As a consequence, festoon systems are considered to be quite reliable.

However, festoon systems also have some distinct disadvantages in the MRS shielded hot-cell applications. Because of the large number of conductors to be carried, and the fact that all cables must be long enough to reach the full length of the cell, the bulk of the cables, when bunched at the feed

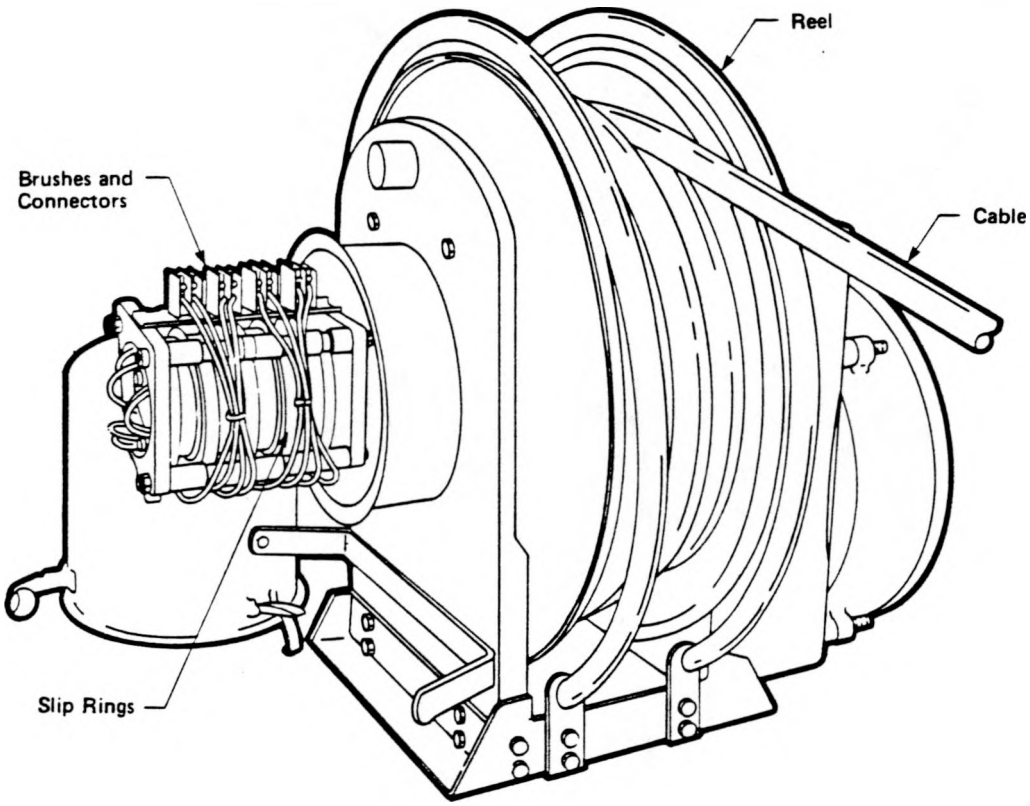


Figure 1-1 - Typical Cable Reel

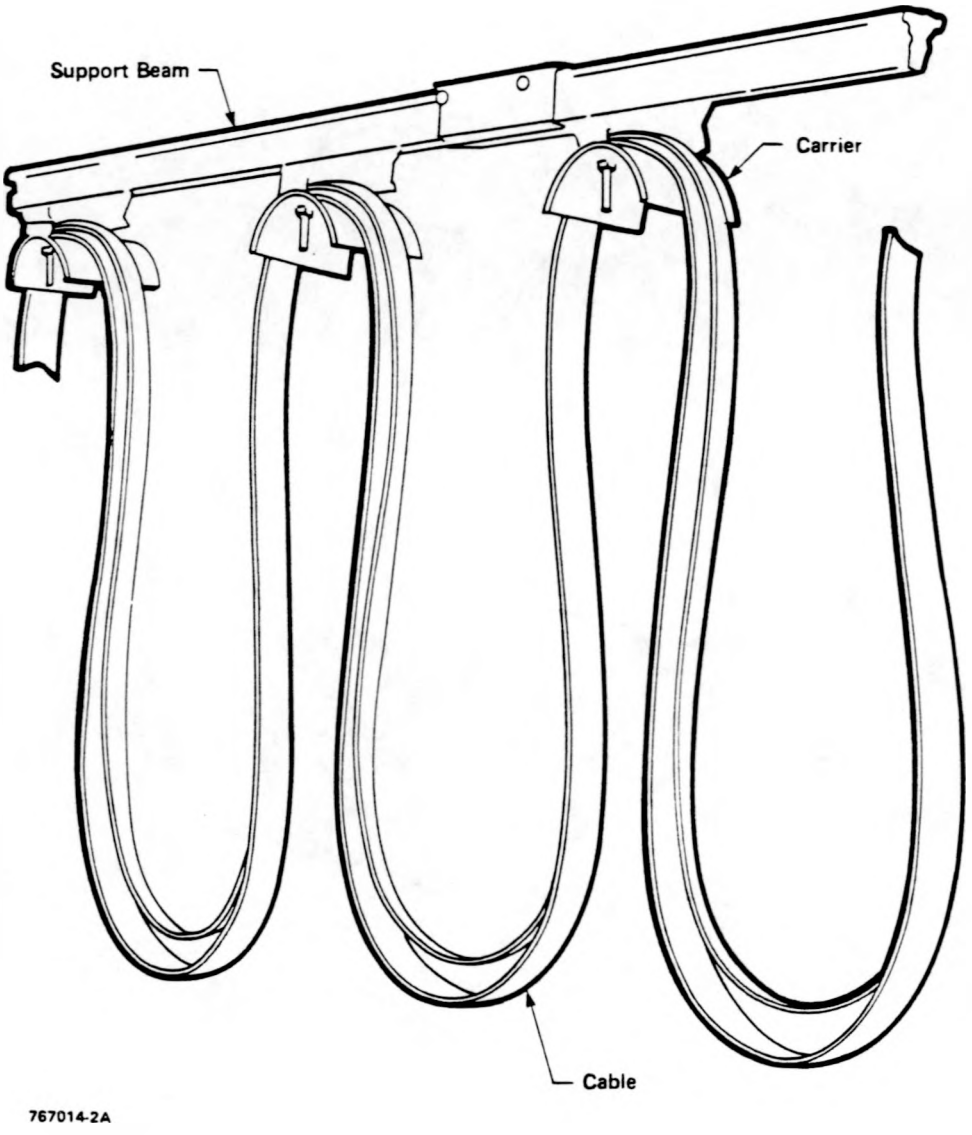


Figure 2-1 - Typical Cable Festoon

end of the cell is too great to allow the crane to service the end of the cell; this is particularly true in the canyon cells. Since all cables must be carried on the same cable carriers, the power and instrument cables would be very close together; this condition should be avoided if possible. All of the cabling is exposed all of the time, creating significant and undesirable crud traps. In the shielded process cells, the suspended loops of cable could cause operating difficulties for the wall-mounted manipulators; more cable carriers and shorter loops would alleviate this problem at the cost of more cable flexing and cable carrier bunching at the parked position. With a festoon system, unlike the cable reel and cable track systems, the cables must reach the full length of the crane travel; for reel and track systems, the cable may be fed to the cell at the midpoint of travel and need be only about half the length of the crane travel. The extra cable length could necessitate use of larger conductors to avoid excessive electrical line losses.

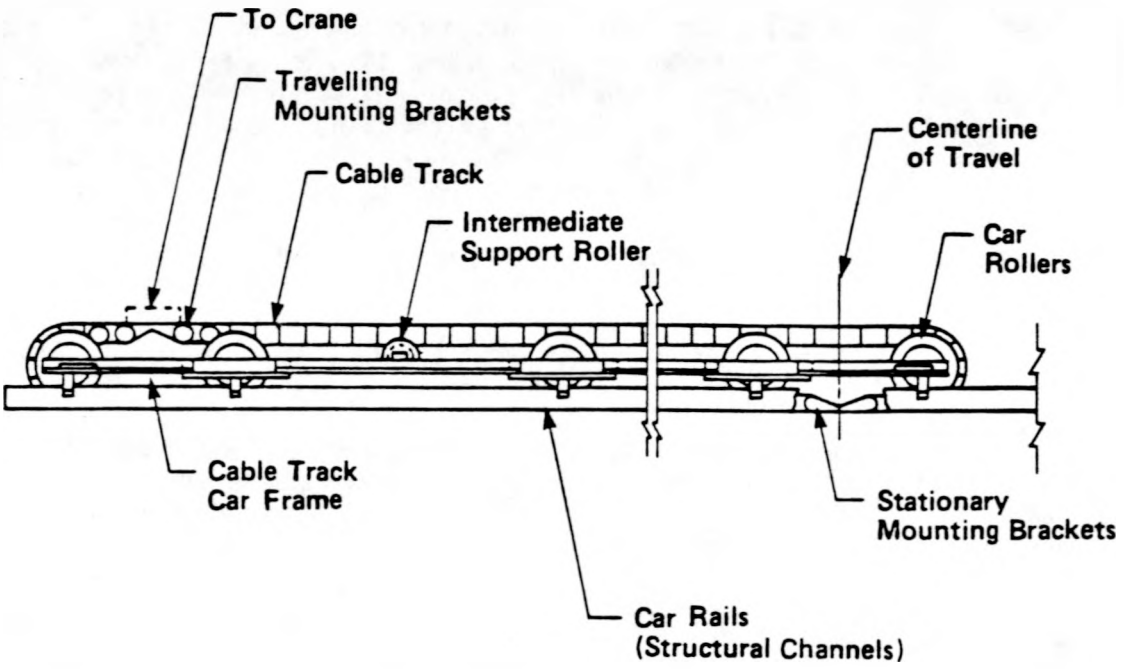
It has been suggested that the crane maintenance bays, which are located at the ends of the shielded canyon and process cells, could be used to store the bunched festoons when the crane is at the "feed" end of the cell. This approach was suggested as a means for obviating the cable storage problem, which occurs when the crane is moved to the "feed" end of the shielded cell. However the maintenance bays are shielded from the process cells by massive steel doors that are only opened to admit or discharge the crane. Routing the festoon carriers around these doors in a manner that maintains the shielding and contamination isolation integrity of the doors would be a monumental task, particularly when the cables will probably carry contamination from the process cells every time they retract into the maintenance bay.

On balance, festoon arrangements appear to be attractive essentially because maintenance is a known situation and can be easily performed. Indeed, they are a part of the design of MRS Facility cranes that do not require the large number of conductors or long travel distances of the shielded process and canyon cell cranes.

2.3 CABLE TRACKS

Cable tracks get their name from the fact that they resemble, in elevation view, the tracks of a crawler-type vehicle, as can be seen in Figure 2-2; obviously the details differ. They were developed to carry cables and hoses in situations where long travel distances and/or high accelerations are encountered, as in cargo cranes and steel mill equipment. They are also useful for machine tools such as planers, because the cables can be covered to protect them from cutting oil and chips.

The attributes noted above suggest that cable tracks would be a good solution for the shielded cells of the MRS, but initially it appeared that the canyon cell travel distance was too great to be accommodated even by this concept. However, by adding a "car" to the concept, as offered by most suppliers, virtually unlimited travel distances are attainable. In addition if two tracks are used in a loop configuration, one routed each way from a



767014-3A

Figure 2-2 - Typical Cable Double Loop Cable Track with Car

central feed point, power and instrument wiring can be separated as completely as necessary to satisfy most requirements. In application, one end of the track is anchored at the cable feed point, and the track is looped around the carrying car. The second end is fastened to the moving portion of the apparatus. Thus, all motions and acceleration forces are transmitted to the track, not directly to the cables. The ends of the cable track do not move, relative to their attachment points, allowing all cables to be "hard-wired" to their terminals. With dual tracks, a tensioning device is used between the two ends to maintain tightness in the track assemblies. The individual cables are supported in the track at the midpoints of each track segment length, and at the midheight of the track. This support minimizes cable flexing; note, too, that the only flexing imposed on the cables is at the ends of the car, where the track makes its return bend. The return bend radius of the track is tailored to the cable diameters so that cable flexing is controlled to enhance cable life. Since the cables are completely contained in and restrained by the cable track, the system is self-storing. This feature allows the system geometry to be fully defined and assures that there will be no interference with other hot cell systems or components. An additional feature derived from the self-storing geometry is that the whole cable track/car apparatus can be contained in an essentially closed housing, thus enhancing contamination resistance of the entire cable management system. It should also be noted that further contamination control can be obtained by introducing the circulating air for the cell through the cable track enclosure, thus putting it at a slightly higher pressure than the balance of the cell.

The cable track concept offers a unique means for moving the cables out of the shielded maintenance bay. An electrical junction box is included in the design of the crane/cabletrack interface. Thus, once the crane has been moved into the shielded maintenance bay, the cables can be disconnected from the crane by remotely removing a locking key, included in the design of the electrical junction box, then energizing a motor to drive the car out of the maintenance bay; cable connector separation happens automatically at the junction box, as the cable track/car is moved away from the crane. Remote removal of the locking key can be visually monitored using the CCTV system and accomplished by using the remotely operated manipulator, both of which are mounted on the crane. A small motor mounted on the cable track car can be used to drive one, or more, of the cable car rollers. Once the cable track/car is beyond the envelope of the shield door, the shield door can be closed without interference from any crane or crane cable management component. Connectors and wiring, duplicating the cable track portion of the junction box, will be provided for use during troubleshooting and maintenance. When the crane maintenance has been completed, the shield door can be opened, and the cable car can be driven back into engagement with the crane. Wiring connector engagement occurs automatically as the car approaches the crane position, because of the guide features built into the mating portions of the junction box. Having engaged the connectors, the locking key can be remotely inserted into the slot in the junction box, the crane can be moved out of the maintenance bay, and the shield door closed again. The capability of disconnecting the crane cables from the crane makes it unnecessary to route the cables around the shield door.

The cable track is composed of many individual parts, and each link must move relative to the adjacent one at the return bend. This may raise a question of reliability. However, this is the type of service for which the system was designed; it has become a well-known and reliable system. The carrying car has a number of rollers on which it rolls, and which, in turn, support the track. These rollers operate on sealed, prelubricated ball bearings for high reliability. It is judged that these rollers are comparable to the rollers on the cable carriers of the festoon system insofar as reliability is concerned. The cable track/car system is expected to require servicing very infrequently in the environment provided for it.

The most significant disadvantage of the cable track/car system is that it cannot be moved out of the hot cell. Thus, when servicing is required, cell entry is probably mandated. However, the number of manned entries required for the cable/track maintenance is expected to be less than 3 times in 20 years. On the other hand, it is not clear that the festoon system can be withdrawn to the maintenance bay either. Thus both of these systems suffer the same drawback.

3.0 SUMMARY AND CONCLUSIONS

The foregoing sections of this report have described three candidate shielded hot-cell cable handling systems. Their perceived advantages and shortcomings for the intended applications have been explored. Cable reels were judged to have more drawbacks than advantages because of the number of conductors needed for these cranes. As a consequence, little time was spent developing this concept. Festoon and cable track systems appear to be competitive in most respects. However, the cable track system seems more advantageous because, as noted in Section 2.3, it is self-storing and easily protected from contamination, i.e., the cables are completely contained in and restrained by the cable track and the cable track/car is contained in an essentially closed housing. In addition the means for interfacing the cable management system with requirements associated with the crane maintenance bay appear to be most easily met with the cable track concept. On these bases, the cable track/car system has been chosen as the cable management system for use in conjunction with the overhead bridge cranes in the shielded process and canyon cells in the MRS Facility.

DESIGN STUDY DS-12

DRUM LIFT STATION

FOREWORD

This study consists of interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-534	Drum Lift Mechanism Information	May 10, 1985

THE RALPH M. PARSONS COMPANY of DELAWARE
Subcontractor
Westinghouse Electric Corporation
Waste Technology Services Division

INTEROFFICE CORRESPONDENCE IOC-534

To J. A. Roll Date 5/10/85
From W. H. Blissell Phone 722-5517 Location WTSD-WM
SUBJECT Drum Lift Mechanism Information

File: 5.7

cc: J. W. Willis R. J. Steffen L. P. Pollono

The purpose of this IOC is to formally respond to the PNL comment at the 30% Design Review, with respect to drawings SK-MH-004-7 and 8. The specific comment reads as follows, "The drum elevator requires a very high hydraulic lift. Suggest a simplier system using spring-loaded latches at the bottom of the guide cage, into which each drum is inserted from beneath. This system would require a lift equal to just one drum height."

The following discussions contain information with respect to the elevator system and the drum indexing system. The design requirement was to provide clean drums for the secondary waste system from a drum storage area located below each of the decon cells. It is also assumed drums will contain lids when all transfers are performed. The distance between the first floor (drum storage area) and ceiling is 28 feet. The ceiling thickness is 5 feet-6 inches. The combined distance from the first floor ground elevation to the non-fuel bearing and clean drum processing area floor is 33 feet-6 inches. To provide a consistent elevation for all support handling equipment a 10 inch reference (base of drum) elevation has been set throughout the non-fuel bearing and clean drum processing area. The clean drum must pass through the 10 inch (height dimension) shield valve. Therefore, the total height from ground floor to the top of the shield valve is 34 feet-4 inches.

The two methods of drum lifting that will be discussed are a single drum elevator and multiple drum indexing system. The equipment layout arrangements for these concepts were developed and operational sequences were defined. It should be noted that during the preconceptual period of design, the indexing system was discussed and eliminated for reasons contained hereafter. However, for completeness a drum indexing system sketch was developed to aid in system comparison and is included as SK-WJ-002 (Attachments)

An engineering and system recommendation is provided based on the following; simplicity of design, maintenance of equipment, reliability, impacts on other processing equipment, and operation considerations.

The clean drum indexing system (Reference SK-WJ-002) consists of a drum loading platform, lift cylinder, drum guide support structure, drum leaf spring clips. A clean drum will be loaded onto the lift cylinder platform and raised through the leaf spring clips. This stroke will simultaneously index the upper nine drums approximately 36 inches. The upper most drum will be projecting 26 inches above the 10 inch shield valve.

The drum indexing system directly interfaces with the shield valve and drum push mechanism. To allow the shield valve to fully close and push the clean drum onto the drum guidance system the upper most drum must be raised approximately 10 inches. The drum push mechanism must be capable of gripping, elevating the drum through the shield valve and pushing the drum into the drum guidance system. The detailed operational sequence for this system has been provided (see process flow the Multiple Drum Indexing Method).

The clean drum elevator (Reference SK-MH-010) consists of a drum loading platform, hydraulic cable cylinder, drum carriage platform and drum cage assembly. A clean drum will be loaded and positioned on the drum carriage platform. The cylinder is actuated and the drum carriage is elevated to the full up position. The clean drum is ready to be positioned via the drum push mechanism.

The clean drum elevator system directly interfaces with the shield valve and drum push mechanism. The drum push mechanism is a single advance and return mechanism which moves the elevated drum into the drum guidance system. The detailed operational sequence for this system has been provided (see process flow for Single Drum Elevator Method).

The first observation one makes when comparing the two systems is the additional operational steps required with the multiple drum indexing system. The multiple drum indexing system requires additional operational requirements of the drum push mechanism (the drum push mechanism must grip, raise, lower and advance the drum). These additional steps defeat the "simplicity of design" philosophy approach.

The additional motions of the drum push mechanism which are required with the drum indexing method also decrease the system reliability. The drum indexing system adversely affects the support equipment, by adding the additional mechanical hardware.

Each drum will contain its own lid when transferred into the decon cell and finally into the consolidation cell. Stacking drums could damage or knock-off these lids. Additionally, the stability of empty drums must be considered based on the lower ring of a drum supported on the top lid of the lower drum.

In either the drum indexing method or elevator system an operator will be required to load a new drum on a platform to provide a drum at the push mechanism location. Therefore, no perceived benefits are achieved in either case.

The elevator system uses a cable cylinder actuated with hydraulic fluid. This approach eliminates the bends and wobbles of rod column effect. Hydraulic fluid was selected over pneumatic power based on off-normal circumstances where a line or power supply failure would cause the pneumatic cylinder to free fall. The cable cylinders have a drain chamber between the seal packagings, so any oil that leaks by the seal is returned to the reserve oil tank. The elevator system allows the drum push mechanism to be designed with only one motion. This elimination of motions is consistent with keeping the overall system as simple as possible. The relevant pages from the cable cylinder manufacturer's catalog are provided.

Based on the previous discussion of simplistic design and least impact on support equipment it is our opinion that the elevator concept best serves the drum lift purpose and will be kept as the baseline concept for the MRS Facility.

W. H. Blissell 2/21/85

W. H. Blissell

(Attachments to follow)

SECONDARY WASTE SYSTEM - PROCESS FLOW
REF SK-MH-005* Sheets 1-3 & SK-WJ-002
MULTIPLE DRUM INDEXING METHOD

1. Clean drum introduction w/dolly onto staging platform

2. Drum is placed on cylinder platform

3. Operator exits

4. Shield valve opens

5. Drum is elevated ~38" and indexs other nine drums vertically

6. Drum is pushed through three leaf spring clips and springs return to uncompressed position to hold ten drums in position

6a. Upper most drum is projected ~26 inches above 10 inch shield valve

7. Push mechanism grips the drum

8. Push mechanism raises griped drum approximately 10.5" (through shield valve)

9. Push mechanism advances drum to guide rails

10. Push mechanism lowers drum to 10" elevation (so as not to tip lid off on other drum when lowering)

11. Drum push mechanism pushes drum onto guide rail structure (other drums are moved along rail guides)

12. Two drum separator cylinders are fired to position outer most drum ~2"

12a. Push mechanism gripper is released

12b. Push mechanism is retracted

12c. Shield door is closed

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*Drum Index System and Push Mechanism replace elevator and drum push mechanism Reference SK-MH-005, all other equipment remains as shown.

SECONDARY WASTE SYSTEM Y PROCESS FLOW (Continued)
REF SK-MH-005 Sheets 1 - 3
& SK-WJ-002

12d. Two drum separator cylinders are retracted to a stow position

13. Jib crane is rotated into position, lowered, and grapples the drum at three points

14. The drum is lifted, rotated and placed onto a translational cart

15. The cart moves into the consolidation cell

16. The drum lid is removed and held fast at the liding station on the shredder

17. The cart moves under the shredder

18. The drum is lifted into a sealed condition onto the out-feed hopper of the shredder

19. The secondary waste is fed into various ports 1.) PWR skeleton grids and thimble tubes, BWR skeleton grids and water rods, 2.) BWR-PWR end-fittings, 3.) BWR grids; a total of three access ports

20. The drum is filled

21. The filled drum is moved to the liding station and the lid is crimped on

22. The filled drum is moved back into the decon cell

23. The overhead crane picks-up the drum and translates to the decon station

24. Drum lift cylinder is returned to a stow position

25. Repeat Steps 1 through 24

SECONDARY WASTE SYSTEM - PROCESS FLOW
REF SK-MH-005 Sheets 1 - 3
SINGLE DRUM ELEVATOR METHOD

1. Clean drum introduction w/dolly onto staging platform

2. Drum placed on elevator platform (71" elevation)

3. Operator exits

4. Shield valve opens

5. Drum is elevated ~31 feet (10" reference to top of shield valve)

6. Drum push mechanism pushes drum onto guide rail structure (other drums are moved along rail guides)

7. Two cylinders are fired to position outer most drum ~2"

7a. Push mechanism is retracted

7b. Drum elevator is returned to bottom position and shield door is closed

7c. Two drum separator cylinders are retracted to a stow position

8. Jib crane is rotated into position, lowered, and grapples the drum at three points

9. The drum is lifted, rotated and placed onto a translational cart

10. The cart moves into the consolidation cell

11. The drum lid is removed and held fast at the liding station on the shredder

12. The cart moves under the shredder

13. The drum is lifted into a sealed condition onto the out-feed hopper of the shredder

SECONDARY WASTE SYSTEM - PROCESS FLOW
REF SK-MH-005 Sheets 1 - 3

14. The secondary waste is fed into various ports 1.) PWR skeleton grids and thimble tubes, BWR skeleton grids and water rods, 2.) BWR-PWR end-fittings, 3.) BWR grids; a total of three access ports

15. The drum is filled

16. The filled drum is moved to the liding station and the lid is crimped on

17. The filled drum is moved back into the decon cell

18. The overhead crane picks-up the drum and translates to the decon station

19. Repeat Steps 1 through 18 again

DESIGN STUDY DS-13

RADWASTE TREATMENT SYSTEM

FOREWORD

This study consists of interoffice correspondence (IOC) and Minutes of Meetings (MM) listed below.

Document No.	Subject	Issue Date
MM-043	Radwaste Treatment System Meeting	Aug. 10, 1984
MM-039, Rev. 1	Radwaste Treatment Meeting	Aug. 15, 1984

MINUTES OF MEETING

Date August 10, 1984 MM-043

Location Pacific Northwest Laboratory

Richland, WA

SUBJECT Job No. 6440 MRS Facility

Radwaste Treatment System Meeting

I. Attendees

DOE-RL	PNL	Parsons	GAI
G. S. Rokkan	R. M. Gale	A. K. Jowdy	J. W. Voss
	R. I. Smith	W. D. Woods	
	W. S. Kelly		
	D. S. Jackson		
	O. M. Lyso		
	W. V. Thomas		

II. Purpose

This meeting was commenced to review and obtain DOE-RL/PNL's comments and concurrence with RMP's Radwaste Trade-Off Studies. (Attachment 1, MM-039, Rev. 1).

II. Discussions

The following paragraphs summarize the discussions during the meeting.

The methodology employed for this trade-off included the following:

A. Review of the systems and components to assure their conformance with FDC requirements.

B. Reverification of waste stream quantities and compositions.

C. Identification of the source (building in process areas) of the waste stream.

D. Classification and quantity of radiological waste materials; classification of waste in accordance with 10CFR60 and 10CFR61; and identification of areas for ALARA cost trade-offs.

E. Identify system in component alternatives.

F. Performance of capital and life cycle costing for the various alternatives.

The assumptions used for this study included:

A. All liquid waste is to be cemented.

B. HEPA filter compaction of 6:1 without frames and 3:1 with frames.

C. Mital framed filters are used where cost effective.

D. Repository waste package can contain 25%, by volume, combustibles (based on WIPP criteria).

E. All waste not proven to be low level is assumed to be TRU.

F. Non-combustible waste material includes tools or metal objects used in decontamination operations and will be decontaminated prior to packaging.

G. Discarded contaminated clbthing will be washed prior to waste packaging.

A reevaluation of the HEPA filter quantities was made and based upon the calculations, Attachment 1 of MM-039, all in-cell non-testable filters are considered RHTRU and would be packaged in either the hot cell or maintenance cell. The first stage Zone 1 and 2 HEPA filters are considered to be classified as TRU. All other HEPA filters are considered low level waste. In addition, a review of the frequency of filter changeout was conducted resulting in the filter quantities shown on Attachment 4 of MM-039.

In response to a PNL request, RMP will consider compaction of all in-cell filters to minimize MRS storage costs.

The radwaste liquid streams were evaluated as to quantity and radioactive material content. The process flow sheet quantities were confirmed and based on the source of the liquid stream a waste classification was determined. The results are shown on Attachment 2 of MM-039.

Based on the quantities and split between suspect TRU and non-TRU, the study concluded that it was not cost effective to provide two liquid treatment systems. Therefore, it was decided that a single system should be used and all liquid waste, due to mixing, be considered as suspect TRU. The need for evaporation was evaluated and resulted in the conclusion that volume reduction was cost effective due to the great number of cemented waste drums which would be required if the liquid waste was not reduced by evaporation.

The alternatives for solid radwaste treatment were discussed. The alternatives considered included:

A. Incineration with filter compaction.

B. Incineration without filter compaction.

C. No incineration and no filter compaction.

D. No incineration and filter compaction.

This trade-off did not include the constant operational costs associated with the various alternate such as disposal of RHTRU wastes, cementing operations and decontamination of non-combustibles.

The cost elements considered included:

A. Capital cost of equipment.

B. Capital cost of facility space @ $12/cu. ft.

C. Capital cost of on-site storage @ $60/drum assuming a minimum of 25 drum shipment.

D. Drum cost at @ $40/C.S. 55 gal.; $60/C.S. 80 gal.; $120/S.S. 55 gal.; and $180/S.S. 80 gal.

E. Stainless steel filter frame cost differential @ $41/filter.

F. Operating costs based on estimated manhour/operation and @ $25/hr.

G. Maintenance costs based on estimated manhours for equipment operation @ $25/hr.

H. Equipment replacement cost estimated to be equal to original cost.

I. Decommissioning cost estimated to be 10% of capital cost.

The cost associated with off-site transport and disposal was discussed. It was agreed that these were soft spots in the cost analyses. However, no revisions were made to the assigned unit costs.

It was recommended that the solid radwaste system be revised by the deletion of the incinerator system as noted on Page 4 of MM-039. This recommendation was concurred with by DOE-RL and PNL representatives.

This study also provided a life cycle cost comparison for the use of a neutron interrogator as a method of classifying low levels and TRU waste drums. This trade-off indicated that there was no cost benefit to re-classify the suspect TRU waste drums as low level. It was agreed that a neutron interrogator is not required for the MRS Facility. However, a gamma analysis of each waste drum will be required prior to release from the MRS site.

W. D. Woods

WDW:gp

Attachment

THE RALPH M. PARSONS COMPANY of DELAWARE

ATTACHMENT 1

MINUTES OF MEETING

Rev. 1
August 15, 1984

Date August 6, 1984

MM-039

Location Ralph M. Parsons Company
Pasadena, CA

SUBJECT Job No. 6440 MRS Facility
Radwaste Treatment Meeting

I. Attendees

Parsons	WEC	GAI
T. L. Gregory	J. A. Roll	J. W. Voss
C. H. Keehn		
C. H. Ahn		
J. P. Walker		
A. K. Jowdy		
W. D. Woods		
S. T. Huang		

II. Purpose

To develop a logic for radwaste treatment which will allow the minimization of waste treatment equipment, costs, and occupational exposure.

III. Discussions

The following paragraphs summarize the discussions during the meeting. The items to be addressed included the HEPA filters, liquid radwaste, and solid radwaste.

According to the FDC, the MRS Facility must treat, package, and store TRU resulting from on-site operations. The stored CHTRU is to be non-combustible and normally packaged in 55 gallon drums. The facility must also provide for treatment, packaging, storage, and eventual shipment off-site for disposal of low-level radioactive waste resulting from MRS operation.

Constraints on waste treatment were identified as: ALARA by 10CRF50, Appendix I ($1000/manrem); 10CFR61 for non-TRU disposal in commercial burial grounds; 10CFR60 for TRU disposal in repositories; and other NRC rules on exposures and emissions.

HEPA Filters:

Wood (HEPA frames) account for more than 40% of the total incineration feed in the current design process flow. This quantity assumes that all facility HEPA's are suspect TRU. However, by examining the HVAC flow diagrams it can be shown that only those filters associated with various hot cell operations could be suspect TRU since a fuel rod breach and fuel pellet damage must occur before TRU would be airborne. Fuel assemblies are handled only in

Cells 1, 2, and 3, although it is felt the aide "A" of the cells have the highest potential for TRU contamination. Sample gas from the shipping cask is released to the cell, routing potential TRU laden gas to the cell HEPA's.

According to preliminary calculations (Attachment 1), only the in-cell filter and the first stage HEPA are suspect TRU under routine operating conditions. These calculations are conservative since they use an 80% efficiency for the in-cell filter (HEPA which may not be fully sealed), an efficiency of 99.9% for the first stage (99.97% specified by HVAC), and a single in-cell filter receiving all airborne TRU (three filters are shown by HVAC). Credit for multiple (3) first stage HEPA banks was also ignored. The calculations show that the entire content of 16 PWR pellets or 9 BWR pellets would need to be airborne before the second stage filters could be suspect TRU, based on the criteria for TRU. These quantities increase to 48 PWR and 27 BWR pellets if credit is taken for all in-cell filters. The maximum quantity of fuel in a cell is 11.04 MTU in lag storage plus the fuel exposed at the disassembly/consolidation station.

Based on these calculations, the suspect TRU filters could be metal framed and disposed of as RHTRU (due to possible crud accumulation on the filters). According to RTC-089 a cost increase of $31 per filter would result if galvanized steel frames are used, an increase of $41 if 409 stainless steel frames are used. (The in-cell filters are currently stainless steel framed.) The second and third stage cell filters and other facility HEPA's would be packaged as low-level waste for eventual shipment off-site.

It was noted that an interrogator may be required by NRC to prove the filters are non-TRU. This step would occur prior to temporary storage in the CHTRU Facility. The question of transporting waste containers containing respirable fines was raised. DOT may require a binder to satisfy their requirements.

Liquid Radwaste:

The sources of liquid radwaste were reviewed in terms of flow rate and potential TRU contamination. The TRU evaluation was based on the stream type and origin, again assuming only the handling of exposed fuel could result in TRU contamination. Attachment 2 summarizes the discussions relative to the liquid radwaste system. Note that a high percentage of the flow rate indicated is suspect TRU.

Solid Radwaste:

Based on the current process flow diagrams, the solid radwaste materials being fed to the incinerator were discussed. The origin of the materials was not identified since they are assumed transported to the treatment area either remotely (oil emulsion and resins) or in drums from various points throughout the plant. See Attachment 3 for the solid radwaste source summary.

The incinerator receives an average of 1,000 pounds per day total, operating 24 hours a day for 11 days every 2 months. Of the total combustible feed, approximately 490 pounds are made up of HEPA filter frames from the total R&H Facility. Approximately 3,100 pounds a year (8.5 pounds per day average) is currently shown as paper received from prefilter medias. Since these prefilters are at the supply air intake, they would be deleted for the suspect TRU waste feed stream. If no HEPA frames or paper prefilter media become incinerator feed, an approximate 400 pounds per day feed rate would result.

Disposal of Combustible TRU:

Although the FDC identifies that containers with TRU cannot contain combustibles, rationale for accepting combustibles resulted in the following discussions:

1. No acceptance criteria currently exists for TRU at the repository.

2. WIPP criteria allows 25% combustibles by volume.

3. Combustibles are not defined by the FDC or the WIPP criteria.

4. Combustibles are allowed in HLW forms at the repository (Ref: 10CFR60.135) if the consequence of combustion are not unacceptable in terms of structural damage, long term isolation, or personnel safety. Combustibles in other waste forms would be evaluated on a case-by-case basis by NRC. It is therefore felt that TRU combustibles may go to the repository if the likelihood of in-drum fire is low and if the consequences of such a fire are minor, and if the WIPP criteria is used as a guideline since no repository criteria has been established.

IV. System Evaluations

Evaluations of the current system and discussed modifications were made, including trade-offs based on estimated related costs, to determine the feasibility of the incineration system, filter compaction, and drum interrogation at the MRS.

A revised count of the quality and location of various filters was performed, plus the anticipated change frequency (Attachment 4). Based on the calculations in Attachment 1, all in-cell filters are assumed to be RHTRU and all 1st stage Zone 1 and 2 HEPA's are suspect CHTRU (taking credit for crud removal by the consolidation equipment filters). Using data from the process material balances, calculations were preferred to determine the quantity of drums generated at the R&H Facility with various filter compaction and incineration options (Attachment 5). Costs were developed relative to capital, operating, and life cycle costs, referencing the drum quantities indicated for the incineration/compaction options (Attachment 6).

The use of an interrogator may shift a percentage of suspect CHTRU drums to LLW disposal. An estimated equipment and facility cost was compared to determine if an amortized value exists in terms of drums (Attachment 7). This question may become academic if the nuclide content of a drum must be identified prior to final disposal.

V. Recommendations

The following recommendations will be presented to DOE-RL and PNL for comment and to establish a design rationale for the MRS Conceptual Design:

A. All Zone 1 and 2 first stage HEPA's should be metal framed and be considered suspect CHTRU.

B. All liquid radwaste streams will be immobilized in concrete and considered CHTRU.

C. CHTRU waste drums may contain up to 25 volume percent combustibles.

D. On-site storage of LLW drums will be a maximum of 3 months prior to shipment.

E. No incineration of combustibles will be performed at the MRS based on:

- o Substantial savings in labor (325,000 manhours over 40 years) with an accompanying reduction in potential exposure.
- o Possible licensing impacts (no alpha incinerators have been licensed to date).
- o Decrease in capital cost ($2,500,000).
- o Marginal increase in 40 year life-cycle cost ($3,000,000 or 10%).
- o Deletion of incineration effluents (radiological and non-radiological).
- o Deletion of complex equipment (i.e. shredders, conveyors).
- o Deletion of sodium carbonate (no USA suppliers).

F. The interrogator will be deleted since it is not cost effective.

A. K. Jowdy

AKJ:gp

2ND HEPA FILTER TRU CONTENT

Problem: Is 2nd HEPA filter TRU or non-TRU?

Approach: Determine the total Ci's of spent fuel which would have to be airborne and exposed to the air cleaning system to make the 2nd stage HEPA to be classified as TRU.

Constraints:

1. Per J. Ang and T. Crump, a wood-framed HEPA weighs 30 lb.

2. Per DOE/ET-0028, 10 year old "LWR" fuel has 7.5×10^4 Ci/MTHM of TRU fission product isotopes; for a total of 2.7×10^5 Ci/MTHM all isotopes contained in fuel (excludes cladding and hardware).

3. A roughing filter has an efficiency of 80% (assumed).

4. A HEPA filter has an efficiency of 99.9% (per DOE/ET-0028).

5. A typical PWR assembly

   - has 46.1 KgHM
   - has 17 x 17 pins
   - has active fuel height of 3.658 M

   } Per ERDA 76-43 (P.2.32)

   - has fuel pellet height of 0.5 inches (assumed)

6. A typical BWR assembly

   - has 188.7 KgHM
   - has 8 x 8 pins
   - has active fuel height of 3.759 M

   } Per ERDA 76-43 (P.2.32)

   - has fuel pellet height of 0.5 inches (assumed)

7. TRU = 100 nCi/gm average TRU content or less (based on 10CFR61)

8. Any TRU Ci's exposed to air cleaning system will exist with an amount of fission product Ci's in direct proportion to their concentration in spent fuel (not essential to calculation; assumed).

   a. Assume all airborne goes to one bank (i.e. only one 2nd stage present).

Calculations:

1. Assume air cleaning system as shown:

$$\text{Efficiency} = \frac{\text{Ci In} - \text{Ci Out}}{\text{Ci In}}$$

2. Assume 2nd stage HEPA hass 100 nCi/gm TRU.
Then Ci exposed to roughing filter as follows:

$$\frac{30 \text{ lbs}}{16} \left| \frac{454 \text{ gms}}{\text{gm}} \right| \frac{100 \text{ nCi TRU}}{10^9 \text{ nCi}} \left| \frac{10^{-3}}{0.2} \right.$$

10^{-3}: 1st Stage HEPA Efficiency $= \frac{\text{Ci's Out}}{\text{Ci's In}}$

0.2: Roughing Filter $\frac{\text{Ci In}}{\text{Ci Out}}$

= 6.8 TRU Ci in roughing filter

$$= \frac{6.8 \text{ TRU Ci}}{7.5 \times 10^4 \text{ TRU Ci/MTHM}} \left| \frac{3.45 \times 10^5 \text{ Ci/MTHM}}{} \right.$$ = 31.3 total Ci in to roughing filter

3. Calculate MTHM in 31.3 Ci

$$\frac{31.3 \text{ Ci}}{3.45 \times 10^5 \text{ Ci}} \left| \frac{\text{MTHM}}{} \right. = 9.07 \text{ E-5 MTHM}$$

4. Calculate MTHM in BWR and PWR pellets

PWR:

$$\frac{0.4614 \text{ MTHM}}{\text{PWR Assembly}} \left| \frac{1 \text{ PWR Assembly}}{(17 \times 17) \text{ Rods}} \right| \frac{\text{Rod}}{3.658 \text{ m-active}} \left| \frac{\text{Meter}}{39.4 \text{ inches}} \right| \frac{0.5 \text{ in}}{\text{Pellet}}$$

= 5.54×10^6 MTHM/Pellet in PWR

BWR:

$$\frac{0.1887 \text{ MTHM}}{\text{BWR Assembly}} \left| \frac{\text{BWR Assembly}}{64 \text{ pins}} \right| \frac{\text{Pin}}{3.759 \text{ m-active}} \left| \frac{\text{Meter}}{39.4 \text{ inches}} \right| \frac{0.5 \text{ in}}{\text{pellet}}$$

$= 9.95 \times 10^{-6}$ MTHM/Pellet in BWR

5. Calculate equivalent pellets in air at roughing filter to get necessary Ci on 2nd stage HEPA to make TRU

PWR:

$$\frac{9.07 \times 10^{-5} \text{MTHM}}{5.54 \times 10^{-6} \text{ MTHM}} \left| \frac{\text{PWR Pellet}}{} \right. = 16.4 \text{ PWR pellets}$$

BWR:

$$\frac{9.07 \times 10^{-5} \text{MTHM}}{9.95 \times 10^{-6} \text{MTHM}} \left| \frac{\text{BWR Pellet}}{} \right. = 9.1 \text{ BWR Pellets}$$

Conclusions

1. In order to make the 2nd stage HEPA into TRU waste, the entire radionuclide content in at least 16 PWR or 9 BWR fuel pellets must be disbursed into the cell air and pass through one filter bank.

2. Because of two conservative aspects of the calculations, more fuel than this would likely have to be disbursed into cell air before this source term would be seen by the filter bank. First, no consideration has been taken of the settling-out of particles from a source. Second, only one filter bank is considered, although many serve each fuel handling cell.

3. Under routine operations, it is not anticipated that this quantity of radioactive material would be entering the cell air cleaning equipment. Thus, it is anticipated that the 2nd stage HEPA filters, in routine operations, would be non-TRU waste.

4. It is possible that under upset or accident conditions, circumstances could exist which would lead to the 2nd stage HEPA to be classified as TRU.

   (Note: According to T. Crump, the roughing filter is actually a HEPA with minimum 99% efficiency expected; and efficiency of 1st stage HEPA expected to be 99.97%.

PRIMARY LIQUID RADWASTE SOURCES

Title/Description	Nominal Flow Rate	TRU ?	Comments
R&H Collection Sump			
Truck and Rail Washdown Sump	70 gpm (0.19 gpd nominal)	No	Intermittant Flow Contamination could not exceed limits for TRU
Retention Drain System			
CHTRU Storage Sumps	20 gpd	No	Water from runoff or ground water Damaged drums overpacked prior to storage
Radwaste Drain System			
Analytical Lab Drains	110 gpd	Suspect	
Radwaste Treatment Area Drains	11 gpd		
TRU system		Suspect	Assumes possible separate systems
non-TRU system		No	
Equipment Maintenance Decon	223 gpd		Intermittant flow
Hot Cell equipment		Suspect	
Other equipment		No	
Hot Cell Decon	229 gpd	Suspect	Intermittant flow
Health Physics Drain	53 gpd	Suspect	
Crane Maintenance Decon	10 gpd	Suspect	Intermittant flow
Shipping Cask Handling Decon	462 gpd	Suspect	
Canister Loadout Decon	315 gpd	No	No flow if freon used
Retrieved Canister Decon	8.4 gpd	No	No simultaneous with Loadout Decon

Title/Description	Nominal Flow Rate	TRU ?	Comments
Radwaste Drum Decon	20.4 gpd		
TRU drums		Suspect	Assumes possible separate systems
non-TRU drums		No	Flow assumes incineration system
Personnel Decon	105 gpd	Suspect	
Equipment Maintenance Room Drains	2 gpd	Suspect	i.e., master-slaves, radwaste tanks
Contaminated Laundry	45 gpd	Suspect	
SUMMARY			
non-TRU	298 gpd		
Possible split	254 gpd	(TRU/non-TRU would require new material balance calculations)	
Loadout Decon	315 gpd		
Suspect TRU	1,020 gpd		
If Freon not used:			
non-TRU	298 gpd		
Possible split	254 gpd		
Suspect TRU	1,335 gpd		
If neither Freon or separated systems used:			
Suspect TRU	1,890 ± gpd		

PRIMARY SOLID WASTE SOURCES

Title/Description	Nominal Flow Rate	TRU ?	Comments
Oil Emulsion	6.4 lb/hr	Suspect	Flow Rate before liquid evaporation Intermittant flow Assumes single liquid radwaste treatment system
Spent Resins	1.7 lb/hr	Suspect	Intermittant Flow Assumes single liquid radwaste treatment system
Combustibles Wood (49%)	39.2 lb/hr	Suspect	Incinerator Feed Assumes all HEPAs are TRU Assumes all HEPAs, except in cell untestable, are wood framed
Polyethylene/Polyurethane (35%)			
Paper (7.7%)			Smear paper Paper filter media (used on supply intake; will probably not require incineration)
Polyvinyl Chloride (PVC)(6.7%)			
Cloth (1%)			
Miscellaneous (0.6%)			
Non-combustibles	11.0 lb/hr	Suspect	Includes hand tools, etc.
Contaminated HEPA Filter Media	48.2 lb/hr	Suspect	Assumes all HEPAs are TRU

HEPA FILTER CHANGEOUT ASSUMPTIONS
NORMAL OPERATION CONDITIONS

Location	Change Frequency	Filters Per Location	Filters Per Year
In-Cell Filters			
Cells 1A and 2A	Biweekly	3 per cell	156
Cells 1B, 2B, 3A, 3B	Monthly	3 per cell	144
Maintenance cell	Monthly	3 per cell	36
1st Stage Zones 1 and 2			
Cells 1A and 2A	Quarterly	12 per cell	96*
Cells 1B, 2B, 3A, 3B	Semi-annually	12 per cell	96*
Maintenance cell	Semi-annually	12 per cell	24*
2nd Stage Zones 1 and 2			
All	Semi-annually	144 filters total	288
3rd Stage Zones 1 and 2			
All	Annually	144 filters total	144
Other Filters			
Zones 3 and 4	Annually	144 filters total	144
Supply and transfer HEPAs (normally uncontaminated)	As needed (assume 1/4 changes per year)	151 filters total	40

SUMMARY

RHTRU Filters	= 336 per yr
Suspect CHTRU	= 216 per yr*
Others (non-TRU contaminated)	= 576 per yr
Others (uncontaminated	= 40 per yr

*If credit can be taken for consolidation equipment filters for removing majority of crud, 1st stage HEPAs may be classified as suspect TRU.

DRUMS TO BE ...URED
(WITH INCINERATION AND FILTER COMPACTION)

Source/Description	TRU ?	Estimated Drum Quantity
In-cell Filters Use metal frames Package, store onsite, and ship to repository as TRU	RHTRU	336 Drums/yr without compaction (80 gallon)
1st Stage HEPAs Use wood frames Compact media, incinerate frames, temporary store onsite and ship as TRU	Suspect	36 Drums/yr of compacted media (55 gallon)
2nd and 3rd Stage, plus building exhaust HEPAs Use wood frames Compact media, incinerate frames, temporary store onsite and ship as LLW	No	96 Drums/yr of compacted media (55 gallon)
Concreted Waste Includes wood frame, resins, and oil emulsion ash; other combustibles as ash; and liquid radwaste slurry	Suspect	139 Drums/yr (55 gallon)
Noncombustibles Package, temporary store onsite, and ship as LLW	No	8 Drums/yr (55 gallon)

SUMMARY

Total RHTRU Drums	336 drums/year
Total Suspect CHTRU Drums	175 drums/year
Total LLW Drums	104 drums/year

DRUMS TO BE STORED
(WITH FILTER COMPACTION AND WITHOUT INCINERATION)

Source/Description	TRU ?	Estimated Drum Quantity
In-cell Filters Use metal frames Package, store onsite, and ship to repository as TRU	RHTRU	336 Drums/yr without compaction (80 gallon)
1st Stage HEPAs Use metal frames Package, store onsite, and ship to repository as TRU	Suspect	72 Drums/yr (55 gallon)
2nd and 3rd Stage HEPAs, plus building exhaust HEPAs Use wood frames Package, temporary store onsite, and ship as LLW	No	192 Drums/yr (55 gallon)
Cemented Waste Allow drums to contain 25% combustibles, fill drums with cement; store onsite and ship to repository as TRU Cement combined with liquid radwaste slurry	Suspect	417 Drums/yr (55 gallon)
Noncombustibles Package, temporary store onsite, and ship as LLW	No	8 Drums/yr (55 gallon)

SUMMARY

Total RHTRU Drums	336 drums/year
Total Suspect CHTRU Drums	489 drums/year
Total LLW Drums	200 drums/year

DRUMS TO BE STORED
(WITHOUT INCINERATION OR FILTER COMPACTION)

Source/Description	TRU ?	Estimated Drum Quantity
In-cell HEPAs Use metal frames Package, store onsite, and ship to repository as TRU	RHTRU	336 Drums/yr (80 gallon)
1st Stage HEPAs Use metal frames Package, store onsite, and ship to repository as TRU	Suspect	216 Drums/yr (80 gallon)
2nd and 3rd Stage HEPAs, plus building exhaust HEPAs Use wood frames Package, temporary store onsite, and ship as LLW	No	576 Drums/yr without compaction (80 gallon)
Noncombustibles Package, temporary store onsite, and ship as LLW	No	8 Drums/yr (55 gallon)
Combustibles Allow drums to contain up to 25% combustibles, fill drums with cement; store onsite and ship to repository as TRU	Suspect	395 Drums/yr (55 gallon)
Spent Resins Allow drums to contain up to 25% combustibles, fill drums with cement; store onsite and ship to repository as TRU	Suspect	3 Drums/yr (55 gallon)
Oil Emulsions Allow drums to contain up to 25% combustibles, fill drums with cement; store onsite and ship to repository as TRU	Suspect	19 Drums/yr (55 gallon)
Liquid Radwaste Use as Liquid for cementing operation Fills remaining 75% void of drums containing combustibles	Suspect	0 Drums/yr

DRUMS TO BE STORED
(WITHOUT INCINERATION OR FILTER COMPACTION)

SUMMARY

Total RHTRU Drums	336 drums/year
Total Suspect CHTRU Drums	633 drums/year
Total LLW Drums	584 drums/year

DRUMS TO BE STORED
(WITH INCINERATION AND WITHOUT FILTER COMPACTION)

Source/Description	TRU ?	Estimated Drum Quantity
In-cell Filters Use metal frames Package, store onsite, and ship to repository as TRU	RHTRU	336 Drums/yr without compaction (80 gallon)
1st Stage HEPAs Use metal frames Package, store onsite, and ship to repository as TRU	Suspect	216 Drums/yr (80 gallon)
2nd and 3rd Stage, plus building exhaust HEPAs Use wood frames Temporary store onsite and ship as LLW	No	576 Drums/yr (80 gallon)
Concreted Waste Includes resins, and oil emulsion ash; other combustibles as ash; and liquid radwaste slurry	Suspect	132 Drums/yr (55 gallon)
Noncombustibles Package, temporary store onsite, and ship as LLW	No	8 Drums/yr (55 gallon)

SUMMARY

Total RHTRU Drums	336 drums/year
Total Suspect CHTRU Drums	348 drums/year
Total LLW Drums	584 drums/year

WASTE TREATMENT SUMMARY TABLE

Characteristics		Case 1	Case 2	Case 3	Case 4
Compaction of Filters		Yes	Yes	No	No
Incineration		Yes	No	No	Yes
1st Stage HEPA Frames *		wood	metal	metal	metal
CHTRU Drums to Repository					
	55 gallon	175	489	417	132
	80 gallon	0	0	216	216
Drums to SLB					
	55 gallon	104	200	8	8
	80 gallon	0	0	576	576
MRS Capital Costs		2,790,000	236,000	50,000	2,718,000
Life Cycle Costs		32,619,000	38,441,000	64,230,000	58,597,000
Total Cost		35,409,000	38,677,000	60,473,000	61,315,000
Labor (MH)		402,000	73,000	105,000	415,000

*Roughing filters have metal frames, and all other HEPAs have wood frames except as indicated.

		Incineration and Compaction	Compaction	Neither	Incineration
Repository	55	175/yr = 7,000	489/yr = 19,560	417/yr = 16,680	132/yr = 5,280
	80	0	0	216/yr = 8,640	216/yr = 8,640
LLW	55	104/yr = 4,160	200/yr = 8,000	8/yr = 320	8/yr = 320
	80	0	0	576/yr = 23,040	576/yr = 23,040
Transporation @ $500/drum		$ 5,580,000	$13,780,000	$24,340,000	$18,640,000
Disposal Cost @ $200/drum (55) @ $290/drum (80)		$ 2,232,000	$ 5,512,000	$12,587,000	$10,307,200
Storage Capital plus load in/out		$ 2,202,900 (17,856 M/H)	$ 6,004,900 (44,096 M/H)	$ 8,313,000 (77,888 M/H)	$ 5,007,700 (59,648 M/H)
Drum and Filter Cost		$10,225,280	$12,153,920	$14,438,720	$13,070,720
Operating Cost		$ 8,170,000 (326,800 M/H)	$ 250,000 (10,000 M/H)	$ 528,000 (21,120 M/H)	$ 7,920,000 (316,800 M/H)
Maintenance		$ 1,440,000 (57,600 M/H)	$ 480,000 (19,200 M/H)	$ 160,000 (6,400 M/H)	$ 96,000 (38,400 M/H)
Capital		$ 2,790,000	$ 236,000	$ 50,000	$ 2,718,000
Equipment Replacement and Decommissioning		$ 2,770,000	$ 260,000	$ 55,000	$ 2,691,000
Total Cost		$35,409,000	$38,677,000	$60,473,000	$61,315,000
Total Manhours		402,300	73,300	105,400	414,850

ASSUMES:

40 year life cycle
Current dollars, no escalation
Storage cost includes 3-month storage of LLW at MRS
Manhours costed at $25 per hour

DRUM INTERROGATION EVALUATION

Capital Cost

Interrogator = $1,000,000
Facility = 193,000

Operating Cost

Operator = 1 M/H per drum @ $25 for total drums of CHTRU
Maintenance = 1 man year/year @ $25 for 40 year life
Replacement = $1,000,000
Decommissioning = $100,000

Savings per drum if reclassified from CHTRU to LLW

No longer have lifetime storage unit cost, therefore
$250 per storage module

Evaluate each incineration/compaction combination for 40 year life

Case	Interrogation Cost	CHTRU Drums	Drums to Amortize Cost
Incineration and Compaction	$4,548,000	7,000	18,200
Compaction only	$4,862,000	19,560	19,400
Neither	$5,006,000	25,320	20,000
Incineration only	$4,721,000	13,920	18,900

DESIGN STUDY DS-14

LIQUID RADWASTE COLLECTION VESSEL

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-509, Rev. 1	Vertical Liquid Radwaste Collection Vessel vs. Horizontal	May 15, 1985

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC #509, Revision 1

To W. D. Woods

Date May 15, 1985

From S. Dianat

Phone 2773

Location EA-448

SUBJECT Job 6440 - MRS Facility
Vertical Liquid Radwaste Collection
Vessel vs. Horizontal

This IOC is in response to PNL's 30% review comment on the P&ID's requesting reevaluation of vertical liquid radwaste collection vessels vs. horizontal (MRS 5.5 - 128 dated May 3, 1985 page 4, third comment on SK-MP-301-5).

Based on our discussion with Parsons vessels group, the present two horizontal LLW liquid collection vessels (VES-100 A/B) 6'-6" diameter x 18'-0" tan.-tan., will be replaced with two vertical vessels 10'-0" diameter x 7'-6" tan.-top.

This is primarily based on improved mixing in the vertical vessels compared to horizontal ones. Also, each vessel requires one agitator instead of two used for the horizontal vessels.

The cost difference between the two methods is insignificant.

The HAW liquid collection vessel (VES-150) will remain horizontal due to high activity radwaste cell arrangement and remote maintenance requirements. Also mixing requirements for the HAW liquid collection vessel is not as critical as it is for the LLW liquid collection vessels (0.1 wt% solids vs. 0.4 wt%).

Sadi Dianat

S. Dianat

SD:kb

CC: R. Critchley
J. A. Hellinger
J. K. Jones
A. K. Jowdy
C. H. Keehn
S. Y. Mayet
W. L. Santo
W. D. Woods

DESIGN STUDY DS-15

LIQUID RADWASTE EVAPORATOR SYSTEM

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-115	Horizontal vs. Vertical Film Evaporator for Liquid Radwaste System	July 26, 1984
IOC-438	Detecting Upset Conditions in the Liquid Radwaste Evaporators	March 28, 1985
IOC-471	Selection of Liquid Radwaste Treatment Equipment	April 17, 1985
IOC-541	Vertical vs. Horizontal Wiped Film Evaporators	May 22, 1985

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC #115

To W. D. Woods

Date July 26, 1984

From J. P. Walker

Phone 8787

Location EA-45-181

SUBJECT Job 6440-10 - Monitored Retrievable Storage Facility
Horizontal versus Vertical Film Evaporator for Liquid Radwaste System

Parsons has chosen to use two, fifty percent evaporators rather than two vertical fifty percent evaporators or a single one hundred percent evaporator. We judge that this case is best from an overall standpoint.

Parsons chose two fifty percent evaporators over single evaporators on the basis of increased reliability and onstream factor. Two horizontal units cost about 7.7 percent more ($10,000 bare equipment) than a single horizontal unit.

The two horizontal units will be stacked and will require about 12 square feet, or $6,000 based on $500/sq ft, less floor space than two vertical units. Also, an overhead monorail assumed to be of 1 ton capacity at $5,000 required for removal of the wiper assesmbly for the vertical units, is eliminated.

The two horizontal units cost about 2.7 percent ($30,000 bare equipment) more than a single vertical evaporator. Each horizontal unit has two bearings to service and maintain while the single vertical unit has only one bearing; but, a single vertical unit would have to pass through the roof of the Receiving and Handling Building.

The table below shows the cost and overall dimensions of the vertical and horizontal evaporators we obtained by phone from Luwa

Hor V(1)	Sor D(2)	Bare Equipment Cost, $	Overall Length (in.)	Maximum Width (in.)	Rotor Pull Length (in.)
V	S	110,000	204	49	217
H	S	130,000	204	48	150
V	D	116,000 (3)	128	27	135
H	D	140,000 (3)	138	24	129

(1) Horizontal or Vertical
(2) Single, 100% or Dual, 50%
(3) Cost for two evaporators

Therefore the cost comparison between a two vertical and two horizontal evaporator system is as follows:

Two vertical = $127,000 (116,000 + 6,000 + 5,000)
Two horizontal = $140,000

Difference = $ 13,000 or approx. 10%

We judge that the ease of access will make maintaining the equipment much easier and safer, and override the disadsvantages mentioned above.

John Walker

J. P. Walker

JPW:gp

CC: A. K. Jowdy
S. Dianat
W. L. Santo

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC #438

To W. D. Woods

Date March 28, 1985

From S. Dianat

Phone 2773

Location EA 448

SUBJECT Job 6440 - Monitored Retrievable Storage Facility
Detecting Upset Conditions in the Liquid Radwaste Evaporators

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Upset conditions in the liquid radwaste evaporators (LLW and HAW) can result in unusually high contamination carryover in the evaporator overhead vapor. Consequently this would cause early saturation of the downstream ion-exchanger which alerts the operator.

To alert the operator sooner, during Task 2B design, radition monitors will be installed downstream of the evaporator O/H condenser to detect the mal-function of the evaporator as soon as it occurs. Furthermore, density indicators will be installed in the evaporator bottoms slurry tanks (LLW and HAW) to indicate unusual changes in the evaporator bottoms solid concentrations.

Sadi Dianat
S. Dianat

SD:kb

CC: C. H. Ahn
J. A. Hellinger
C. E. Huck
J. K. Jones
A. K. Jowdy
C. H. Keehn
W. L. Santo
R. D. Williams

INTEROFFICE CORRESPONDENCE

IOC #471

To W. D. Woods

Date April 17, 1985

From J. A. Hellinger

Phone 8787

Location EA-4F-185

SUBJECT Job 6440 - Monitored Retrievable Storage Facility
Selection of Liquid Radwaste Treatment Equipment

Following is a summary which states the philosophy and reasons for selecting evaporation as the treatment system for liquid radwaste. Three systems were considered to treat the liquid radwaste: 1) ion exchange, 2) reverse osmosis, and 3) evaporation.

Ion exchange was considered unacceptable because of the following reasons: 1) prefilters would be required to remove suspended solids, causing the filters to become very radioactive and difficult to handle, 2) detergents and decon agents in the feed may not be compatible with the resins, 3) high consumption of resins if the resins are not regenerated,and 4) large quantities of liquid radwaste if resins are regenerated.

Reverse osmosis was considered unacceptable because of the following reasons: 1) prefilters would be required to remove suspended solids, causing the filters to become very radioactive and difficult to handle, 2) the pH of the feed would have to be accurately controlled to insure proper operation of the membrane, and 3) the membrane could be damaged due to the strong oxidizing decon agents that may be required.

Therefore, because of the reasons given above, evaporation was chosen as the method for treating the liquid radwaste.

With regard to the type of evaporator, the thin-film evaporator was chosen because of the following reasons: 1) it can more effectively handle the variety of wastes, including foams and detergents, that are expected, 2) it is less susceptible to fouling-type and scale-forming materials, and 3) it is easier to maintain. Also, PNL suggested that "a wiped-film or thin-film evaporator be considered to eliminate the need for a bottoms filter" in their review comments (see MRS 5.5-16, Drawings SK-MP-03, Item #2, and SK-MP-12, Item #4). RMP agreed that this was a good idea and would follow up.

J a Hellinger

J. A. Hellinger

JAH:kb

CC: S. Dianat
J. K. Jones
A. K. Jowdy
W. L. Santo
J. Wie
W. D. Woods

INTEROFFICE CORRESPONDENCE IOC #541

To W. L. Santo Date May 22, 1985

From S. Y. Mayet Phone 3047 Location EA-436

SUBJECT Job 6440 - MRS Facility
Vertical versus Horizontal Wiped Film Evaporators

In order to respond to PNL's comment on Basis for Design paragraph 2.6.2 A(1)(2)(C) and D, about vertical versus horizontal wiped film evaporators from maintenance viewpoint, Mechanical Specialties has made a comparison and found the following:

1. HAW Liquid Evaporator EVP-151 The present design calls for a horizontal WF evaporator due to the restricted headroom in the HAW cell. In order to reduce the radiation dose to the maintenance personnel, the motor drive of this evaporator will be remotely replaceable utilizing the HAW cell's remote operated overhead crane and electromechanical manipulator. In case of replacement or repair of the rotor, means have been provided to remotely decontaminate internals of the evaporator in situ first to reduce the radiation level, and then the entire evaporator will be remotely transferred to the decon room where the evaporator can be remotely decontaminated to a greater extent if necessary, and the rotor head cover nuts can be remotely removed. At this time the maintenance personnel will enter the decon room to remove the rotor for repair or replacement.

2. LLW Liquid Evaporators EVP-102 A/B Again the present design utilizes horizontal WF evaporators to optimize the headroom in the LLW liquid radwaste room. The horizontal evaporators also facilitate the design to locate the motor drives outside the evaporator rooms to reduce radiation dose to the maintenance personnel. Removable shielding panels are provided in the walls in front of the evaporators to remove the rotors for repair or replacement. Provisions have been made to decontaminate internals of each evaporator in situ to reduce the radiation level before maintenance personnel can enter the evaporator rooms to disassemble the rotor head cover nuts for removal of rotors. The entire evaporator can be removed through the wall openings. This horizontal arrangement does not require permanently installed overhead crane to handle the rotors.

If PNL disagrees with the above mentioned maintenance philosophy and insists on having vertical evaporators, then the R&H Building shall be modified as follows:

(1) The HAW cell (Room No. 1113) eight must be raised from 30'-0" to 42'-0" for a clear hook height of 36'-0" to remove the rotor of evaporator EVP-151.

(2) The maintenance decon room (Room No. 1114) height must also be raised from 30'-0" to 42'-0" to transport the rotor utilizing the crane.

(3) The roof height of the low level liquid radwaste area (Room No. 1063) must be raised from 26'-0" (low point) to 29'-0" (low point) for a clear hook height of 24'-6" to remove the rotors of evaporators EVP-102A/B.

(4) A remote operated 2 ton overhead bridge crane must be added in the low level liquid radwaste area (Room No. 1063) to handle the rotors of evaporators EVP-102A/B.

(5) Platforms must be added at about 10'-0" elevation for the maintenance of motor drives of the evaporators EVP-102A/B.

S. Y. Mayet

SYM:fw

cc: J. T. Ang
R. Critchley
S. Dianat
A. C. Foung
J. A. Hanke
C. E. Huck
R. L. Jarvis
J. K. Jones
A. K. Jowdy
C. H. Keehn
W. D. Woods
A. D. Wilcox
B. C. Kenessey

DESIGN STUDY DS-16

LIQUID RADWASTE TRADEOFF STUDY

EDUCTORS VS. PUMPS

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-136, Rev 2	Eductors vs. Pumps for Liquid Radwaste System	Aug. 20, 1984

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE IOC #136, Rev. 2 (6/11/85)

To W. D. Woods Date August 20, 1984

From J. P. Walker Phone 8787 Location EA-45-185

SUBJECT Job 6440 - Monitored Retrievable Storage Facility
Eductors Versus Pumps for Liquid Radwaste System

Parsons investigated the use of eductors to replace the pumps presently shown on the Liquid Radwaste System PFD's. It was suggested that eductors may require less maintenance than pumps and also might be better from a cost and/or an ALARA standpoint.

Figure 1 shows the system of eductors and heat exchangers required for the Liquid Radwaste System. Each of the clouds indicates the location of a pump and spare that is presently on the PFD. As the sketch shows, the existing five operating pumps and spares are replaced by six eductors and two heat exchangers (water cooled). The exchangers are required to keep temperatures of the liquid radwaste within reasonable limits for the evaporator and the ion exchange resin. Note that the evaporator bottoms exchanger is required for both eductor or pumps although it is not now shown on the PFD.

Eductors and heat exchangers require less maintenance than pumps, but the eductor case requires seven pieces of operating equipment (⑤ the DI eductor is uncontaminated) in radioactive service while the pump case only requires five pieces in radioactive operation. Disadvantages of the eductors are the increased use of cooling water and steam due to steam dilution of the liquid radwaste, and the evaporator would have to evaporate a higher percentage of the evaporator feed.

The pumps used in the Liquid Radwaste System are small, 2 gpm, low head pumps. They are fairly inexpensive and easy to maintain or replace.

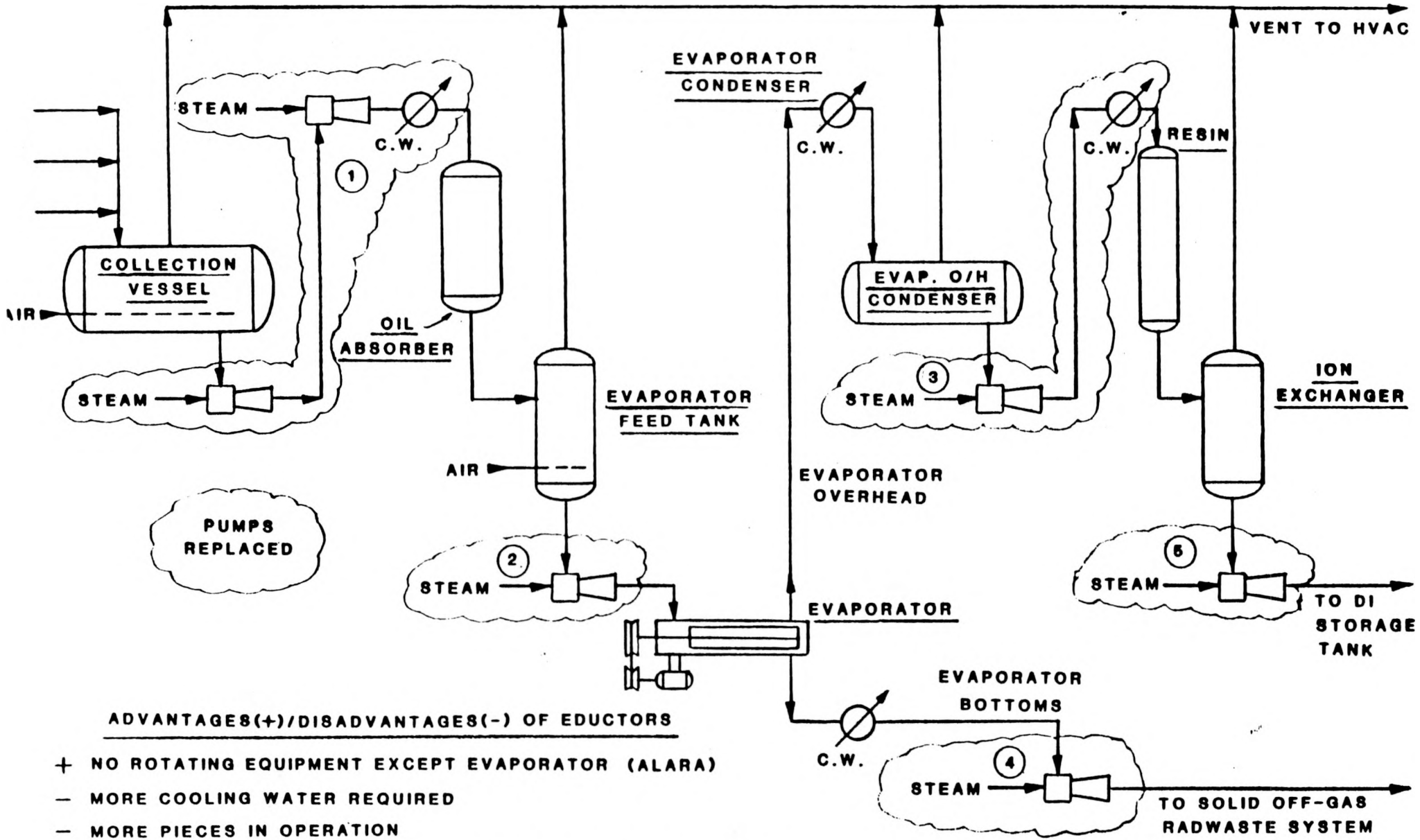
Based on the above, it seems unlikely that eductors would be better from an overall view. Therefore, we have selected pumps for the system.

JK Jones
for John P. Walker

Attachment
JPW:fw

CC: A. K. Jowdy
S. Dianat
W. L. Santo
C. H. Keehn
J. K. Jones
J. Hellinger
H. W. de Angelis

LIQUID RADWASTE SYSTEM



ADVANTAGES(+)/DISADVANTAGES(-) OF EDUCTORS

\+ NO ROTATING EQUIPMENT EXCEPT EVAPORATOR (ALARA)

— MORE COOLING WATER REQUIRED

— MORE PIECES IN OPERATION

— EVAPORATOR MUST EVAPORATE HIGHER % OF FEED OVERHEAD

— MORE DILUTE RADWASTE TO SOLID/OFF-GAS SYSTEM

FIGURE 1

DESIGN STUDY DS-17

PROCESS SEWER HOLDING TANK

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-220, Rev. 1	Process Sewer Holding Tank	Oct. 22, 1984

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE IOC #220, Rev. 1 (7/18/85

To File/J. K. Jones Date October 22, 1984

From W. D. Woods Phone 7288 Location ES-458

SUBJECT Job 6440 - Monitored Retrievable Storage
Process Sewer Holding Tank

The design is now proceeding with two process sewer holding (neutralization) tanks. An alternate to this configuration is to make use of the existing lift sump as the neutralization tank.

The cost trade-off for these two alternates is presented herein.

Holding Tanks - Alternate A:

2 Tanks (24' x 24' x 7') = 62 cyd concrete	=	$19,000
Interior Tank Coating = 1,248 sq. ft.	=	1,900
Instrumentation	=	30,000
2 Transfer Pumps	=	6,000
Piping	=	2,000
Blower	=	7,000
		$65,000

Lift Sump (revised to act as a neutralization tank) - Alternate B:

Enlarged Sump	=	$ 900
Added Sump Coating	=	200
Additional Instrumentation	=	10,000
Transfer pumps (not required)	=	--
Additional Piping (not required)	=	--
Blower	=	4,000
		$15,100

The cost differential between the two alternates is approximately $51 K. Therefore, as a cost savings, you are authorized to revise the design documents to reflect the use of the lift sump as the neutralization tank.

W. D. Woods

WDW:jf

DESIGN STUDY DS-18

WATER SPRAY SYSTEM FOR FINAL HEPA FILTERS

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-619	Water Spray System for Final HEPA Filters	July 19, 1985

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC #619

To W. L. Santo

Date July 19, 1985

From J. T. Ang

Phone 7095

Location EA-439

SUBJECT Job 6440-11 - Monitored Retrievable Storage Facility
Water Spray System for Final HEPA Filters (R & H Facility)

Due to the increased MRS building size and the new exhaust air distribution configuration, two water storage tanks are required to adequately protect the final exhaust HEPA filters. One tank can be located in room no. 3034 and the other in room no. 3049. Each tank will provide spray water requirement for 12 filter plenum units (8 operating and 4 standby).

Based on one hour of spraying time and an estimated spray rate of 32.5 gpm (total of 8 filter units), the required storage capacity for each tank is 2,000-gallon minimum.

Each water tank shall be charged with 100 psi air pressure. This pressure shall not be allowed to drop below 80 psi with the water depletion rate as indicated above.

J. T. Ang

JTA:fw

cc: W. D. Woods
A. K. Jowdy
C. H. Keehn
J. K. Jones

DESIGN STUDY DS-19

FREON DRY CLEANING

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-496	Selection of Freon Dry Cleaning as a Primary Laundry Method	May 7, 1985

INTEROFFICE CORRESPONDENCE IOC #496

To W. D. Woods Date May 7, 1985

From C. H. Ahn/J. M. Wie Phone 2249/8039 Location T-676/EA-4F-184

SUBJECT Job No. 6440 - Monitored Retrievable Storage Facility
Selection of Freon Dry Cleaning as a Primary Laundry Method

The purpose of this memo is to respond to a question raised during the Design Verification Committee Meeting of the Process Discipline held on February 27, 1985 (MM-095) regarding the use of freon dry cleaning in addition to water wash.

The memo discusses the selection basis and compares a water wash system to a freon dry cleaning system. The comparison was based on simplicity of equipment, ease of operations, cleaning efficiency, capital and operating cost, and safety and environmental considerations.

The descriptions of the water wash and freon dry cleaning systems are given in the Process Description for Task 2B.

The major parameters for the two systems are discussed under the appropriate headings.

EQUIPMENT

A single machine carries out the entire freon dry cleaning operation and no ancillary equipment is required. Electricity is the only utility service required to operate the machine. The associated ventilation system must provide more room air changes per hour than one for a water wash laundry to ensure that the solvent vapor concentration is within OSHA requirements. Extra charcoal filters are required to remove freon vapor prior to venting to atmosphere.

A water wash laundry requires more equipment (including a water wash dryer). As a result, it requires a larger floor area. Extensive ancillary equipment such as a heated water tank, effluent collection tanks, and associated piping and valves are required for the water wash laundry.

OPERATIONS

Based on telephone conversations[1.2] with nine nuclear power plants and two commercial laundry service agents, and after reviewing literature[3] and vendor brochures[4.5], the advantages and disadvantages of the freon dry cleaning system are as follows:

Advantages

- o Eliminates contaminated waste washwater and generates only a small amount of contaminated sludge.
- o Is more efficient in removing radioactive contaminants.
- o Increases protective clothing life over water washed garment and permits reduced protective clothing inventory.
- o Cleans garments in less time than water wash.

Disadvantages

- o Does not remove body odors.
- o Does not remove water soluable contaminants.
- o Generates contaminated filters.
- o Is unsuitable for plastics.

COST

In 1979, Ontario Hydro (a Canadian Nuclear Power Plant) conducted a study[3] to determine whether commercial dry cleaning equipment can be used for cleaning active cotton and plastic protective clothing. Since the study is about 6 years old, the cost analysis can be used for comparative purposes. By assigning 100 for water wash, the corresponding present worth(PW) cost for the dry cleaning system was calculated.

The results of this study are summarized in Table 1.

TABLE 1 - COST COMPARISON BETWEEN WATER WASH AND FREON DRY CLEANING

	Water Wash	Dry Cleaning	
	Relative PW Cost	Relative PW Cost	% of Total Cost
Installed Cost	0.6	0.7	1.1
Manpower Cost	32.4	27.9	42.2
Replacement Cost*	61.5	23.4	35.3
Chemicals/Solvent Cost	1.2	11.2	16.9
Other Costs**	4.3	3.0	4.5
Total Cost	100.0	66.2	100.0

* Replacement of protective clothing due to wear and high clothing contamination levels.

** Water Wash - maintenance, electricity, water and steam. Dry cleaning - maintenance, electricity and filters.

During the period of study, when an article of clothing had a high initial contamination level, a maximum of three water washings were carried out before a pair of coveralls was rejected. Further washings proved ineffective. Dry cleaning is particularly effective at minimizing this cost item.

As seen in Table 1, the installed cost of dry cleaning is about 16% higher whereas other costs are lower except chemicals. As expected, the solvent cost for a dry cleaning system is high. Overall, the total cost of the dry cleaning system is lower than that of the water wash system by approximately 34%. Table 1 also indicates that the replacement cost makes up about 62% of the total water wash cost. A major portion of the replacement cost results from replacement of clothing that is not decontaminable.

Since the replacement cost may not be a major item, Table 2 was prepared to compare the two systems excluding this factor. Table 2 shows that the total cost of dry cleaning is about 10% higher than that of the water wash system.

TABLE 2 - COST COMPARISON EXCLUDING REPLACEMENT COST

	Water Wash	Dry Cleaning	
	Relative PW Cost	Relative PW Cost	% of Total Cost
Installed Cost	1.5	1.7	1.6
Manpower Cost	84.4	72.6	65.9
Chemicals/Solvent Cost	3.0	28.1	25.5
Other Costs*	11.1	7.7	7.0
Total Cost	100.0	110.1	100.0

* Dry Cleaning - maintenance, electricity, and filters

Water Wash - maintenance, electricity, water and steam

The cost for waste water treatment from the water wash system is not included in Tables 1 and 2. When considering the treatment cost, a dry cleaning system has a lower present worth cost than a water wash system for cotton products.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

Freon vapor concentrations were measured in the close vicinity of the machines during loading and unloading operations[3]. The concentrations were found to be well within OSHA requirements (i.e., 1000 ppm). The main waste items generated from the freon dry cleaning system are contaminated cartridges and oily aqueous sludge from the freon still. In the water wash system, contaminated waste water is the main waste generated, requiring disposal or treatment. Treatment of phosphate in the waste water is required to meet environmental standards.

CONCLUSIONS

A freon dry cleaning system was compared to a water wash system from the standpoint of equipment, operation, cost, and safety and environmental aspects. It can be concluded that the freon dry cleaning system is preferred over the water wash system because it minimizes liquid radwaste treatment, it is a simpler system with easier operation, it gives better cleaning at shorter turnaround, and it has overall lower cost. However, the drawback of the dry cleaning system is that the system does not adequately remove body odors. Therefore, for the MRS facility, we have proposed a freon dry cleaning system as a primary method and water wash as a secondary system.

C. H. Ahn/J. M. Wie

CHA:JMW:kb
CC: S. Dianat
J. K. Jones
A. K. Jowdy
C. H. Keehn
W. L. Santo

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DESIGN STUDY DS-20

DECONTAMINATION METHODS REVIEW AND RECOMMENDATIONS

1.0 INTRODUCTION

Decontamination is a vital part of the operation of every nuclear facility because of the requirement to keep radiation exposure to operators and the public As Low As Reasonably Achievable (ALARA). Proposed methods of decontamination, and their estimated frequencies of application and volumes of produced waste, have a heavy impact on many design features of a facility. These include the size of waste tanks, the type and size of waste processing equipment, and the surface finish of walls, floors, and ceilings.

This report is the result of a study conducted to determine the general state of the art in the field of nuclear facility decontamination, and to select specific techniques suitable for the MRS Facility. This study was conducted through a search of the available technical literature and through telephone interviews with decontamination engineers at several nuclear facilities.

2.0 CONSIDERATIONS OF DECONTAMINATION TECHNIQUE

Choosing the most appropriate facility decontamination method depends on careful consideration of many factors:

(1) The type of surface material.

(2) The tenacity with which contaminants adhere to the surface.

(3) The chemical structure of the contaminants.

(4) The purpose of the decontamination operation.

(5) Personnel exposure.

(6) The volume of waste generated and subsequent volume reduction.

(7) The tendency of a decontamination agent to redeposit contamination.

(8) The corrosiveness of the solution.

(9) The dependence of solution stability and effectiveness on temperature.

(10) Whether or not the solution passivates the contaminated surface.

(11) The type and size of available radwaste treatment system.

The last factor, the type and size of the radwaste treatment system, is not as critical a limitation for a facility that is in the design stage as it is for an existing facility. This is because any suitable (and cost-effective) radwaste system can be designed into the facility in the early stages, whereas the possibilities of retrofitting an existing facility may be very limited. It is for this reason that we must consider decontamination processes early in the design phase.

The first factor, the type of surface material, limits the choices of decontamination processes to those that are compatible with the surface. As an example, decontamination agents containing chloride should not be used on stressed stainless steel surfaces.

The second factor, the tenacity of contaminant adherance, determines whether the contaminants can be easily removed without harming the base metal, or whether base metal will also have to be removed. Loosely held contaminated dust can be removed mechanically by wiping or liquid rinsing. Ground-in or chemically bonded contaminants can only be removed by surface removal techniques that may be either by mechanical (sandblasting, gouging, etc.) or chemical (acids, oxidation/reduction agents, etc.) means, or electrochemical, such as electropolishing.

The third factor, the chemical structure of the contaminants, determines what types of chemical decontamination techniques will be effective. For example, nitric acid is very effective in dissolving uranium and plutonium and their oxides, but is not very effective in dissolving the typical PWR reactor cooling loop contaminant. This contaminant is nickel ferrite, $Ni_xFe_{3-x}O_4$,[1] which is extremely insoluble in most mineral acids.

The fourth factor, the purpose of the decontamination operation, determines whether an extremely harsh or a milder decontamination procedure is appropriate. For final decontamination of a surface that is to be discarded, such as during decommissioning, any process that yields a sufficiently high decontamination factor might be satisfactory. Alternatively, one should avoid roughening the surface of a material that will be placed back into radioactive service. This is because of the tendency for rough surfaces to recontaminate more quickly, and to higher levels, than smoother surfaces. Rough surfaces are also more difficult to decontaminate again.

The fifth factor, personnel exposure, places constraints on the use, in high radiation fields, of decontamination processes that require unshielded operator contact. There are two ways that personnel exposure can be reduced by optimal selection of a decontamination technique: (1) by selecting a process that can be accomplished remotely, thus eliminating exposure, or (2) by selecting a process that, while of a contact nature, is exceptionally fast, thus minimizing exposure.

The sixth factor, the volume of waste generated and subsequent volume reduction, encourages one to select a decontamination process that produces a minimal quantity of waste. Also favored are processes in which the produced wastes are easily reduced in volume.

The seventh factor, the tendency to redeposit contamination, is a detrimental tendency of some techniques that discourages their use. This tendency not only limits the achievable overall decontamination factor, but occasionally shifts contamination onto localized surfaces ("crud traps"), resulting in higher local radiation exposure than was present before decontamination.

The eighth factor, the corrosiveness of the solution, is of concern for two reasons: (1) because repeated application of highly corrosive solutions will consume an unwarranted depth of the surface, and (2) because corrosives tend to roughen a surface. As was mentioned above, rough surfaces recontaminate more quickly and to higher levels than do smooth surfaces.

The ninth factor, temperature dependence, is of concern because of possible difficulty in controlling the decontamination solution temperature. As an extreme example, some processes require temperatures above the normal boiling point. This can only be achieved in a vessel or piping system that can be externally pressurized. Such a process is obviously inappropriate on open architectural surfaces.

The tenth factor, surface passivation, is a desirable property of a decontamination solution, especially where the surface does not naturally passivate itself during operation. The tendency of stainless steel, aluminum, and titanium to form tightly adhering protective oxide films when exposed to oxygen or oxidizing agents (nitirc acid, for example) is why these materials are normally resistant to chemical attack. Removal of the passive film, however, destroys the corrosion resistance of these materials, leaving them in an "active" state. Hydrochloric acid, for example, dissolves the oxide film, activating the surface, and rapidly corrodes the underlying metal. Rapid corrosion can continue even after neutralization of the hydrochloric acid unless the surface is repassivated.

Thus, the correct choice of decontamination processes requires a thorough knowledge of the contaminants and materials to be decontaminated. The best source of this information is actual testing of sample pieces from an operating facility.

3.0 MRS CONTAMINATION PROPERTIES

Because it is impossible to obtain test samples from a facility that is not yet constructed, reasonable assumptions must be made about the expected properties of contamination at an MRS Facility. It is assumed that the majority of contamination will be the normal reactor-core contaminants found in PWR and BWR reactors. Nickel ferrite, with substituted chromium and cobalt, is expected from PWR fuel elements. The expected major contaminant from BWR fuel will be Fe_2O_3 [2] with chromium and cobalt oxides. The differences between PWR and BWR contaminants are caused by differing water chemistry and material selection between PWR and BWR reactors. Small amounts of transuranics and fission products will probably be found because of fuel element failures.

Because the MRS Facility process systems operate at low temperatures compared to power reactors, there should be very little of the temperature-induced bonding of crud into the oxide film of stainless steel that is such a problem with power reactor decontamination. Likewise, most of the surfaces that will require decontamination at the MRS Facility are not exposed to liquid solutions containing contaminants; thus, most contaminants will be dry and dust-like in nature. They will be loosely held to surfaces, and should be easily removable. Even those equipment surfaces that are exposed to contaminated liquids (such as the liquid radwaste system tanks, pipes, and evaporators) have temperatures low enough to enable decontamination with fairly mild chemical solutions.

4.0 REVIEW OF DECONTAMINATION TECHNIQUES

A great many techniques for decontamination of nuclear facilities have been developed over the years. The search for more effective and less costly techniques continues to the present. Of the following techniques, most were developed to decontaminate power reactor primary coolant loops. Those decontamination techniques most applicable to the MRS Facility are detailed in Section 4.1; those applicable mostly to power reactor systems are mentioned in Section 4.2 for completeness.

It should always be remembered that the best decontamination technique is the least aggressive one that will achieve the desired decontamination factor.

4.1 TECHNIQUES ESPECIALLY APPLICABLE TO MRS FACILITY

Table 4-1 summarizes the following techniques that are applicable to the MRS Facility.

4.1.1 Formic Acid/Formaldehyde

The formic acid/formaldehyde technique is a developmental, one-step Swiss process intended for both BWR and PWR primary coolant loops. The process is expected to be effective against both activated corrosion products and fission products. The solution consists of 2 molar formic acid with 0.1 molar formaldehyde (0.01 molar corrosion inhibitors are added when treating carbon-steel systems). The formaldehyde acts as a reducing agent, oxidizing as it does so into formic acid. The formic acid dissolves the reduced oxides. The solution concentration is monitored, and additional formaldehyde or formic acid is added as required. The required solution temperature is quite high (90°C). Decontamination duration is unusually long (100 hr). Laboratory testing has shown decontamination factors (DFs) for Co^{60} to range up to 1,000.[3] Application to the MRS Facility would be in the in situ decontamination of liquid radwaste system piping and equipment internals. This process has not, however, been proven in actual, in-plant use.

4.1.2 Nitric Acid

Nitric acid has been used for a number of years to dissolve uranium and plutonium and their oxides in inconel and stainless steel systems. This type

Table 4-1 - Decontamination Techniques Applicable to MRS Facility

Technique	Applicability	Area	Experience	Advantages	Disadvantages	Decontamination Factor
Formic acid/ formaldehyde	Corrosion and fission products	Liquid radwaste system piping	Switzerland - developmental	One-step High DFs	Unproven, high temperature, long duration.	Up to 1,000
Nitric acid	Fuel and fission products	Localized hot spots on process cell surfaces	Reprocessing and fuel-fabrication facilities	Good on fuel spills	Not good on corrosion products.	10
Nitric + hydrofluoric acid	Fuel, fission, and corrosion products	Localized hot spots on process cell surfaces	Widespread	High DFs	Extremely corrosive; must repolish surfaces.	Up to 1,000
Oxalic peroxide	Fuel spills	Localized hot spots on process cell surfaces	Reprocessing and fuel-fabrication facilities	Good on fuel spills	Not good on corrosion products.	20
Phosphoric acid	Carbon steel and copper	Equipment	Widespread	Rapid	Redeposition upon long exposure.	20
NS-1	Corrosion products	Liquid radwaste system piping	Dresden-1 reactor 1984	High DFs	Slow. High temperature with pressurization. Extensive rinsing required.	100 to 1,000
Turco 4512A (foamed)	Loose corrosion products	Remote hot cell surfaces	Rockwell International hot laboratory	Low volume Good for large areas; easy remote application	Low DF. Defoamer is essential for processing.	2 to 12
Turco 4324NP	General dirt and light contamination	Contact rooms, laundry	Widespread	Mild	Low DF.	No data

Table 4-1 (Contd)

Technique	Applicability	Area	Experience	Advantages	Disadvantages	Decontamination Factor
Electropolishing	Loose or baked-on, ground-in contamination on equipment	Process cell equipment	Widespread	Polishes surface. Rapid. Extremely high DFs. Contract services are available for in situ work.	Expensive equipment. Not for nonmetals. Limited to small items. Requires highly trained operator.	1,000+
Ultrasonic cleaning	Loose contamination	Equipment	Widespread	Good DFs. Works on non-metals as well as metals.	Limited to small items.	From 2 to 200
High-pressure water hydrolaser	Loose contamination	Remote hot cell surfaces, remote equipment, and waste drum decon	Widespread	High DFs. Good for large surfaces.	Large volume of waste.	Up to 1,000
Freon 113	Oily, loose contamination	Equipment	Widespread	High DFs. Good for electrical items. Good oil solvent. Very low waste volume.	Limited to small items.	Estimate up to 1,000
CO_2 blasting	Loose contamination	Hot cell surfaces, equipment	Developmental	High DFs. Extremely low waste volume. All waste is solid.	Unproven	Estimate up to 1,000

Table 4-1 (Contd)

Technique	Applicability	Area	Experience	Advantages	Disadvantages	Decontamination Factor
Strippable coatings	Loose contamination	Low-level surfaces	Widespread	No cross-contamination. All waste is solid.	Sometimes difficult to remove; removal must be done manually.	100
Handscrubbing	Fuel, corrosion, fission products	Low-level surfaces and equipment; also hot spots	Widespread	None (used as a last resort).	Slow.	Various

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of application occurs most frequently in reprocessing and fuel-fabrication plants. In contrast, the crud formed in PWR reactor loops has been found to be various spinel compounds, especially nickel ferrite. Spinels are extremely insoluble at temperatures below 100°C, even in mineral acids, such as HNO_3. As a result, nitric acid is not suitable for PWR cooling loop decontamination nor, by extension, is it suitable for the MRS Facility decontamination involving PWR crud. Typically, nitric acid is used at about 100 g/L concentration for about 1 hr. The usual application temperature is about 75°C. Typical decontamination factors are about 10. Application to the MRS Facility would be limited to localized areas of fuel and fission product contamination from failed fuel rods.

4.1.3 Nitric and Hydrofluoric Acids

Mixtures of these aggressive acids have been used for decontamination for a number of years. A wide range of solution concentrations has been advocated. Most recently (1980), Studsvik Energiteknik AB performed tests on PWR and BWR components, using 1% HNO_3 combined with 0.1 to 0.3% HF at temperatures from 50 to 80°C and treatment times of 1 to 3 hr.[4] Decontamination factors of 1,000 were reported. In this test, general corrosion of 0.5 to 2 mils was reported. These decontamination factors are impressive, but it should be remembered that aggressive acids that roughen a surface may, in the long run, cause more problems than they solve. Generally, aggressive acids should only be used during facility decommissioning, when the maximum decontamination factor is the primary selection criterion, or for localized attack on stubborn "hot spots." After such use on hot spots, the surface should be refinished, either mechanically or by use of an electropolisher.

4.1.4 Oxalic Peroxide

A mixture of oxalic acid and hydrogen peroxide is generally used on uranium and uranium oxides after fuel failures. Typical concentrations are 2 or 3 g/L oxalic acid and 50 g/L H_2O_2. Decontamination duration is 1 to 4 hr at temperatures of about 80°C. Typical decontamination factors average about 20. Application to the MRS Facility would be similar to that for nitric acid.

4.1.5 Phosphoric Acid

Phosphoric acid is a rapid decontaminant of carbon steel and copper alloys. Decontaminating duration must be kept below 20 minutes to prevent redeposition of contaminants onto base metal. Typical concentrations are 90 to 130 g/L. Application temperature is usually about 85°C. Typical decontamination factors average about 20. Application to the MRS Facility would be for carbon steel or copper alloys, as needed.

4.1.6 NS-1

The NS-1 process is a proprietary product of IT Corporation, Knoxville, Tenn., and was designed especially for BWR corrosion product removal. First used on the Dresden-1 reactor in 1984, the process requires about 100 hr of contact time for completion. The solution is circulated at about 120°C, and

produces about four system volumes of radwaste because of the necessity for extensive rinsing. Very high decontamination factors (100 to 1,000) are possible. Application to the MRS Facility would be in the in situ decontamination of liquid radwaste system piping and equipment internals.

4.1.7 Turco 4512A

Turco 4512A is a phosphoric acid/citric acid proprietary solution that is useful primarily on carbon steel; it is also useful on epoxy-coated concrete and on stainless steels that have not been exposed to high temperatures. Tests have shown that Turco 4512A can be very effectively foamed with compressed air and foaming concentrate (a detergent, Turco 5865) for remote applications on surfaces up to 20 ft away. The typical concentration for Turco 4512A is 10%. Typical decontamination factors for foamed Turco 4512A ranged from 2 to 12 in tests conducted on epoxy-coated concrete and bare carbon steel.[5] Application to the MRS Facility would be as remotely sprayed foam on hot cell floors, walls, and ceilings for the purpose of dissolving any oil film and loosening the contaminants so that subsequent water flushing will be more effective. The use of foaming agents requires fairly careful attention to the proper injection of defoaming agent to maintain adequate evaporator performance.

4.1.8 Turco 4324NP

A mildly alkaline detergent, Turco 4324NP is useful for general mopping and cleaning of contamination that is not tightly bound to a substrate. The typical concentration used is 4 to 8 oz/gal of warm water. Application to the MRS Facility would be for general mopping of low-radiation-level room surfaces.

4.1.9 Electropolishing

Electropolishing is a decontamination process that electrochemically removes metal from the surface of an object, removing virtually all of the contaminants at the same time. Most electropolishing operations are conducted in a phosphoric acid tank after establishing an electrical potential between the contaminated item (which is wired as the anode) and a cathode in the tank. The cathode may be a fixed plate when electropolishing a large exposed surface, or it may be a movable rod for insertion into the interior of the item. Contaminants removed during the process are collected on submicron filters, which are changed frequently to prevent dissolution of the contaminants in the electrolyte. Application to the MRS Facility would be in the decontamination of process cell equipment, such as laser cutting, consolidation, and secondary waste shredding equipment. These will be the most contaminated surfaces in the facility, and will also be the most difficult to decontaminate because of the strongly adherent laser-deposited metal and ground-in contamination. These difficult surfaces can be fully decontaminated in a few minutes by electropolishing. Contract services are available for infrequent applications, such as prepolishing or decommissioning large surfaces in situ.

4.1.10 Ultrasonic Cleaning

The ultrasonic cleaning technique uses an ultrasonic generator submerged in a liquid (usually water) with the item to be cleaned. Ultrasonic energy causes the liquid to cavitate and implode. The shock waves from these implosions scour the surface of the contaminated item, causing loosely held contaminants to leave the surface and enter the solution. Application to the MRS Facility would be in the decontamination of small pieces that are contaminated with easily removable, dusty types of contaminants.

4.1.11 High-Pressure Water Hydrolaser

A hydrolaser consists of a high-pressure (1,000- to 10,000-psi), positive-displacement pump, a spray gun, and interconnecting flexible hose. The pump can be supplied on a portable cart with a heated suction tank. The hydrolaser nozzle must be held very close to the surface being decontaminated for maximum spray impact. Hydrolasers are very commonly used in the nuclear industry to effectively decontaminate components, structures, walls, floors, ceilings, and the interiors of tanks.

Epoxy-coated concrete may be adequately resistant to hydrolaser sprays; however, care should be taken not to hold the nozzle too close to the coating or exposed edges of the coating to ensure that the water jet does not separate the coating from the substrate. Hydrolasers should not be directed at shielding window glass from close range because of the danger that the impacted dust particles could pit the glass.

A useful accessory is a "pipe mole" nozzle for cleaning the interior surfaces of pipes and ducts. This nozzle is attached to a flexible hose and is inserted into the pipe opening. Circumferential water jets that are directed slightly backward provide enough thrust to center the nozzle in the pipe and advance the nozzle through the pipe, dragging the hose along. The nozzle can pass through bends and climb limited vertical sections.

Extensive testing of hydrolasers at Three Mile Island (Unit 2) has shown that a 1,000-psi unit was insufficient for effective decontamination.[6] A 10,000-psi unit was found to be very effective on smearable contaminants, yielding decontamination factors of 1,000.[7] These high decontamination factors were on concrete and rusted, carbon-steel surfaces. Decontamination factors of loose dust on stainless steel surfaces could be expected to be still higher. Water usage is fairly high for this type of decontamination: TMI-2 used 42 to 72 gal/100 sq ft of surface. Recontamination of previously cleaned surfaces by splash from adjacent areas is a problem that must be addressed. Splash can be limited by using a spray shield surrounding the spray nozzles. Four rollers are positioned near the corners of the shield. These rollers allow the shield to be pressed against a flat surface to minimize splash while allowing enough wall separation to permit drainage.

Application to the MRS Facility would be in the remote or contact decontamination of contaminated floors, walls, and ceilings; large pieces of equipment; drums of contaminated waste; and the interiors of ductwork. These surfaces are contaminated with dusty particulates that will be easily dislodged by the vigorous action of an impinging water stream.

4.1.12 Freon 113 Solvent

Freon 113 is a low-viscosity liquid at room temperature. It is an excellent solvent of oils, although not of water-soluble contaminants. The main advantages of Freon are its low viscosity (helpful in penetrating into small surface fissures), its powerful solvent abilities, and its low boiling point. The low boiling point and low heat of vaporization make distillation of Freon 113 a very economical method of purifying the spent liquid.

Freon 113 has been used in ultrasonic, vapor degreaser, dip tank, and high-pressure spray applications in the electronic and nuclear industries. Freon equipment vendors, such as Quadrex and Allied Nuclear, favor the use of high-pressure spray chambers for nuclear facility decontamination. In this application, Freon spray is usually more effective than ultrasonic cleaning.

In most applications, a vapor-condensing chiller system is used to minimize the unwanted vaporization and loss of the rather expensive solvent. Because of the need for chilling the air in the chamber, there are limits to the size of the chamber that may be used in Freon decontamination. Most standard chambers are less than 100 cu ft in volume. No tools are now available to use Freon in the decontamination of large facility surfaces, such as floors, walls, and ceilings.

Application to the MRS Facility would be in the decontamination of small pieces that are contaminated with easily removable, dusty or oily contaminants, and in the decontamination of electrical and electronic components and CCTV camera equipment that would not tolerate aqueous solutions.

4.1.13 Grit Blasting

Several varieties of grit blasting have been used in radioactive decontamination of facilities. Common dry sandblasting uses compressed air to propel silica sand at the contaminated surfaces. Dust migration and disposal of large quantities of radioactive sand make dry sandblasting an unpopular variation. The use of liquid water as the motive fluid solves the dust problem, but heightens the disposal problem because, in wet blasting, both the water and the sand must be disposed of. Also, the sharp, hard sand particles tend to pit metal surfaces, making subsequent contamination more difficult to remove.

Glass beads in wet or dry blasting have been used effectively where the glass grit is itself used in the process. Savannah River uses glass beads to decontaminate high-level waste canisters, then uses the spent beads to make glass logs for waste immobilization.[8]

Carbon dioxide blasting has been used effectively by General Electric to decontaminate BWR turbine blades. In this process, liquid carbon dioxide is mixed in a spray gun with compressed air, forming a high-velocity stream of CO_2 chips to decontaminate a work surface. Although the CO_2 chips are too soft to penetrate a hard, high-temperature oxide film, they have the advantage of immediately subliming away, thus drastically reducing the solid waste volume. Decontamination factors similar to those of hydrolasers are expected.[9] The potential for uncontrollable dust migration and recontamination of previously cleaned surfaces needs further study before CO_2 blasting can be recommended. If these problems are resolved, application to the MRS Facility could be widespread: hot cell surfaces and equipment contaminated with easily removable dust would be appropriate applications.

4.1.14 Strippable Coatings

A strippable coating is a strong, paint-like material that can be sprayed or rolled onto a surface, allowed to dry, and then easily peeled off in large strips. Consideration should be given to applying a layer of cheesecloth backing to the surface. The cloth provides reinforcement to the coating, ensuring that the coating can be removed quickly in large sections. This is especially important if the coating has been left in a high-radiation environment for a long time because strippable coatings have a tendency to become difficult to remove after suffering radiation damage. Specially formulated coatings have been used very effectively in nuclear decontamination. In use, the newly applied coating bonds loose contaminants to the film. When the coating is peeled, the contaminants come with it. The film is disposed of as compactible waste. This process is not suitable for remote decontamination because the stripping must be done manually. Application to the MRS Facility would be in the decontamination of contact and limited contact room surfaces.

Decontamination factors of about 100 were observed at TMI-2 during testing of the ALARA 1146 strippable coating by Imperial Coatings. Overall cleaning rates were 0.6 manhour/100 sq ft, with about 0.64 cu ft of waste produced per 100 sq ft of surface.[10]

4.1.15 Steam Cleaning

Steam cleaning is a widely used industrial and commercial technique for the cleaning of greasy and dirty equipment. It has been used in nuclear facilities for decontamination, but has been mostly replaced by the use of hydrolasers, which have been found to be more generally effective.[11] Steam cleaning should not be used around any electrical equipment without special provisions to prevent water intrusion. Application to the MRS Facility would be for exceptionally greasy surfaces.

4.1.16 Handscrubbing

Handscrubbing is a very common, although laborious, technique that is used to remove localized contaminants. It is used to some degree at most nuclear

facilities. The technique requires a decontamination solvent and an applicator. The solvent may range from the most innocuous (water), through common detergents and organic solvents, to highly corrosive acids. Any absorbent cloth, swab, or mop may be used as an applicator. One of the most common applicators for the removal of loose contamination is feminine sanitary napkins.[12]

4.2 OTHER TECHNIQUES

A number of other decontamination processes have been and continue to be developed, especially for use by the nuclear power utilities. These techniques fall into two general categories: the high-concentration and the low-concentration processes.

The high-concentration processes characteristically use chemical solutions of about 10% concentration in an effort to achieve fairly high decontamination factors: 20 or more. Because of the high decontamination factors, the decontamination process may be done fairly infrequently (every few years). Because the chemicals are so concentrated, however, waste disposal is a problem for most utility companies, as the waste tankage and volume-reduction and solidification equipment necessary to handle these wastes tend to be large and costly. The most prominent of the high-concentration processes are those based on alkaline permanganate (AP), usually with a second step, such as ammonium citrate (APAC), ammonium citrate plus EDTA (APACE), sulfamic acid (APSUL), or citric plus oxalic acids (APCITROX). The NS-1 process, detailed in Section 4.1.6, is another high-concentration process developed for power reactor decontamination.

The low-concentration processes characteristically use chemical solutions of about 0.1% concentration to achieve decontamination factors from 2 to 5. The lower DFs achievable necessitate more frequent decontamination operations: yearly is typical. The low concentrations, however, enable efficient waste treatment by simple ion exchange and resin disposal, without the need for waste tankage and other special volume-reduction equipment. The most prominant low-concentration processes are CAN-DECON and LOMI (low oxidation-state metal ion).

5.0 DECONTAMINATION OF MRS FACILITY

In general, selection of routine and special decontamination techniques requires a life-cycle assessment. Such an analysis is beyond the scope of this study, which is limited to conceptual review and preliminary recommendation of decontamination methods.

Based on the experience of other hot cell facility operators, as determined by literature search and telephone interviews, the decontamination procedures described below are recommended at this time.

The crane maintenance rooms have been designed for monthly contact decontamination and maintenance of the bridge cranes. This frequency ensures that the cranes will not become "too hot to handle."

5.1 FREQUENCY OF DECONTAMINATION

Remote-maintenance hot cells are operated without manned entry for many (5 to 10) years, until a major modification or repair is required.[13,14] As such, there is no scheduled period recommended for full decontamination of remote hot cells. Nevertheless, some period must be assumed for calculation purposes. A period of 5 yr between major hot cell decontaminations has been assumed for the MRS Facility. It is, however, recommended that routine remote light housekeeping be performed to minimize the accumulation of large amounts of loose radioactive contamination.[15] Compressed-air-driven vacuum cleaners will be sufficient for this purpose.

Equipment will be decontaminated on an as-needed basis, with the exception of bridge cranes.

Low-level contamination of contact maintenance rooms will be removed on an as-needed basis whenever the radiation level exceeds a predetermined upper limit.[16]

5.2 SELECTED METHODS OF DECONTAMINATION

5.2.1 Remote Hot Cell Surfaces

The major expected contamination on MRS hot cell surfaces will be a dry, dustlike film, held together, at most, with a light oil film. Therefore, chemical methods of decontamination, designed to dissolve oxide films, will be unnecessary on these surfaces. Instead, a procedure for frequent remote vacuuming will be followed to prevent the accumulation of large quantities of contaminants. Full decontamination will involve:

(1) Remote removal of all fuel and in-cell equipment.

(2) Remote vacuuming of loose contamination, using a HEPA filter portable vacuum cleaner.

(3) Remote application of foamed decontaminating agent (Turco 4512A), produced by a portable, compressed-air foamer, using plant air and pumped decontaminating agent to educt and mix foaming agent (Turco 5865) for discharge from a hose nozzle.

(4) Remote wet vacuuming of foam drainage.

(5) Remote 10,000-psig water rinse. This step must be sequenced to prevent overflow of the HAW liquid collection vessel.

Following the above operations, a remote radiation survey will be taken to determine whether the cell is safe for personnel entry to perform detailed surveys and final contact decontamination of hot spots, or whether additional

remote decontamination operations are necessary. Table 5-1 summarizes the decontamination techniques and frequencies recommended for remote areas and equipment. Table 5-2 represents the high-activity liquid radwaste generated as a result of decontamination operations.[17]

Localized hot spots will probably appear near the laser from laser-deposited metal. Some fuel and fission products will accumulate near the consolidation equipment because of failed fuel rods. Depending on the adherence of these contaminants, the basic techniques may not be adequately effective. More aggressive solutions would then be appropriate: nitric acid or oxalic/peroxide-soaked wipes should be tried on fuel spills, whereas laser-deposited metal may well require nitric-hydrofluoric/acid-soaked wipes. As mentioned above, the surface should be repolished after use of any aggressive decontaminants.

5.2.2 Contact Maintenance Rooms

Limits will be established for the allowable average contamination level of contact maintenance rooms. Upon reaching this level, the room will be fully decontaminated down to a predetermined, "clean" level. In addition, "hot spots" will be decontaminated as they are discovered, and regularly scheduled vacuuming and floor mopping will be performed. Table 5-3 summarizes the decontamination techniques and frequencies recommended for low-level radiation areas and equipment. Table 5-4 represents the low-level liquid radwaste generated as a result of decontamination operations.[18]

5.2.3 Equipment Decontamination

High-activity equipment from the process cells and the maintenance cell will be decontaminated in the maintenance cell decon station. This is a shielded room equipped to decontaminate objects through the use of any of three different processes: a manipulator-operated, high-pressure water spray hydrolaser, a manipulator-operated electropolisher, and a manipulator-operated Freon 113 spray chamber. The hydrolaser affords the ability to decontaminate large and irregularly shaped objects that are not capable of fitting into either the electropolisher tank or the Freon spray chamber. The electropolisher can be used to decontaminate smaller, stainless steel objects to extremely low radiation levels in a very short time. The Freon 113 spray chamber can be used to decontaminate smaller objects that would be damaged by water or electropolishing techniques, such as cameras, motors, micrometers, and electrical equipment.

Contaminated manipulators will be removed from service by a bag-out operation, and transported to the manipulator maintenance room for decontamination and repair. They will be lowered into the Freon manipulator decon station, where the bag will be removed and the manipulator decontaminated by high-pressure Freon spray. Small contaminated tools and equipment will be decontaminated in a manner similar to that used for the manipulators.

Table 5-1 - Decontamination of High-Activity Radiation Areas and Equipment

Area	Frequency[a]	Technique	Liquid Application Rate
Process cells	All surfaces: 5 yr	Remote: dry vacuum, foam, wet vacuum, high-pressure rinse. Contact: as required.	1.08 gal/sq ft
Maintenance cell	All surfaces: 5 yr	Remote: dry vacuum, foam, wet vacuum, high-pressure rinse. Contact: as required.	1.08 gal/sq ft
High-activity radwaste cell	All surfaces: 5 yr	Remote: dry vacuum, foam, wet vacuum, high-pressure rinse. Contact: as required.	1.08 gal/sq ft
Remote equipment decontaminating room	All surfaces: semiannually	Remote: high-pressure rinse. Contact: as required.	1.0 gal/sq ft
Remote handling air filtration cell	All surfaces: 5 yr	Remote: dry vacuum, foam, wet vacuum, high-pressure rinse. Contact: as required.	1.08 gal/sq ft
Filter compaction area of remote handling air filtration cell	All surfaces: annually	Remote: dry vacuum, foam, wet vacuum, high-pressure rinse. Contact: as required.	1.08 gal/sq ft
Crane maintenance room	All surfaces: annually	Contact: dry vacuum, foam, wet vacuum, high-pressure rinse.	0.5 gal/sq ft
Process cell ventilation ducts between nontestable and testable HEPA filters	Internal surfaces: 5 yr	Remote: self-propelled spray hose.	1.0 gal/sq ft
Drum decontaminating cells	All surfaces: 5 yr	Remote: dry vacuum, foam, wet vacuum, high-pressure rinse.	1.08 gal/sq ft

[a]Actual decontamination will be on an as-required basis. Frequencies given are for calculation purposes only.

Table 5-1 (Contd)

Area	Frequency	Technique	Liquid Application Rate
Canyon cell	All surfaces: 5 yr	1. Floor near canister upender equipment: Remote: dry vacuum, foam, wet vacuum, high-pressure rinse.	1.08 gal/sq ft
		2. Other surfaces: Contact: vacuum, mop, and rinse.	1.0 gal/100 sq ft
Cranes (in crane maintenance cells)	All surfaces: monthly	Contact: mops, rags, high-pressure rinse.	60 gal/decon
Crane hooks and power mast wrist	All surfaces: monthly	Remote: high-pressure rinse.	10 gal/decon
Compaction equipment in remote air filtration cell	Annually	Remote: high-pressure rinse. Contact: electro-polisher, as required.	1 gal/sq ft
Sealed storage canisters	3,253 canisters/yr	Remote: Freon.[b]	-
In-cell equipment components	Every 2 wk	Remote: high-pressure rinse, electropolisher, or Freon spray, as required.	1 gal/sq ft
Secondary waste drums	1,582 drums/yr	Remote: Freon.[b]	-
HAW filter drums	676 drums/yr	Remote: Freon.[b]	-
Solid radwaste drums (assume 50% contaminated)	17 drums/yr	Remote: high-pressure rinse.	20 gal/drum
Manipulators (70, once every 2 wk)	1,820 decons/yr	Remote: Freon.[b]	-
Tool decontamination	As needed	Remote: Freon or electropolisher, as required.	-

[b]Water-soluble contaminants are not expected.

Table 5-2
Spent Decontamination Solution to High-Activity Liquid Radwaste System[a]

Area Decon Sumps[b]	Spent Decon Solution (lb/yr)[c]
Process cell decon	113,300
Maintenance cell decon	72,100
Crane maintenance decon	357,071
Remote handling air filtration cell decon	96,134
Remote handling air filtration cell equipment decon	8,584
High-activity radwaste cell decon	46,352
Drum decon cell decon	25,750
HAW solids drum decon	4,292
In-cell equipment decon	85,835
Shielded canyon cells decon	25,752
Total	835,170

[a]See Table 5-1 for sources.

[b]Includes equipment decon

[c]Includes steam used for steam jets.

Table 5-3 - Decontamination of Low-Level Radiation Areas and Equipment

Area	Frequency	Liquid Technique	Application Rate
Cask handling and decon	Floor: weekly All surfaces: biannually	Vacuum, mop, and rinse	1 gal/100 sq ft
Loadout and decon rooms	Floor: weekly All surfaces: biannually	Vacuum, mop, and rinse	1 gal/100 sq ft
Contact repair room	Floor: weekly All surfaces: biannually	Vacuum, mop, and rinse	1 gal/100 sq ft
Weld, test, and decon equipment room	Floor: weekly All surfaces: biannually	Vacuum, mop, and rinse	1 gal/100 sq ft
Low-level radwaste (solid and liquid)	Floor: weekly All surfaces: biannually	Vacuum, mop, and rinse	1 gal/100 sq ft
Decon rooms (contact handled)	Floor: weekly All surfaces: biannually	Vacuum, mop, and rinse	1 gal/100 sq ft
Laundry room	Floor: weekly All surfaces: biannually	Vacuum, mop, and rinse	1 gal/100 sq ft
Analyzer room	Floor: weekly All surfaces: biannually	Vacuum, mop, and rinse	1 gal/100 sq ft
Analytical laboratory	Floor: weekly All surfaces: biannually	Vacuum, mop, and rinse	1 gal/100 sq ft
Equipment			
Solid radwaste drums (assume 50% contaminated)	267 drums/yr	High-pressure rinse	20 gal/drum
Remote air filtration cell crane	Monthly	Mop and rinse	60 gal/decon
Shipping casks	680 casks/yr (30%)	Wipe and rinse	4 gal/cask

Table 5-4
Spent Decontamination Solution to Low-Level Liquid Radwaste System[a]

Area Decon Sumps[b]	Spent Decon Solution (lb/yr)[c]
Low-level liquid radwaste area decon	25,920
Low-level solid radwaste area decon	27,644
Low-level solid radwaste drum decon	45,610
Health physics and personnel decon drain	44,634
Cask handling and decon	51,828
Manipulator maintenance rooms decon	25,916
Loadout/decon drains	47,510
Weld test and decon equipment room	12,957
Laundry room decon	8,638
Total	290,657

[a]See Table 5-3 for sources.

[b]Includes equipment decon.

[c]Includes steam used for steam jets.

The potentially highly contaminated hot cell crane hooks and the wrists of electromechanical manipulators will be disconnected and left in the process cell before the start of crane maintenance. These pieces will be taken to the maintenance cell for remote decontamination or repair, as necessary.

The crange bridges and trollies will not normally require remote decontamination because the scheduled monthly contact decontamination will keep the radiation levels from building up. Normal contact decontamination will be performed with detergent or alcohol-soaked wipes within the crane maintenance rooms. Limited remote decontamination of the cranes for the shielded process cells may be performed inside those cells by using the wall-mounted electromechanical manipulator to wipe accessible crane surfaces.

5.3 SURFACE PREPARATION

Proper surface preparation before commencing facility operations can be of significant value in easing subsequent decontamination efforts when they are eventually required. For example, electropolishing of the stainless steel surfaces of the cell liner walls and floor, and of exposed surfaces of equipment after installation, but before operations begin, would be of significant help to subsequent decontamination efforts. Similarly, prepolishing of the interior of the radwaste system piping, tankage, etc., would greatly reduce the rates of accumulation of contaminants on those surfaces, and would ease subsequent decontamination efforts.

6.0 SUMMARY AND CONCLUSION

Of the large number of decontamination techniques available, it is anticipated that some of the simplest will be adequate to accomplish effective decontamination at the MRS Facility. Hot-cell decontamination will start with vacuum cleaners, progress through foamed application of relatively mild Turco 4512A phosphoric/citric acid solution, and finish with a high-pressure water rinse. Low-level contamination in contact maintenance rooms will be mopped up with detergent (Turco 4324NP) and water. Systems will be provided to allow equipment and tools to be decontaminated with high-pressure water spray, Freon spray, or electropolishing, as appropriate.

The subject of decontamination is evolving at a rapid rate. Techniques that, at present, are only developmental may in the future be proven to be superior to those currently favored. New techniques surely will be developed. As a result, the testing of new techniques and the flexibility to modify procedures based on new information will be very valuable.

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INTEROFFICE CORRESPONDENCE (IOC)

Document No.	Subject	Issue Date
IOC-339	Basis for Lag Storage Thermal Analysis for Modified MRS Design	Jan. 22, 1985
IOC-360	Spent Fuel Canister Layout for Criticality Analysis	Feb. 6, 1985
IOC-372	Lag Storage Vault Cooling Calculations	Feb. 8, 1985
IOC-472	Lag Storage Vault Thermal Design Guide No. 1	Apr. 17, 1985
IOC-505	Gamma Radiation Heating in Lag Storage Pit Wells	May 10, 1985
IOC-520	In-Cell Lag Storage Heat Load	May 15, 1985
IOC-697	Lag Storage Vault Temperatures	Sept. 23, 1985
IOC-703	Investigation of In-Cell Lag Storage Pit Cooling and Concrete Temperatures	Oct. 18, 1985

DESIGN STUDY DS-21

PASSIVE VS ACTIVE COOLING FOR CANISTERED FUEL LAG STORAGE AREAS

1.0 INTRODUCTION

In the MRS Facility, the consolidated spent-fuel canisters are stored in open-cycle vaults located in the canyon cells of the Receiving and Handling (R&H) Building. The minimum capacity of this in-building lag storage is 1,000 metric tons (MT) of consolidated fuel in canisters. Based on a spent-fuel mix of 60% PWR to 40% BWR by weight, the 1,000-MT capacity amounts to a storage of 741 canisters if each canister is assumed to contain consolidated fuel rods of either three PWR fuel assemblies or seven BWR fuel assemblies. With the decay-heat load of 550 W per PWR assembly and 180 W per BWR assembly, the lag storage area will have a heat generation rate of 1.1 MW.

The canister array needs to be housed in a heavy-shielded structure because of the strongly penetrating neutron and gamma radiation from the spent-fuel rods stored in the canisters. The storage area should also have crane access because of handling requirements. A top-loading lag storage area, with vertical storage of the canisters in a vault-type configuration, was chosen for the R&H Building. These canisters are supported by a "grid" structure system. The roof slab of the vault contains plugs that provide top access to the canisters by the crane located in each canyon cell.

A study was conducted to assess the use of passive vs active cooling for the lag storage area. The lag storage thermal problem was determined to have several technical requirements, including:

(1) Cooling the canisters to maintain the canister surface temperature below 285°C.

(2) Cooling the concrete vault structure below 200°F.

(3) Maintaining an acceptable flow distribution within the vault.

It is noted that other technical concerns (such as radiation shielding, nuclear criticality prevention, remote handling, contamination control, and seismic design) are parts of the integrated design activities. They are outside the scope of this study, however, and will not be addressed herein.

1.1 CANISTER TEMPERATURE

Based on previous thermal analysis for canistered, consolidated PWR fuel with a decay-heat burden of 1,650 W, the surface temperature of the canister

must be maintained at or below 285°C. This ensures that fuel rod temperature will not exceed 370°C in an inert atmosphere.

1.2 CONCRETE TEMPERATURES

The thermal analysis assumed a maximum temperature at any location on the concrete structure of 200°F. This value was selected in accordance with that allowed for local conditions by Reference 1. In addition, if the final analysis indicates that a significant portion of the concrete structure is subjected to the maximum temperature value, the structure will be designed for a reduced concrete compressive strength in accordance with Reference 2.

1.3 FLOW DISTRIBUTION

It is not expected that a lag storage area will be filled to its storage capacity at all times. Design of the cooling system needs to accommodate a partially filled lag storage. Therefore, the distributed cooling air must be primarily directed to the occupied areas of the lag storage vault.

One approach to ensure proper flow distribution would be to store each canister in its own cooling channel. In this approach, the lag storage area will consist of an array of vertical pipes into which canisters are placed. Layout of HVAC ducts and related controls to supply air to individual channels becomes complicated. We have assessed this cooling system design and have concluded that, if possible, the canisters should be stored in an open-vault-type arrangement.

For the open-vault cooling concept, the air will tend to flow to unoccupied regions of the lag storage area because of lesser coolant path resistance. Also, the distribution of airflow to concrete walls is not ensured, thereby raising wall temperatures above the allowable limits.

2.0 TECHNICAL ASSESSMENT

Two cooling concepts, passive and active, were considered for the canistered fuel lag storage area of the R&H Building.

2.1 PASSIVE COOLING (NATURAL OR FREE CONVECTION)

For passive cooling, removal of heat from the canister array is through natural convection of air and through thermal radiation from the canister array onto the vault concrete structure. Air is introduced into the storage vault beneath the canister array and rises because of the buoyancy generated by the heat load of the canisters. Although free convection will generate an upward thermal draft because of thermal expansion of the air, the amount of air exhausted depends upon pressure resistance of the HVAC ducts and filtration arrangement. Exhaust ducts located at the center of the vault ceiling region would be required to accommodate the thermal design requirements. The exhaust ducts would be located above the crane to permit crane access to the canister array, and the thermal draft will have to rise more than 20 ft above the top of the storage array. The theoretical draft

produced from free convection cooling of a canister was calculated to be approximately 0.1 in. of water (see Appendix). This is insufficient to force the exhaust air through the required HVAC filters.

The natural convection cooling of the consolidated spent fuel canisters was analyzed. The canister was modeled as being in the center of a large array. This assumed no net radiant heat loss with all of the heat removal by convection in the surrounding air. It was also assumed that the surface-to-surface separation of adjacent canisters was sufficient to eliminate interactions among their respective convective airflow layers. Separation distances of 6 in. or more will meet this assumption. The inlet air temperature was assumed to be 100°F. This analysis showed that natural convection would remove the 1,650 W of decay heat from the canister and keep the maximum canister surface temperatures from exceeding 285°C (545°F).

The interaction of a single canister with the lag storage pit wall was also analyzed to determine the maximum wall surface temperature. This analysis showed that the maximum wall surface temperature would far exceed 200°F if natural convection cooling were used. Since the radiant heat flow to the wall would increase with additional canisters, natural convection cooling will be inadequate, and forced convection will be needed.

The passive cooling system is not recommended because the pressure differential is insufficient to allow air to be drawn through the required HEPA filters. Also, a passive system does not provide adequate airflow to maintain concrete temperatures within the acceptable limit.

2.2 ACTIVE COOLING (FORCED CONVECTION)

For active cooling, removal of heat from the canister array is through forced convection and through thermal radiation from the canister array onto the vault concrete structure.

In this cooling mode, the driving force of the cooling medium is by an external force. Depending upon the cooling medium transfer channel design, the driving force can be determined by evaluating the sum of flow resistance in the supply and exhaust systems. Major factors governing the design are: (1) system pressure drop and (2) canister surface heat-transfer coefficient. The first factor is a function of the HVAC equipment (filters plus duct resistances). The second factor is a function of heat removal rate from the canister.

Using the lag storage design configuration, air would be exhausted by a fan. The amount of airflow and the velocity of air through the vault can be designed to meet the canister cooling requirements. Use of higher air velocity results in a larger heat-transfer coefficient, and hence faster heat removal from the canisters. However, the cooling system has a larger pressure drop and will require larger driving forces, resulting in higher system capital and operating expenditures. By directing some airflow to the vault concrete wall surfaces, temperature of the concrete can be maintained

below a preset limit of 200°F. This feature is desirable, given the long-term exposure of the concrete to high heat flux and the inaccessibility of the vault because of the high-radiation environment. The active cooling method can accommodate airflow control by providing a larger pressure drop in portions of the distribution system.

Although an active cooling system can be designed to meet the temperature requirements, it will require higher capital and operating expenditure than would a passive system.

2.3 SEMIACTIVE COOLING

An analysis was performed to determine whether a combined active and passive system could maintain canister and concrete temperature limits, thereby minimizing additional equipment and related facility space. This system introduces air actively by a fan, but the airflow rate is slow enough that heat is removed passively from the canister by using the buoyancy force of natural convection. By using fans, airflow into/out of the vault is designed to overcome the pressure drop of the HVAC system, including filters. Because of the external driving force, the airflow distribution system can be designed to distribute the airflows properly. The decay-heat load of the canisters is removed passively. The cooling system is, therefore, smaller and less expensive than an active cooling system.

3.0 CONCLUSION

Based on the analysis noted herein, a semiactive cooling system, which uses fans to handle airflow in and out of the vault and uses the buoyancy of air to remove heat from the stored canisters, is recommended for the canister lag storage area in the R&H Building.

To provide proper airflow distribution, each vault is compartmented and each compartment will have its own air supply and exhaust. A compartment will house a 4x4 array of canisters. Air supply to a compartment is through a plenum located 2 ft below the canister bottom. The plenum is designed to properly distribute airflow to the canister storage positions in a compartment. A separate side stream is directed toward the concrete wall surface, which is adjacent to one or two sides of a compartment.

Our recommendation results in the following preliminary design parameters:

(1) Natural convection requires a minimum airflow of 70 cfm at 100°F inlet air temperature. With this flow the center canister surface temperature will not exceed 320°F.

(2) The minimum airflow required for cooling the concrete wall to a temperature below 200°F is 300 cfm at 100° inlet air temperature.

(3) The minimum airflow required for a compartment of 4x4 canisters is 1,250 cfm to the canisters at 100° air inlet temperature, assuming 10% margin in airflow.

(4) The minimum total airflow required for a lag storage vault of eight compartments is 18,000 cfm, including 8,000 cfm required to cool the concrete vault surfaces.

REFERENCES

1. ACI 349, Code Requirements for Nuclear Safety Related Concrete Structures.

2. AMES-843, High Temperature Properties of Concrete Relevant to Monitored Retrievable Storage Applications.

APPENDIX

MAXIMUM STATIC HEAD FROM NATURAL CONVECTIVE CANISTER COOLING

The maximum theoretical static head was calculated for the natural convective cooling of the spent fuel canister in an in-building lag storage area. The equation used was taken from the Chemical Engineers Handbook[1] and is for the draft in a furnace stack.

The equation is:

$$p = (0.256)(L)(P)\left(\frac{1}{T} - \frac{1}{T_1}\right) \qquad \text{(Equation 9-26)}$$

where

p = theoretical stack draft, inches of water
L = stack height, ft
P = barometric pressure, in. Hg
T = ambient temperature, °R
T_1 = average stack temperature, °R

For the in-building lag storage area, the following constants were used:

L = 20 ft
P = 1 atmosphere = 29.91 in. Hg
T = 100°F = 560°R
T_1 = 410°F = 870°R

The static head was calculated as:

p = 0.098 in. water =, say, 0.1 in. water

This pressure is not enough to drive the exhaust hot air through the HEPA filters. Since this is a maximum value with no allowance for the losses encountered in a real physical system, the lag storage area cannot depend on natural convection to maintain circulation through the system.

---

[1]Perry, R.H., and Chilton, C.H., Chemical Engineers Handbook, 5th Edition, McGraw-Hill Publishing Company, New York, 1973.

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC #339

To	Distribution			Date	January 22, 1985
From	A. D. Wilcox	Phone	3790	Location	EA-4F-216
SUBJECT	Job 6440 - Monitored Retrievable Storage Facility Basis for Lag Storage Thermal Analysis for Modified MRS Design				

The thermal analysis of the lag storage vault for the Modified MRS Facility will be based on the following:

The lag storage capacity will be 300 metric tons of consolidated spent fuel.

The fuel mix will be 60% PWR/40% BWR by weight. This is calculated as 130 canisters of PWR and 92 canisters of BWR consolidated fuel for a total of 222 consolidated fuel canisters.

The facility concepts being considered show one or two lag storage areas. Both layouts will be studied until the final layout is chosen.

The limiting canister surface temperature will be 285°C for consolidated PWR fuel with a decay heat burden of 1650 watts per RTC-181.

This lag storage is on the ground floor of the Modified MRS Facility and is separate from any lag storage in the hot cells.

The heat generation rate for one PWR assembly is 550 watts and for one BWR assembly is 180 watts based on the FDC.

A. D. Wilcox

ADW:gp

Distribution

D. Gross
S. T. Huang
N. Razfar
W. D. Woods
A. K. Jowdy
B. Kenessey
R. L. Jarvis
K. J. Chang
J. T. Ang
C. H. Keehn
W. L. Santo
J. A. Roll

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE IOC #360

To File Date 2/6/85

From J. Chang Phone 2044 Location A2-55

SUBJECT Job 6440 - MRS Facility
Spent Fuel Canister Layout for Criticality Analysis

Reference: R & H Facility - Drawing No. H-3-54903, Material Handling
Spent Fuel Canister Layout - 9/20/84

Following assumptions are the bases for the criticality analysis of the lag storage of consolidated PWR and BWR canisters (Study ID A.3 and A.4).

1. Per reference above, the canister body is a 12 inch, sch 20 stainless steel pipe which has 12.75 inch O.D. and 12.25 inch I.D. The maximum height of the canister including the lifting pintle is 192 inches. The maximum height of an unconsolidated fuel assembly is 178.30 inches for PWR and 178.50 inches for BWR. The maximum height of a consolidated fuel bundle is 161.60 inches for PWR and 162.80 inches for BWR.

2. A canister can take 1 unconsolidated PWR fuel assembly or 2 unconsolidated BWR fuel assemblies. However, the canister can take 3 consolidated PWR fuel assembly fuel rods (792) or 7 consolidated BWR fuel assembly fuel rods (448). There is no spacer or filler inside the canister to fix the fuel assembly (assemblies) or fuel rods.

3. The moisture content of void region in this study will range from complete dry to complete water flooding for both inside and outside of the canister.

Joseph Chang
Joseph Chang

JC:jf

cc: S. Dianat
C. E. George
S. T. Huang
A. K. Jowdy
S. Y. Mayet
J. A. Roll
W. L. Santo
A. D. Wilcox
W. D. Woods

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE IOC #372

To A. D. Wilcox Date February 8, 1985

From J. T. Ang Phone 7095 Location EA-439

SUBJECT Job 6440 - Monitored Retrievable Storage Facility
Modified MRS Facility
Lag Storage Vault Cooling Calculations

Reference: IOC #339 and 360

Until advised otherwise, heat transfer and pressure drop calculations for the lag storage vault will be based on the following:

Storage capacity:	1000 metric tons of consolidated spent fuel (60% PWR & 40% BWR)
Total No. of Canisters:	444 PWR, 296 BWR (740 total)
Canister Dimensions:	12.75" OD x 192" height max. (both PWR and BWR)
Canister exterior surface:	Smooth stainless steel pipe
Max. allowable surface temperature:	285°C (canister exterior)
Heat release rate:	1.65 KW per PWR canister 1.26 KW per BWR canister
Canister spacing:	36" centers, in-line arrangement, not staggered

J. T. Ang

JTA:gp

CC: W. L. Santo
C. H. Keehn
S. T. Huang
A. K. Jowdy
W. D. Woods

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC #472

To Distribution

Date April 17, 1985

From N. Razfar Phone 3984 Location A2-02-6

SUBJECT Job 6440 - Monitored Retrievable Storage Facility
Lag Storage Vault Thermal Design Guide No. 1

The thermal analysis of the Lag Storage Vault for the Modified MRS Facility requires the following:

1) The supply cooling air per vault (128 canister with 211.2 Kw decay heat) is 18,000 CFM for the 100°F inlet condition.

2) The distribution of cooling air within the vault is shown on the attached sketch No. 1.

3) The supply air must be distributed uniformly within the compartments through a performed plate.

4) The supply air must be directed uniformly on the surface of the concrete walls and sheet metal within a compartment for effective cooling.

5) The individual supply system must be provided by a damper control that is pre-set prior to loading the vault with canisters.

6) The air must be collected on both sides of each compartment and manifolded together for exhausting.

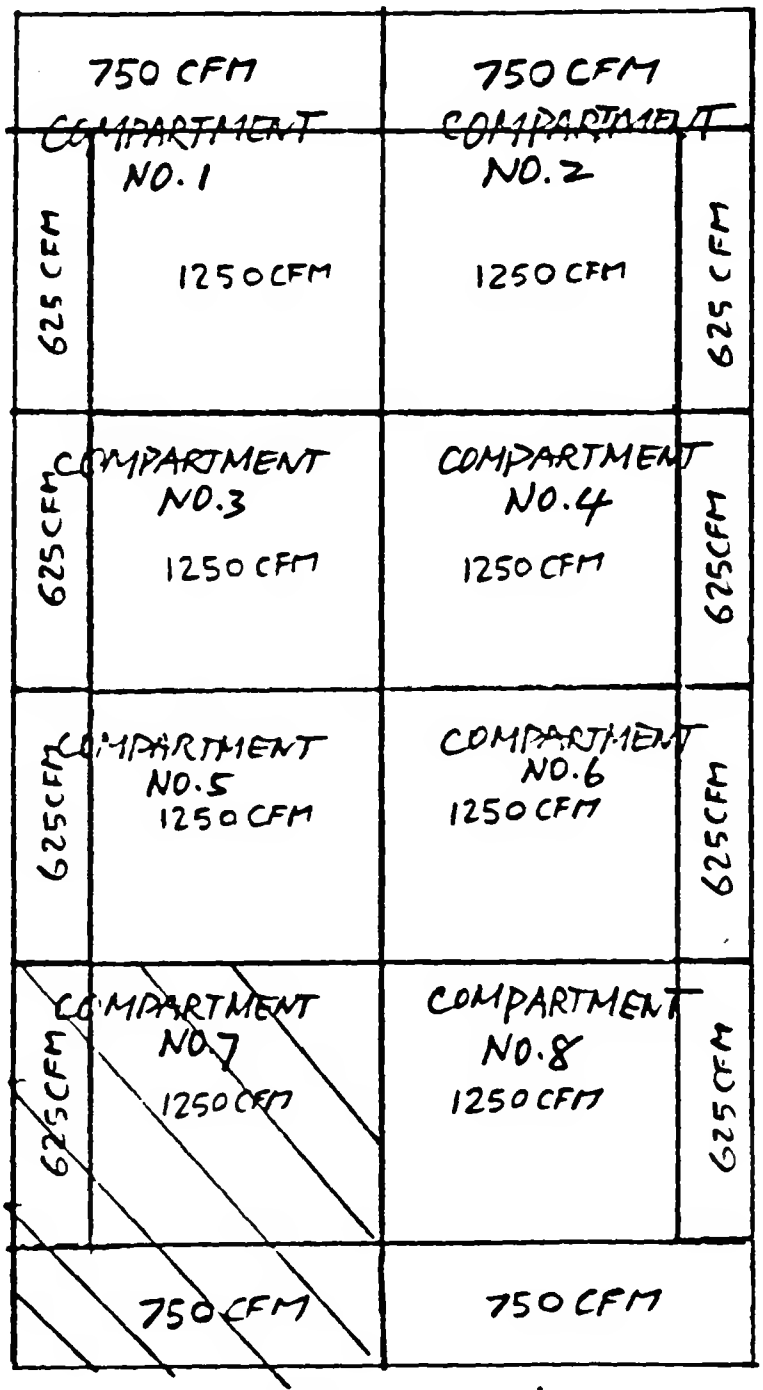
7) The individual exhaust system per compartment must be provided with a damper control located outside the radiation region.

8) The canister must be elevated at least 2 feet above the perforated plate.

9) The compartment's wall must go all the way to the ceiling.

10) The ceiling slab must be elevated at least 5 feet above the canister.

N. Razfar



SKETCH No. 1

LAG STORAGE VAULT AIR DISTRIBUTION

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC #505

To Those Listed

Date May 10, 1985

From A. D. Wilcox

Phone 3790

Location EA-4F-216

SUBJECT Job 6440 - Monitored Retrievable Facility
Task 2B, Gamma Radiation Heating in Lag Storage Pit Wells

The gamma heat deposition rate in the lag storage pit walls has been calculated with the results as shown in Figure 1. The calculations were done with the QAD P5A radiation analysis program. The canister was modeled with the source from 3 PWR spent fuel assemblies with 55,000 MWD/MTU burnup and 10 years decay.

These heating rates will be used in the thermal analysis of the lag storage pit.

A. D. Wilcox

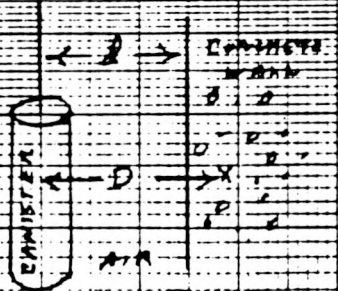
ADW:lb

Distribution

J. T. Ang
A. C. Foung
S. T. Huang
D. L. Gross
A. K. Jowdy
C. H. Keehn
J. Leloudis
N. Razfar
J. Chang
S. Y. Mayet
J. A. Roll
W. L. Santo
W. D. Woods
T. Crump

FIG. 1 GAMMA HEATING RATE IN CONCRETE WALL

NOTES: 1. SINGLE CANISTER
2. RODS FROM 3PWR ASSYS,
3. 55,000 MWD/MTU BURNUP
10 YEARS DEC 74

d = 1' 1.5' 2' 2.5' 3' 3.5' 4' 4.5' 5' 5.5' 6'

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC #520

To J. A. Roll/WEC Date May 15, 1985

From J. T. Ang/RMP Phone 7095 Location EA-439

SUBJECT Job No. 6440 - Monitored Retrievable Storage Facility
In-Cell Lag Storage Heat Load

With an assumption that the subject heat load may be increased from the present 30 KW to as high as 101 KW, the questions from WEC are:

1. Based on the design now in progress, what is the maximum possible air flow rate we can provide for each of the four shielded process cells?

2. What is the maximum heat load the room can tolerate at maximum air flow without exceeding FDC temperature limitation?

3. What is the allowable hot gas discharge temperature from natural convection of the in-cell lag storage pit?

The following tabulation provides answers to the first two questions. The last question may require thermodynamic and heat transfer analysis which I cannot provide.

Attached for your information is a sketch showing the air flow pattern and the floor space required for the in-cell HEPA filters.

J. T. Ang

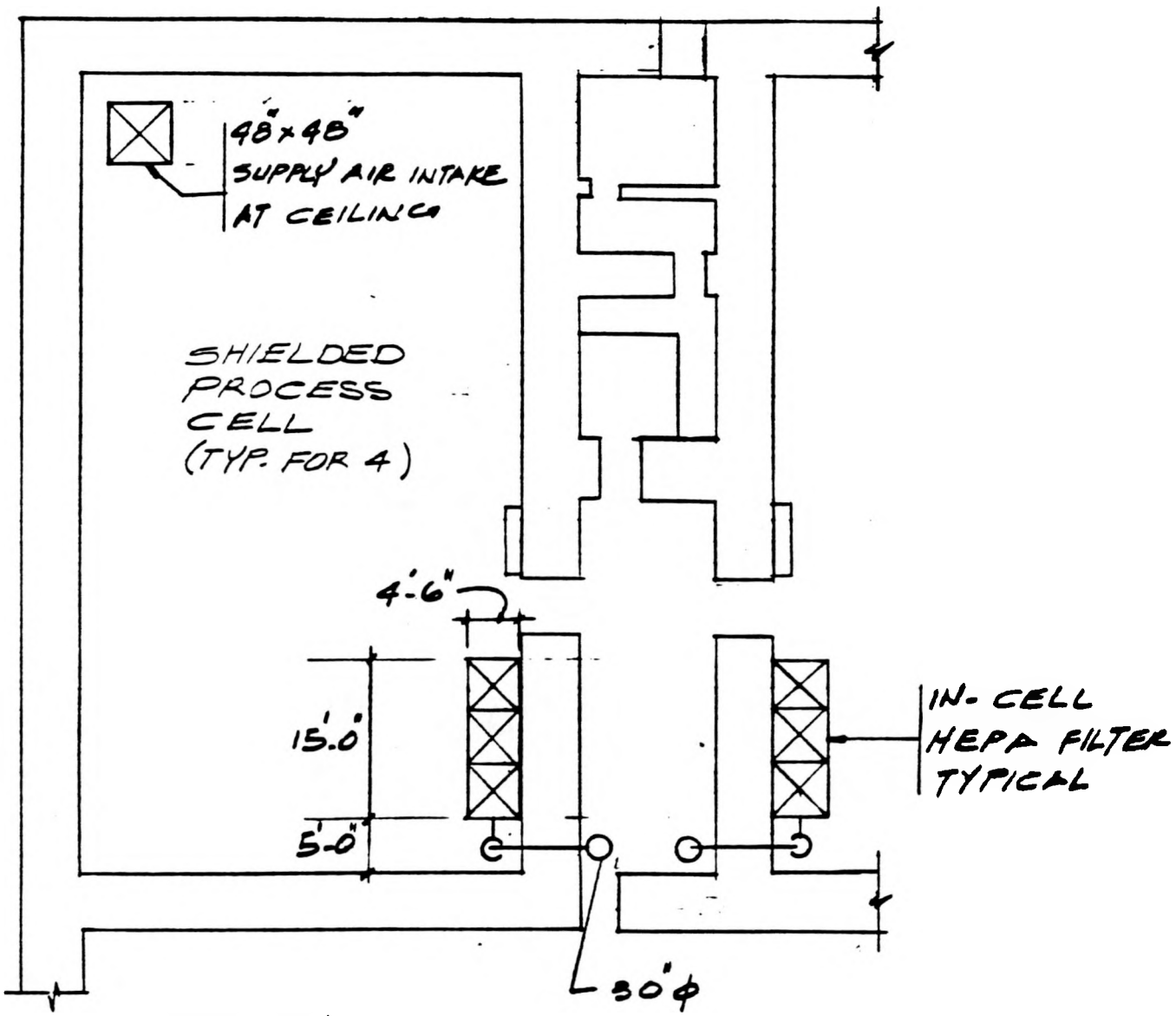
JTA:lb
Attachment

CC: A. K. Jowdy
W. D. Woods
C. H. Keehn

	Design in Progress	Design with Increased Lag Storage	Design with Max. Lag Storage
Lighting & Equipment	47 KW	47 KW	47 KW
Lag Storage	30 KW	48 KW	101 KW
Air Flow Rate (ACFM)	9,730	12,000	12,000
Incoming Air Temperature	80°F	80°F	80°F
Cell Temp. (Normal Operation)	105°F*	105°F*	120°F*
Max. Cell Temp. (upset condition)	120°F	120°F	Will exceed 120°F during summer

Upset Condition: Loss of commerical power,
Loss of mechanical cooling and/or supply fans

* Assuming good bulk cell air mixing



PLAN
TYPICAL

INTEROFFICE CORRESPONDENCE IOC-697

To Those Listed Date September 23, 198

From A. D. Wilcox Phone 3888 Location EA-4F-137

SUBJECT Job 6440 - MRS Facilities Canisters
Lag Storage Vault Temperatures

Reference: (1) WAES-TME-2999, "Experimental Demonstration Package Program Drop Test Final Report" by G. E. Driesen and L. I. Steiner, Westinghouse Electric Corporation, Pittsburgh, PA, March 1980

(2) RHO-C-54, "Effects of Long-term Exposure to Elevated Temperatures on the Mechanical Properties of Hanford Concrete" Construction Technology Laboratories, Portland Cement Association, October 1981

The MRS building is designed with lag storage for 1,000 MTU (metric tons of initial uranium) of spent fuel in canisters. The canisters are made of 12 inch stainless steel pipe. They are manufactured 16 feet long with a welded end cap in place. After the canister is loaded with the consolidated fuel rods, the remaining air in the canister is replaced with argon gas and the closure end cap is welded in place to seal the canister. This weld is then tested and the canister is decontaminated.

The canistered fuel lag storage area, shown in plan view in Figure 1, consists of six vaults. Each vault is divided into six compartments with one exception as shown in Figure 1. Each compartment has storage space for sixteen canisters, again with one exception as shown in Figure 1. An elevation view through two compartments is shown in Figure 2.

The lag storage area is maintained at a negative air pressure with respect to the atmosphere for contamination control purposes. The chance of any contamination in the lag storage area is very small because it would involve breached canisters. In addition to the weld leak tests described above, prototype canisters have been drop tested successfully by Westinghouse, Ref (1).

The negative air pressure and the canister cooling air flow are maintained by drawing the air out of the lag storage area. This is done with exhaust fans powered by two 123 horsepower motors with a third unit on standby in case an operating unit fails. The motors are supplied by dual-normal power feeds with standby generator(s) and the dedicated lag storage standby power supply. Thus it would take four failures to interrupt the vault cooling air flow.

The decay heat generated in the consolidated spent fuel canisters is 1,650 watts for the fuel rods from three PWR assemblies or 1,250 watts for rods from seven BWR assemblies. This heat is removed by an air flow rate of 1,250 cfm per compartment provided by the HVAC system.

The thermal analysis of the canisters in the lag storage assumed the worst case conditions with all canisters being filled with PWR fuel and generating 1,650 watts of decay heat. It was also assumed that the incoming air temperature was 100°F. Under these conditions, the peak canister surface temperature was calculated as 310°F while the peak vault wall concrete temperature was calculated as 157°F and the maximum temperature of the concrete vault cover was calculated as 172°F.

The loss of the cooling air flow to the canister lag storage is a very low probability event because it would involve four independent equipment failures to interrupt the power supply. The power supplies and the exhaust fans and motors are readily accessible for repairs or replacement with no radiation or radioactive contamination problems.

Even though it is a low probability event, the rate of temperature increase in the canister and for the vault concrete walls and the vault cover concrete were calculated for loss of cooling air flow. The maximum temperatures are shown in Figure 3 as a function of time. This analysis assumes an inner compartment surrounded by other compartments, as shown in Figure 1, with the heat flow upward through the compartment cover into the canyon cell air. The analysis is based on heating the canister and its payload; the vault cover concrete and iron plug masses; and the air in the canyon cell associated with one compartment.

As shown in Figure 3, it will take about 45 hours for the maximum canister surface temperature to reach 545°F (375°C pin temperature) and about 136 hours to reach 1,000°F. The corresponding maximum concrete temperatures at 45 hours are 420°F for the vault wall concrete and 440°F for the vault cover concrete. At 136 hours, the maximum vault wall concrete temperature would be about 840°F with the vault cover concrete temperature of about 860°F. The basic assumption is that there is a constant temperature difference between the canister and the compartment surfaces as the temperatures rise.

The 545°F canister surface temperature has been associated with a peak fuel pin temperature of 375°C. The fuel pins can be maintained at this temperature indefinitely without sustaining damage to the fuel pellets or to the pin cladding. The structural concrete will retain its strength at these concrete temperatures for a number of years, Ref (2).

The 1,000°F temperature represents an extreme condition. It is well below the melting point of the fuel pin cladding and of the fuel pellet material, UO_2, as well as of the canister stainless steel. The canister will retain its integrity at this temperature and continue to contain the fuel pins and any associated contamination. Fuel pin damage is a function of the time at temperature and will not be a problem for short time heating excursions. The concrete would retain its structural strength during such a temperature excursion. Tests have shown that concrete retains 80% of its structural strength after several years at these temperatures.

A. D. Wilcox

ADW:fw
Attachments
Distribution:

A. K. Jowdy	J. T. Ang
C. H. Keehn	A. C. Foung
W. L. Santo	S. T. Huang
W. D. Woods	H. W. de Angelis

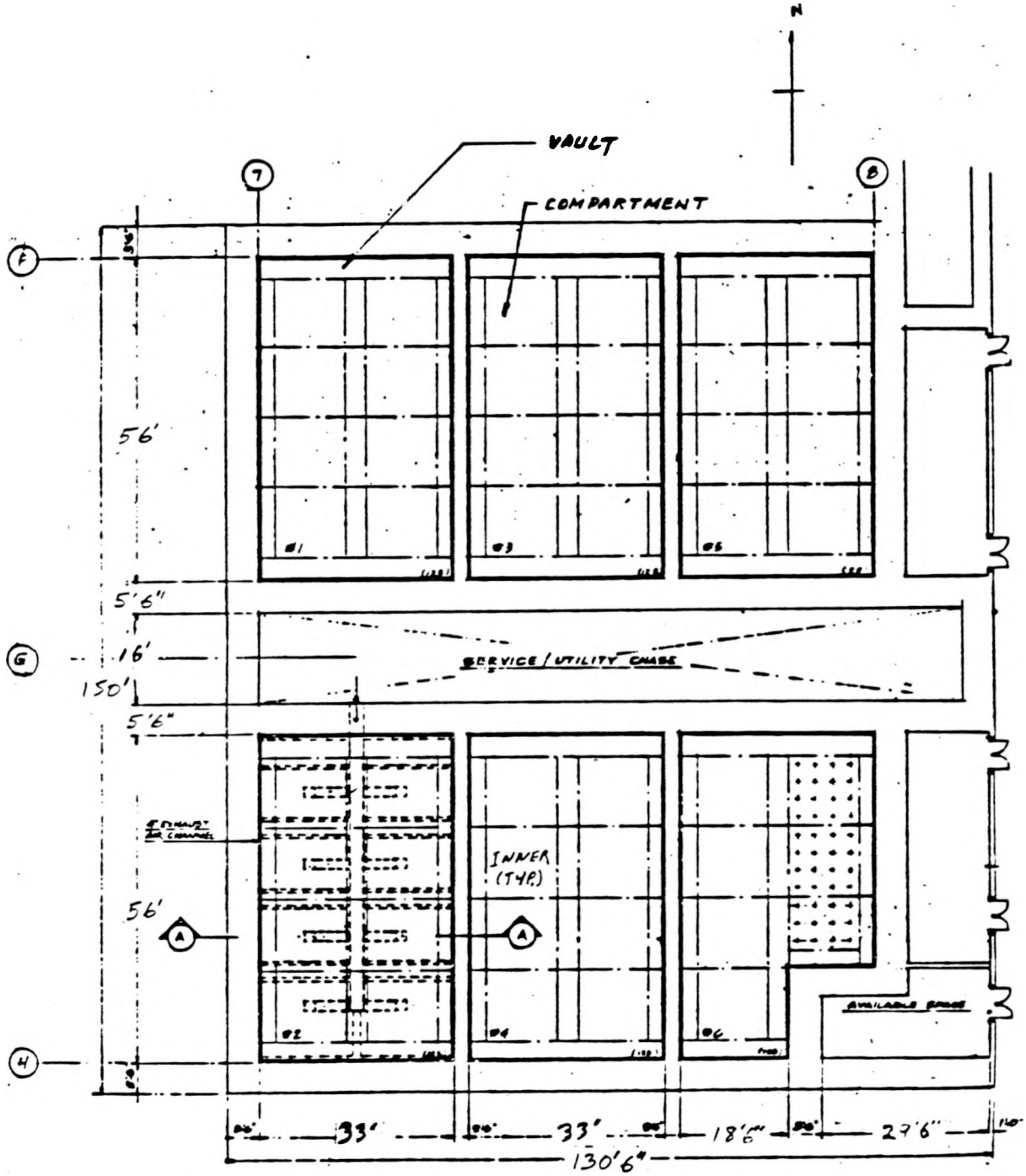


FIG 1 LAG STORAGE

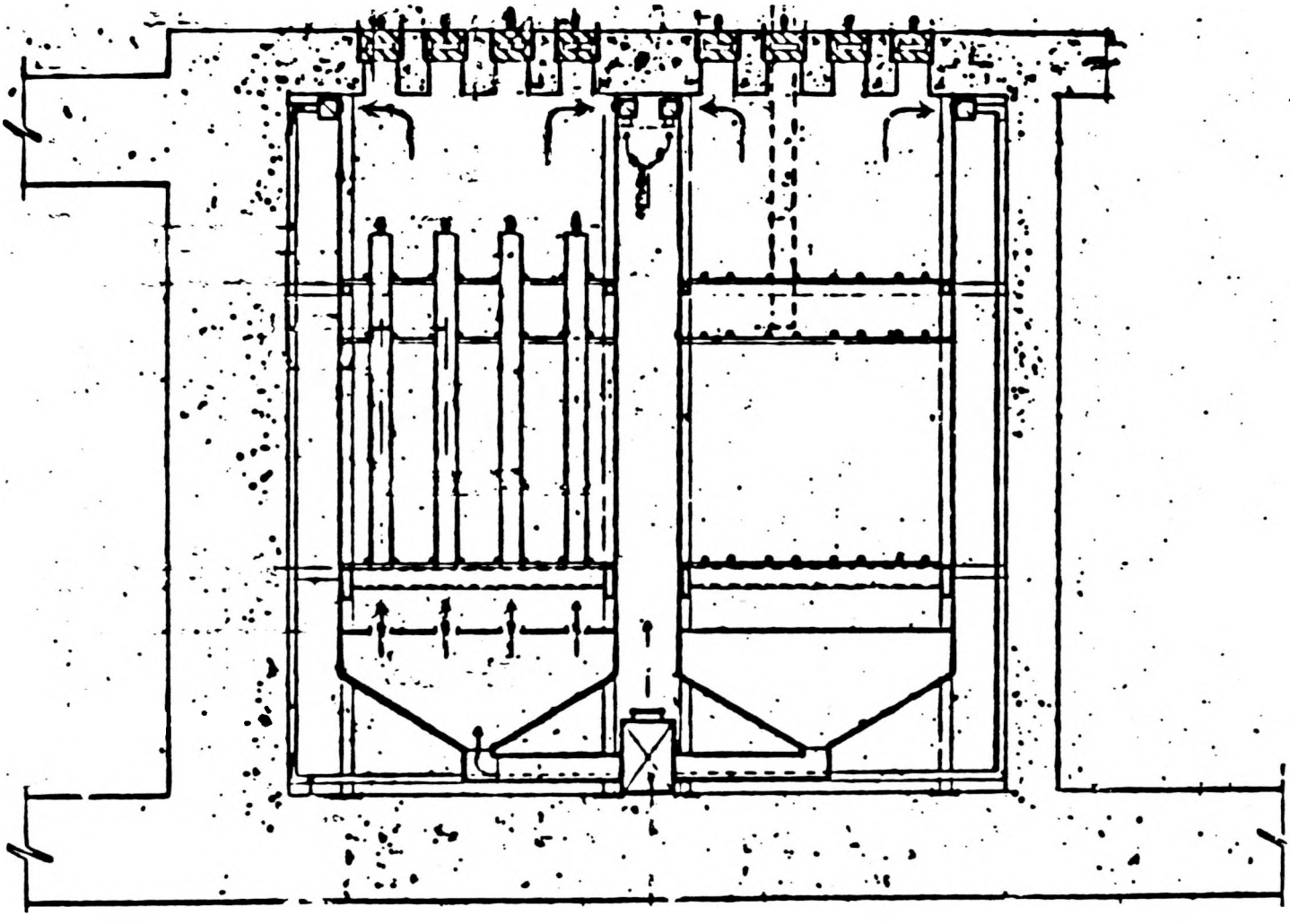
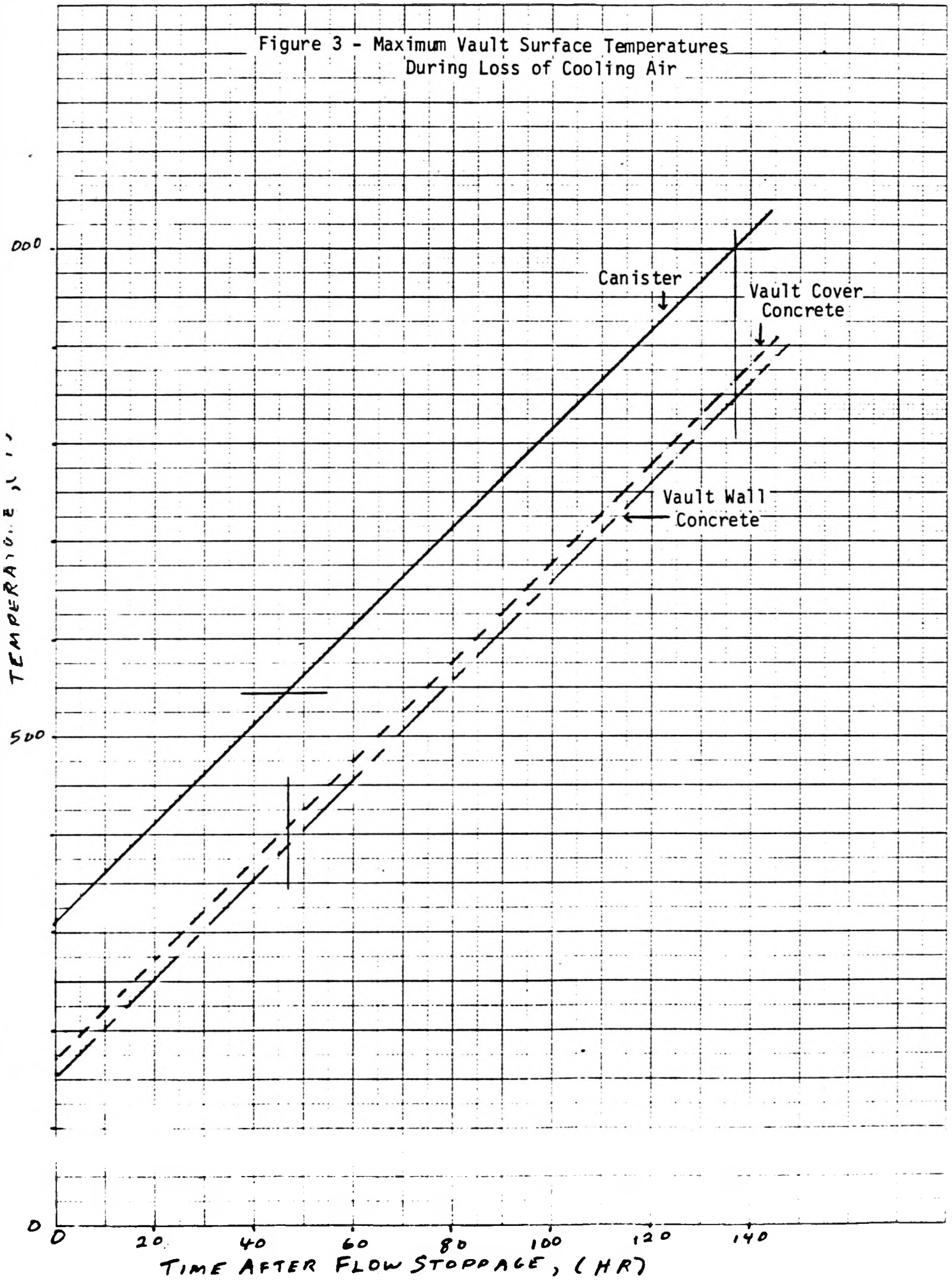


Figure 2 - Lag Storage Section

Figure 3 - Maximum Vault Surface Temperatures
During Loss of Cooling Air



THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE IOC-703

To W. D. Woods Date October 18, 1985

From J. T. Ang/J. E. Zeile Phone 7095 Location EA-439

SUBJECT Job 6440 - Monitored Retrievable Storage Facility
R&H Building; Investigation of In-Cell Lag Storage
Pit Cooling and Concrete Temperatures

Attached is a copy of our investigation for in-cell lag storage pit cooling and concrete temperatures.

J. T. Ang

J. E. Zeile

JTA:fw
Attachment: as noted

cc: A. K. Jowdy
C. H. Keehn
H. W. de Angelis

INVESTIGATION OF IN-PROCESS LAG STORAGE PIT COOLING AND CONCRETE TEMPERATURES

I. SCOPE OF INVESTIGATION

Three general questions have been addressed in this investigation:

(1) Is it feasible to cool the specified fuel rods by natural convection in a pit below each hot cell, with assurance that the 220°C (428°F) maximum cladding temperature will not be exceeded?

(2) If supply air to the hot cell is interrupted, how long will it take to exceed the specified fuel rod cladding surface temperature limits? Based on an assumed pinhole leak, the allowable times are 600 hours at 220°C (428°F), 100 hours at 250°C (482°F), and shorter durations at specified higher temperatures.

(3) What is the temperature of the concrete surrounding the pit?

The second question has been divided into three parts:

(2a) Loss of cooling capability with no interruption of supply or exhaust air flow.

(2b) Loss of normal power, which would mean loss of cooling and loss of the supply fans, but the exhaust fans would continue to operate on standby power. Most of the electrical loads would be off because they are served by normal power.

(2c) "Safe shutdown" with the building isolated and only the fuel rods continuing to generate heat.

II. ASSUMPTIONS

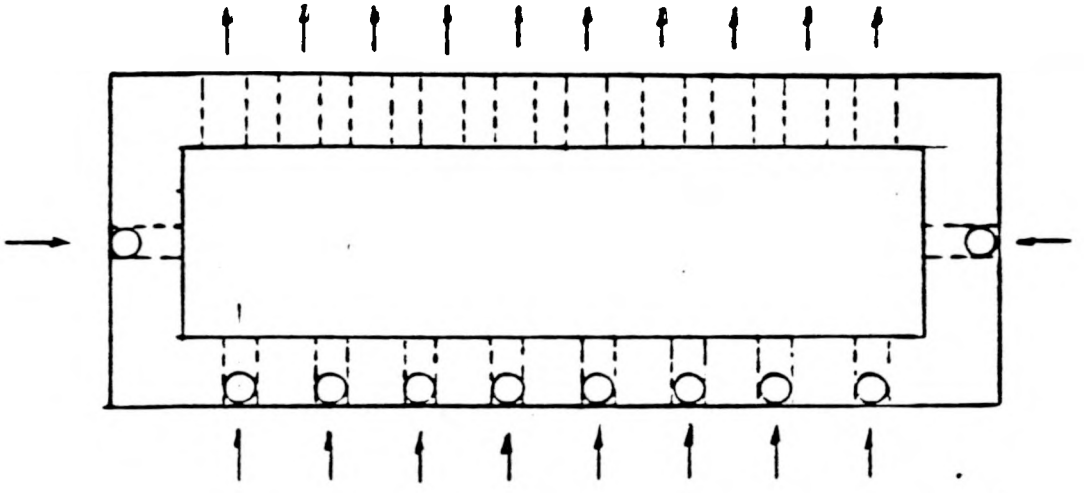
(1) The physical configuration shown on the Parsons conceptual design drawings (configuration #1) has been assumed. A modified configuration with more air intake pipes and an open screened air exhaust duct has also been evaluated (configuration #2).

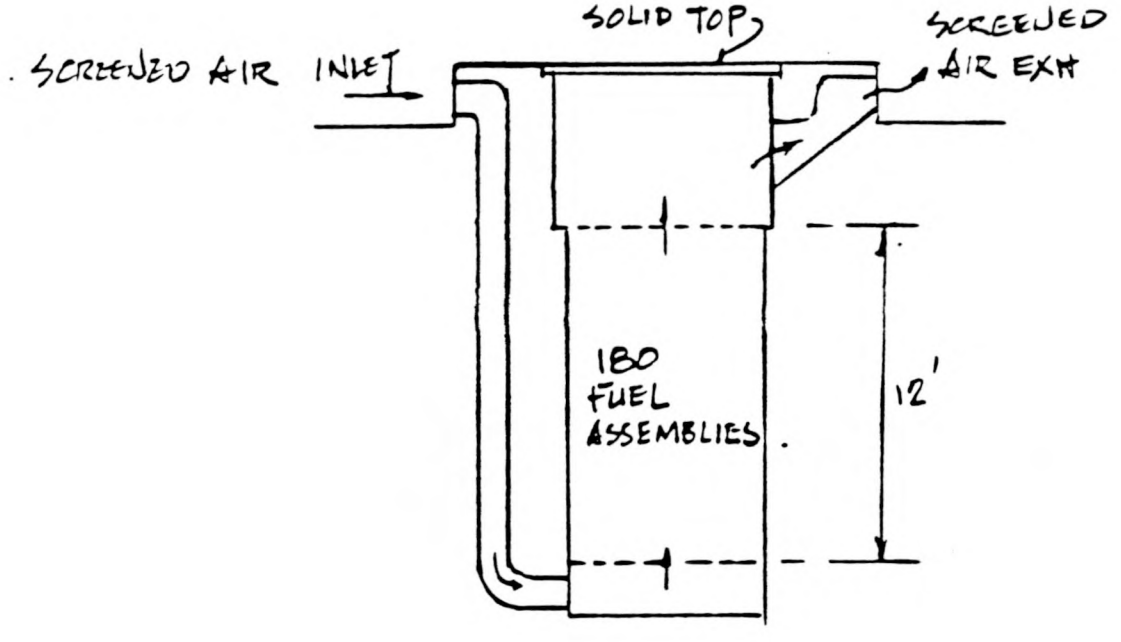
(2) The heat dissipation in each hot cell pit has been taken to be 99 kW from 180 PWR assemblies. (A mixture of PWR and BWR assemblies would have a somewhat lower total heat dissipation.)

REV	CHECKER	DATE	REV	CHECKER	DATE	REV	CHECKER	DATE

ASSUMED AIR INLET AND EXH CONFIGURATION #1

10- INLET WITH VARIOUS PIPE SIZES
10- EXH OUTLETS WITH VARIOUS SIZES





TITLE NATURAL CONVECTION COOLING SHEET NO. ____ OF ____

JOB NO. 6440-31 DEPARTMENT MECH UTILITY AUTHOR AWG DATE 9/17/85

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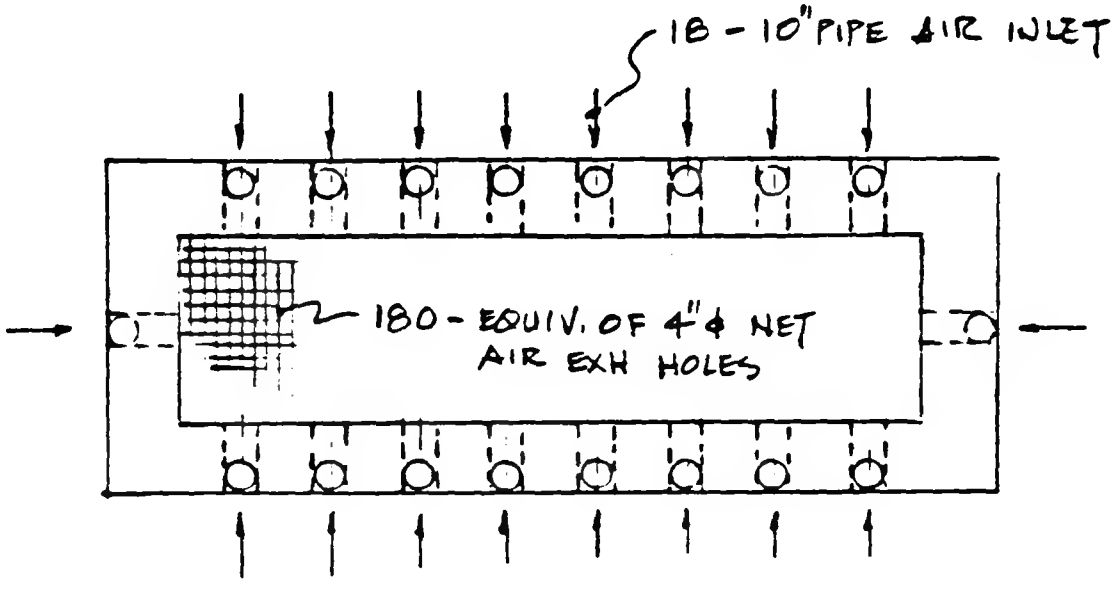
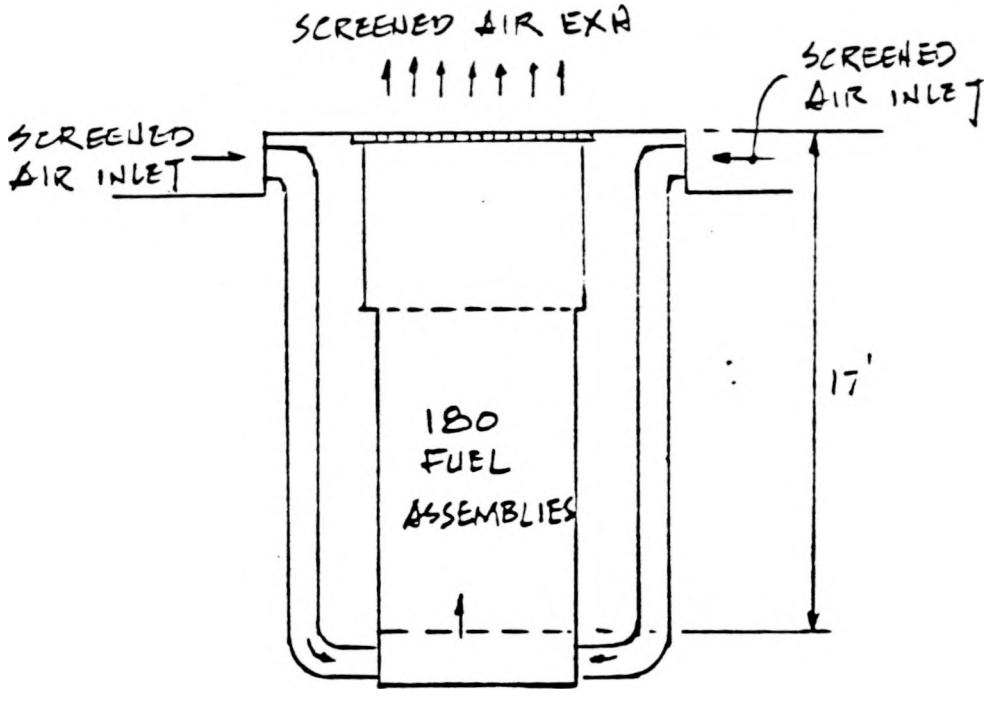
ASSUMED OPEN TOP CONFIGURATION #2





III. METHODS OF ANALYSIS

A. Maximum Fuel Rod Cladding Temperatures

The natural convection heat transfer at the surface of the fuel rods has been calculated by computing the balance between the buoyant forces and the air flow resistance, for assumed air inlet temperatures (hot cell room temperatures). The natural convection air flow rate then determines the maximum cladding surface temperature at the top of the fuel rods. The calculations have been programmed for solution by an Apple III computer.

B. Concrete Temperatures

The calculations have established that the exhaust air temperature is five degrees F lower than the cladding surface temperature for this geometry and heat flux rate.

A first approximation for the concrete surface temperature surrounding the pit is the cooling air temperature, which increases linearly with vertical distance from a normal (maximum) cell air temperature of 125°F to 423°F maximum at the top of the fuel rods.

In principle, the interior of the concrete will be hotter than the surface temperature because of nuclear gamma radiation that is absorbed by the concrete. The radiation entering and leaving each one-inch or two-inch thick slab of concrete has been calculated assuming an exponential absorption rate and a linear attenuation coefficient based on mass. The distance between each slab and the surface determines the thermal resistance and, therefore, the temperature rise required to drive the heat out to the surface. Summing the incremental temperature rises gives the total temperature difference above the surface. A convection film resistance must also be added to the cooling air temperature.

C. Loss of Cooling Capability

If cooling is lost and all other conditions remain unchanged, outside air will be drawn into the various other areas of the facility. It will be heated by the normal heat dissipation loads, blended, and then supplied to the hot cells. The supply air temperature will increase with higher outside air temperature, but the flywheel effect of the building mass will temper the outside air fluctuations by a few degrees. The hot cell temperature is calculated from the maximum supply air temperature, the hot cell load, and the supply air flow rate.

D. Loss of Normal Power

This calculation is similar to the one for loss of cooling, except that the normal heat dissipation loads will be off and the air flow will be reduced because only the exhaust fans will be operating on standby power.

E. "Safe Shutdown" Case

In the event of a safe shutdown, which can occur due to a DBE, DBT, criticality, or offsite emergency, there is no forced air supply to the hot cells. The only load is the 99 kW heat dissipation assumed for the fuel rod assemblies.

Since the natural convection air flow leaving the pit will be very hot, in the neighborhood of 400°F, it will rise to the top of the hot cell and stratify. Even with mixing, the air at the top of the cell will be at least 100°F hotter than the initial concrete roof temperature.

The capability of the concrete roof to absorb the 99 kW of liberated heat has been calculated vs. time for an assumed 100°F hotter air temperature, using the Schmidt graphical method. (The results can be scaled to any other desired initial temperature difference.) Temperature profiles inside the roof concrete have been plotted up to 48 hours. It should be noted that the back of the 5-1/2-foot thick concrete roof will experience very little temperature change, even after 48 hours.

In addition to the underside of the roof, the concrete wall surfaces at the top of each hot cell will absorb some of the heat.

IV. CALCULATION RESULTS

A. Maximum Fuel Rod Cladding Temperatures

Based on configuration #1 with a solid pit cover and separate air inlet and exhaust ducts, the calculations give temperatures above the 220°C (428°F) required maximum.

Based on configuration #2 with lower air flow resistance, the calculations show that the natural convection pit cooling concept is feasible. The system can be designed so that the 220°C maximum cladding surface temperature will not be exceeded with configuration #2.

B. Concrete Temperatures

Based on the worst case of just meeting the 220°C (428°F) maximum cladding surface temperature, the maximum cooling air temperature would be 423°F at the top of the fuel rods. The cooling air temperature would increase linearly from the cell air temperature at the bottom of the fuel rods to 423°F at the top.

Neglecting nuclear gamma radiaiton heating, the concrete surface temperature would equal the cooling air temperature. The concrete would have a maximum temperature of 423°F above the top of the fuel rods.

In principle, gamma radiation absorbed by the concrete will raise the interior temperatures because this heat must be removed at the concrete surfaces. However, in this case, the radiation entering the concrete only amounts to approximately 2.0 BTU per hour per square foot of surface. The

calculations show less than one degree F temperature rise in the concrete due to gamma radiation. There would also be a 2°F temperature gradient in the surface convection film. In this application, the gamma radiation heating of the concrete is neglible.

The normal maximum concrete temperature in the pit is therefore approximately 425°F, above the top of the fuel rods. During loss of cooling or loss of normal power, it would be approximately 440°F.

C. Loss of Cooling Capability

The hot cell temperatures are calculated to reach 135°F to 140°F on a hot day upon loss of cooling. The lower temperature is for the condition with lights and equipment off, which should be the procedure during maximum outside temperatures. The maximum cladding temperature would then be approximately 438°F, within the specified 250°C (482°F) limit for 100 hours. The allowable duration at 438°F would be in excess of 300 hours.

D. Loss of Normal Power

The maximum cell temperatures during loss of normal power are approximately the same as during loss of cooling. The maximum cladding temperature would also be approximately 438°F and the allowable duration would be in excess of 300 hours.

E. "Safe Shutdown" Case

The calculations indicate that the 99 kW of nucelar decay heat will be carried to the top of the hot cell by the hot coolant air exhaust. The concrete roof and upper walls of the cell will absorb all of the heat, but the rate of absorption will diminish with time. Calculations carried out to 48 hours show that all of the heat would still be absorbed up to that time. Therefore, at least 48 hours would be available without exceeding the allowable cladding temperature limit of 250°C (482°F) for 100 hours.

V. CONCLUSIONS

- Based on the open configuration #2, the natural convection pit cooling system is feasible and can be designed so that the 220°C maximum cladding surface temperature will not normally be exceeded.

- The normal maximum concrete temperature in the pit is approximately 425°F. It will occur above the top of the fuel rods at the in-process lag storage pit.

- During loss of cooling or loss of normal power, the maximum concrete temperature in the pit would be approximately 440°F.

- The hot cell temperatures could reach 135°F to 145°F on a hot day upon loss of cooling. Load shedding is recommended under these conditions during high outside temperatures.

- The maximum cladding temperature of approximately 438°F would then have an allowable duration in excess of 300 hours for loss of cooling conditions.

- Loss of normal power conditions are essentially the same as for loss of cooling.

- Under "safe shutdown" conditions, at least 48 hours will be available without exceeding the allowable cladding temperature limits.

FOREWORD

This Breathing Air Systems Evaluation is a design optimization that will be incorporated into the definitive design.

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DESIGN STUDY DS-22

BREATHING AIR SYSTEMS EVALUATION

1.0 INTRODUCTION

"A Review of Breathing Air Provisions Applicable to the Monitored Retrievable Storage Facility," prepared by the Radiological Sciences Department of Pacific Northwest Laboratories, is used as the basis for development of much of the information contained in this design study.

The design criteria for normal operation of the MRS Facility provide engineered systems and detection devices to maintain the concentration of airborne radioactive materials at normally less than the concentrations requiring respiratory protective devices. Exceptions are Ventilation Zone 1 areas. These highly contaminated and restricted access zones include shielded process cells, remote-handled maintenance equipment rooms, and high-activity radwaste cells.

For most conditions and activities, fullface air-purifying respirators, with a protection factor of 50, will provide adequate personnel protection.

Abnormal conditions and/or accidents, however, may generate concentrations of airborne contamination requiring respiratory protection. In addition, some decontamination and maintenance activities may be necessary on an infrequent basis, and these may require the wearing of respiratory protective devices.

The design criteria for the MRS Facility also require that breathing air will be provided to all areas where life-support equipment will be required.

This report is the result of a study conducted to review the options available to provide the breathing air supply and to select a system or systems suitable for the MRS Facility.

2.0 REQUIREMENTS

2.1 REGULATORY REQUIREMENTS

The regulatory requirements for breathing air systems are basically identical for DOE controlled and operated facilities and for NRC licensed facilities. DOE Orders 5480.1A and 5480.4 specifically identify Title 29 CFR 1910 and ANSI Z88.2 for mandatory compliance by the DOE.

NRC licensed facilities are required to comply with federal regulations, Title 10 CFR 20 and Title 29 CFR 1910. Title 29 CFR 1910 specifically references ANSI Z88.2 for respiratory protection.

Consequently, the basic requirements for breathing air systems and respiratory protection are compatible within both DOE and NRC controlled facilities.

2.2 EMERGENCY REQUIREMENTS

The entry of emergency personnel into unknown atmospheres or atmospheres described as "Immediately Dangerous to Life or Health" (IDLH) requires the use of respiratory protective devices that comply with federal regulations, Title 10 CFR 20, Title 29 CFR 1910, and NUREG-0041. Title 29 CFR 1910 specifically references ANSI Z88.2 for respiratory protection.

2.3 RESPIRATORY PROTECTION

A respiratory protection device, at a minimum, is required to meet the following:

- Provides sufficient air supply to permit reasonable wearing time.
- Shall not unduly interfere with the movements of the wearer.
- Allows reasonable mobility to the wearer under emergency and accident conditions.
- Does not present unnecessary hazards to the wearer.
- Is readily donned and removable.
- Is reasonably comfortable to the wearer.
- Meets the requirements of 10 CFR 20.103(c)(2).
- Approved for use in IDLH and unknown atmospheres by NIOSH/MSHA certification.

Two general types of respiratory protective devices are approved for use in IDLH atmospheres:

(1) The self-contained breathing apparatus (SCBA) pressure demand, open circuit, or positive-pressure-type, closed-circuit respirator.

(2) An air-line, continuous-flow or pressure-demand type, with facepiece, helmet, hood, or suit with escape provisions. The escape provisions shall be an auxiliary, self-contained supply of breathing air.

Air-line respirators that operate in the demand mode have negative air pressure inside the respiratory-inlet covering during inhalation that allows the contaminated atmosphere to leak into the respiratory-inlet covering if it does not fit perfectly.

The demand-mode type is, therefore, not considered to be adequate protection.

Air-line respirators that operate in the continuous-flow or pressure-demand mode always have positive air pressure inside the respiratory-inlet covering that prevents the contaminated atmosphere from leaking in. Thus, an air-line respirator operating in the continuous-flow or pressure-demand mode provides better protection.

Approval tests for respiratory protective devices are in 30 CFR 11, Subpart H.

Additional factors to be considered in selecting the respiratory protective device include:

- Cost.
- Maintenance, repair and recertification requirements.
- Level of inspection and training of the wearer necessary for safe and efficient use.
- Adaptability for use during normal operating conditions and/or emergency and accident conditions.

3.0 ASSUMPTIONS

It is assumed that a maximum of six persons will require breathing air at three separate locations simultaneously within the plant while performing decontamination and/or maintenance duties. This will require connections for 18 respirators, which, at 5-scfm normal use rate, require 90 cfm.

It is assumed that, for a major accident cleanup or decommissioning, additional equipment will be made available, if required, to perform that operation.

It is assumed that the initial entry into a suspect or known contaminated area will be made by a health physicist, wearing an SCBA of the pressure-demand, open-circuit type that provides very good protection.

The health physicist is allowed comparatively free movement with this device, being independent of any other breathing air source, to monitor the area and select the procedures required to administer the protection program, based on the hazard evaluation, to be used by personnel during decontamination of the area and/or maintenance of the equipment in the area.

It is assumed that separate, dedicated SCBA pressure-demand, open-circuit-type equipment will be made available at all entry points to suspect or known contaminated areas. This equipment will be immediately available to support personnel for emergency use in case of rescue or accident situations.

4.0 SYSTEM DESCRIPTIONS

The following options have been considered for the MRS Facility life-support breathing air system:

(1) A permanently installed, hard-piped, breathing air system.

(2) A supply of SCBAs.

(3) A semiportable supplied air system:

(a) Compressed breathing air cylinders on a hand cart.
(b) Hand power blower.
(c) Electric-powered portable breathing air pump (compressor).
(d) Air-powered portable air breathing pump (compressor).

(4) A combination of permanently installed manifolds and a semiportable supplied air system.

4.1 STANDARD REQUIREMENTS

Although each of the above options permits variations in installation location, types of devices and/or fittings, and system pressures, there are several common requirements:

(1) The masks, hoods, suits, hoses, fittings, and most component parts must be approved by NIOSH/MSHA in compliance with 30 CFR 11.

(2) The breathing air supply must meet or exceed the requirements of the specification for Grade D breathing air as described in CGA Commodity Specification G7.1.

(3) Compressors for supplying breathing air must be equipped with necessary safety and standby devices. These include high-temperature alarms, carbon monoxide monitor and alarm, an alarm to indicate compressor failure, in-line air purifying sorbent beds and filters to ensure breathing air quality, and an air receiver. Alarms shall be local in the vicinity of the respirator user.

(4) Compressed air cylinders must be tested and maintained as prescribed in the Shipping Container Specification Regulations of DOT 49 CFR 178.

(5) Hose coupling and manifold fittings for breathing air must not be compatible with those of manifold fittings for plant or instrument air, gas supplies, or the liquid supply system.

4.2 DESIGN REQUIREMENTS

The following design requirements are in accordance with HPS-156-M, Rev. 1:

(1) A compressor-supplied breathing air system shall be designed to provide a minimum flow rate of 4 to 6 cfm. The flow rate of 5 cfm is selected to be used.

(2) The design capacity for a permanently installed, hard-piped, breathing air system is the maximum number of outlets anticipated to be in use simultaneously times 15 scfm.

On the assumption that six persons will be using the breathing air at the same time, the capacity of the MRS Facility system is 90 scfm.

(3) A maximum length of 300 ft of 3/8-in.-ID air hose, recommended by 30 CFR, Part 11, made up from standard lengths (multiples of 25- or 50-ft lengths), should be used for design; an exception is that portable air supply compressors require a 1/2-in.-ID air hose with a maximum length of 50 ft, and this must be used for design.

4.3 OPTION 1 - A PERMANENTLY INSTALLED, HARD-PIPED, BREATHING AIR SYSTEM

A permanently installed, hard-piped, breathing air system consists of seven basic components: air compressor, air receiver, in-line air purifying equipment, air quality monitoring instrumentation, distribution piping, outlet manifolds, and personnel wearing devices that include masks and hoses (hoseline respirators).

The compressor for supplying breathing air shall be an independent, oil-free, breathing air type compressor. The compressor intake shall be located so as to avoid entry of contaminated air into the system.

Suitable in-line, air-purifying sorbent beds and filters should be installed to further ensure breathing air quality.

Air quality monitoring instrumentation should be provided to ensure that the breathing air supply and breathing air quality are maintained. A sensor and alarm should be installed to indicate compressor failure and alert the users to the loss of air supply. An instrument should be installed to indicate low oxygen level. An alarm should be installed that will alert the operators and/or respirator users when the carbon monoxide levels approach the limits allowable by ANSI Z86.1, CGA Specification G7.1, minimum Grade D, at a level that will allow users to escape the area before stopping the compressor.

The air from the compressor shall be tested frequently for carbon monoxide and other requirements to ensure that the air quality specifications are met.

To be usable in an atmosphere immediately hazardous to life, an air-line respirator must have an auxiliary air supply to protect against potential failure of the primary air supply. This is provided by adding a self-contained tank of high-pressure compressed air (SCBA) to the air-line respirator. The auxiliary air supply shall be approved for 15-minute service time. The self-contained part of the device is used only when the air-line part fails and the wearer must escape.

A hard-piped system network distributes the breathing air from the air receiver to the manifold at each use location. The piping shall be sized to provide adequate volume and pressure to support the number of users at each location.

The breathing air piping system shall not be cross-connected to other air or gaseous distribution piping. The breathing air piping should be color-coded and marked to minimize the potential for inadvertent cross connections. The breathing air piping should be kept internally clean; moisture-collection locations and dead-legs with moisture traps should be minimized to reduce odor buildup.

Outlet manifolds shall be fitted with couplings that are not compatible with couplings of other gas systems to prevent inadvertent servicing of on-line respirators with noncompatible gases or oxygen. Regulator and pressure gauges should be fitted at the manifold to ensure that the pressure to the respiratory protective device air line meets the requirements of the device. Outlet manifolds should be fitted with the number of quick-disconnect fittings determined by the expected workload. Manifolds should be located in the area of use and near the normal entryway to minimize potential damage to hoses in doorways and to facilitate access. Quick-disconnect couplings should be provided with removable coverings for protection from contamination when not in use.

The respiratory protective devices provided with fittings must be approved by NIOSH/MSHA. Several manufacturers can provide acceptable and approved devices. Acceptable devices for use with supplied air include full-face masks; special-purpose, full-face masks (e.g., for welding, cutting, and grinding); hoods; and suits. Several types of approved devices, including dual-purpose SCBA units, have independent air-supply bottles and controls that permit entry to an area using bottled air so that connection can be made to the breathing air outlet manifold and emergency escape in case of loss of air from the supplied air line.

4.3.1 Permanently Installed Breathing Air System

4.3.1.A. Advantages. This system can provide the body cooling required when personnel must be totally encased in impermeable outer clothing with full-facepiece respirators. It is not anticipated, however, that personnel will be required to wear impermeable clothing.

The air-line respirator provided with a self-contained tank of high-pressure compressed air (SCBA) for emergency escape, with possible increased service time, would permit the wearer to disconnect the air line temporarily while changing locations. The SCBA part should be classified for 15 min or longer service, and not more than 20% of the air supply rated capacity is used.

4.3.1.B. Limitations. The air-supply hose limits the respirator wearer to a fixed distance from the air-supply source at the manifold location. According to 30 CFR Part 11, the maximum permissible hose length is 300 ft.

The trailing air-supply hose of the air-line respirator restricts the wearer's mobility. This may make the air-line respirator unsuitable if the wearer must move frequently between widely separated work stations.

4.4 OPTION 2 - SELF-CONTAINED BREATHING APPARATUS

An SCBA unit consists of a 45-cu-ft tank of high-pressure (approximately 2,000-psi) compressed breathing air, with a harness that allows the tank to be carried on the back; it supplies breathing air to a two-stage regulator that reduces the pressure for delivery to the facepiece. The regulator also serves as a flow regulator by passing air to the facepiece only on demand. A flexible, corrugated hose connects the regulator to the respiratory-inlet covering, usually a full facepiece.

SCBA units are available in pressure-demand, open-circuit, or positive-pressure-type, closed-circuit systems.

The type of device generally used for emergency applications (such as fire-fighting, rescue, and entry into unknown concentrations for mitigation of accidents) is the SCBA, pressure-demand, open-circuit type.

The breathing air supply is a pressure tank with a 30- or 60-min supply of air, depending on the level of exertion of the wearer.

Tanks can be replaced during use to extend working time and can be refilled by using appropriate air-compressing systems.

Manufacturers of approved SCBA respiratory protective devices include:

Scott Aviation
USD Corporation (SurvivAir)
Mine Safety Appliances Company

Several models and styles are available from each of the manufacturers.

4.4.1 Self-Contained Breathing Apparatus - Open-Circuit, Pressure-Demand Type

4.4.1.A. Advantages. The SCBA units are immediately available for emergency and accident conditions. They can be specifically maintained and administratively controlled for emergency use only.

Pressure-demand SCBA units maintain positive pressure in the facepiece at all times; therefore, any leakage is outward, and the unit provides very good protection. Pressure-demand SCBA units should be used in firefighting.

Refilling stations can be shared with MRS Facility firefighting personnel and the R&H Building compressed breathing air cylinder system (if selected).

Because the SCBA wearer carries his own supply of respirable air, he is independent of the surrounding atmosphere. The wearer need not be connected to a stationary air supply; therefore, he has comparatively free movement over an unlimited area.

Pressure gauges, which indicate the quantity of air remaining in the cylinder, are visible to the wearer. Remaining service-life indicators or warning devices show when only 20 to 25% remains.

The apparatus can be stored in clean, noncontaminated areas, and strategically located throughout the facility.

SCBA units can be filled from either a compressed breathing air cylinder system or a high-pressure cylinder filling system consisting of a compressor, aftercooler, purification filters, air quality monitor, controls, and water bath-filling station.

4.4.1.B. Limitations. A 30-min air-supply SCBA system weighs approximately 23 lb. A 60-min air supply SCBA system weighs approximately 35 lb. The weight and bulk make them unsuitable for strenuous work or use in a very confined space.

The duration will be substantially reduced when strenuous work effort is performed.

The apparatus cannot provide the body cooling required when personnel must be totally encased in impermeable outer clothing with full-facepiece respirators.

The limited work time permitted before air bottles would require changeout makes them unsuitable to use for long continuous periods.

The especially short life of open-circuit-type devices may limit them to use where the wearer can go conveniently and quickly from a hazardous atmosphere to a safe atmosphere to change the tank of supply air.

The equipment must be returned to the distributor for test and/or repair after each 5-yr period to comply with DOT 49 CFR 178 and NIOSH.

Visual inspection should be made monthly in accordance with the distributor's recommendations. Inspection should be more frequent if the apparatus is used daily.

4.4.2 Self-Contained Breathing Apparatus - Open-Circuit, Demand Type

The demand-type SCBA unit is not considered adequate for the MRS Facility for the following reasons: negative pressure in the facepiece during inhalation opens the demand valve. The negative pressure would allow inward leakage; therefore, a demand-type, open-circuit SCBA should not be used in atmospheres immediately hazardous to life or health.

4.4.3 Self-Contained Breathing Apparatus - Closed-Circuit Type

The closed-circuit type SCBA unit is not considered adequate for the MRS Facility for the following reasons: it is a "rebreathing" device. The air is rebreathed after the exhaled carbon dioxide has been removed and the oxygen content restored by a compressed or liquid oxygen source or an oxygen-generating solid. An adequate supply of pure oxygen is not at present provided for in the MRS Facility to replenish the SCBA tanks.

The negative pressure in the facepiece during inhalation would allow inward leakage; therefore, this type of device should not be used in atmospheres immediately hazardous to life or health.

The complete apparatus is bulky and would interfere with the movements of the wearer.

4.5 OPTION 3 - A SEMIPORTABLE SUPPLIED BREATHING AIR SYSTEM

This option considers four possible systems:

(a) Compressed breathing air cylinders on a hand cart
(b) Hand-operated blower
(c) Electric-powered portable breathing air pump (compressor)
(d) Gas-powered (air) portable breathing air pump (compressor)

A semiportable supplied breathing air system consists of five basic components: compressed breathing air supply, regulators, instrumentation and filtration components, main distribution line, outlet manifold and respiratory device, including mask and air hose.

The air supply may be one or more compressed breathing air cylinders, a hand-operated blower, or a gas- or electric-powered air compressor. Each type of breathing air supply system is available from manufacturers, and can be moved on a portable carrier to locations where needed.

The positioning of the hand-operated blower and the air intake of the gas- or electric-powered compressors is critical to ensure that incoming air is not contaminated.

The regulators and instrumentation and filtration components will be determined by the air supply source.

Regulators are required to ensure that overpressurization of respiratory devices does not occur and that adequate air supply is provided (applicable to Options 3a, 3c, and 3d).

Instrumentation is required to alert personnel to compressor high temperature (applicable to Options 3c and 3d).

Instrumentation is required to alert personnel to impurities in the breathing air supply (applicable to Options 3c and 3d).

Instrumentation is required to alert personnel to loss of breathing air supply flow, (applicable to Options 3a, 3c, and 3d).

Filtration is required to ensure that breathing air quality is maintained (applicable to Options 3c and 3d).

Commercial systems (portable or fixed) that remove solid particles, liquid water, and oil; convert carbon monoxide; remove objectionable odors; and remove residual water vapor are available.

The main distribution line for a semiportable system can be a flexible hose, sized to provide the required volume and pressure of breathing air.

The outlet manifold consists of a portable case containing the connection for the main breathing air supply line, one or more quick disconnects for individual respiratory device air lines, a pressure gauge to verify air pressure to the respiratory device air lines, and an inline filter to remove any particulate material before delivery to the respiratory device air line. Quick-disconnect fittings must be incompatible with couplings of other gas systems to prevent inadvertent connection to other air or gas systems (applicable to Options 3a, 3c, and 3d).

The respiratory protective device and air line connected to the manifold must be approved by NIOSH/MSHA.

(a) A compressed breathing air cylinder system consists of one or more 300-cu-ft, compressed breathing air cylinder. Each cylinder can provide 3 to 5 hr of breathing air for one man depending on the air-consumption rate. Air cylinders are charged to 2,400 psi at 70°F. Cylinders can be connected in series for greater supply of air.

When high volume usage is required, portable cylinder cradles provide for orderly grouping and manifolding of cylinders in a neat, compact, safe, maneuverable unit. Normally, these cradles are available in two sizes, and accommodate 6 or 12 cylinders.

Regulator and pressure gauges should be fitted at the manifold to ensure that the pressure to the respiratory protective device air line meets the requirements of the device. A portable outlet manifold is used with this system.

(b) A hand-operated breathing air blower system consists of a manual handle-operated blower that pushes low-pressure air through the hose to the respiratory-inlet covering. The blower is designed so that air flows freely through it when the blower is not in operation. If the blower fails, the wearer can still inhale respirable air by normal breathing. A large-diameter hose supplies the air to the wearer.

The hose mask with the blower may have a facepiece, helmet, or hood. No instrumentation or filtration is provided. An outlet manifold is not required for this system.

(c) An electric-powered, portable, breathing air pump (compressor) system consists of an electric motor-driven, portable, oil-free air pump that can supply breathing air up to 15 cfm. A 1-hp electric motor operates on 115 Vac, 60 Hz, or 230 Vac, 60 Hz.

The complete assembly, air pump with motor and a 12-gal air receiver (ASME code), is mounted on a handtruck or cart.

A relief valve, intake filter, rubber-mounting feet, and grounding plug are also part of the assembly. Regulator and pressure gauges should be fitted at the manifold to ensure that the pressure to the respiratory protective device air line meets the requirements of the device.

Instrumentation and filtration components are required for carbon monoxide protection. A portable outlet manifold is used with this system. This system will supply a maximum of three persons using a maximum of 5 cfm each.

(d) A gas-powered, portable, breathing air pump (compressor) system consists of a gas (air), motor-driven, portable, oil-free air pump that can supply breathing air up to 15 cfm.

The air motor requires approximately 40 cfm of compressed plant air at 40 psig for the air pump to deliver 15 cfm of breathing air. The complete assembly, air pump with air motor and a 12-gal air receiver (ASME code), is mounted on a handtruck or cart.

A relief valve, intake filter, and rubber-mounting feet are also part of the assembly. Regulator and pressure gauges should be fitted at the manifold to ensure that the pressure to the respiratory protective device air line meets the requirements of the device.

Instrumentation and filtration components are required for carbon monoxide protection. A portable outlet manifold is used with this system. This system will supply a maximum of three persons using a maximum of 5 cfm each.

4.5.1 Advantages

Portable breathing air systems can be moved to locations where they are needed; therefore, they do not require an extensive piping distribution system.

A hand-operated blower does not require electrical or gas connections.

The hand-operated blower is designed so that air flows freely through it when the blower is not in operation. If the blower fails, therefore, the wearer can still inhale respirable air by normal breathing. No instrumentation is required. No outlet manifold is required.

A compressed breathing air system can share the refilling stations with the MRS Facility firefighting SCBA equipment and the R&H Building SCBA equipment.

A hard-piped distribution system would not have to be installed.

These systems would be available at an accident location where hard-piped systems could be unusable because of fire or damage.

Mobile, semiportable, breathing air supply systems would be available to support operations in areas not anticipated.

The compressed breathing air cylinders can be filled from a high-pressure cylinder filling system consisting of a compressor, aftercooler, purification filters, air quality monitor, and controls if a contractor/supplier is not conveniently available.

4.5.2 Limitations

Air intakes of portable breathing air pumps must be located in areas that will ensure that incoming air is not contaminated. The maximum hose length from the air-intake filter is 312 ft for these pumps.

A hand-operated blower system should not be used in an atmosphere immediately hazardous to life or health because air flow as low as 50 liters per minute (lpm) will result in negative air pressure during inhalation and allow contaminated atmosphere to leak into the respiratory-inlet covering. Also, if the air supply hose is cut or flattened, the wearer will be unprotected.

A hand-operated blower system pushes low-pressure air through the hose to the respiratory-inlet covering. The hose is required to be large diameter compared to the hose diameter for a compressed air supply; therefore, it is more restrictive to the wearer's mobility. A harness and attached lifeline are necessary for safety.

A hand-operated blower system is not fitted with filtration to monitor for carbon monoxide.

A hand-operated blower system will supply only one person.

An electric-powered breathing portable air pump (compressor) system will supply only a maximum of three persons using a maximum of 5 cfm each, with a maximum air-hose length of 50 ft (1/2 in. ID).

A gas (air)-powered portable breathing air pump (compressor) system will supply only a maximum of three persons using a maximum of 5 cfm each, with a maximum air-hose length of 50 ft (1/2 in. ID).

A gas (air)-powered portable breathing air pump (compressor) system must rely on plant air being available. Plant air compressor equipment is electric-motor-driven, but is on standby power.

4.6 OPTION 4 - A COMBINATION OF PERMANENTLY INSTALLED MANIFOLDS AND A SEMI-PORTABLE SUPPLIED BREATHING AIR SYSTEM

This option would provide the features of permanently installed manifolds at each location where life-support equipment will be required and a semi-portable breathing air source to connect to the manifold if breathing air is required.

The outlet manifolds would be in the same locations and configured similarly to these described in Section 4.2, Option 1. The air supply to the outlet manifold would be hard-piped through the wall of the area of potential need to the clean corridor outside. The connection in the clean corridor would be made to the selected semiportable, supplied breathing air system whenever respiratory protective devices were required.

The semiportable supplied breathing air system would be the same as the semiportable supplied breathing air system described in Section 4.4, Option 3.

(a) Compressed breathing air cylinders on a handcart
(c) Electric-powered portable breathing air pump (compressor)
(d) Gas-powered (air) portable breathing air pump (compressor)

4.6.1 Advantages

Permanently installed breathing air manifolds would be available at identified areas of potential need. This avoids the problem of running hoses through changerooms, air locks, and entryways.

Mobile, semiportable breathing air supply systems would be available to support operations in areas not anticipated.

4.6.2 Limitations

The limitations listed in Section 4.4.2 are applicable. In addition, the hand-operated breathing air blower system [Section 4.4(b)] should not be used because the distance from the breathing air source to the user would be excessive for the user's protection.

5.0 COSTS

5.1 OPTION 1 - A PERMANENTLY INSTALLED, HARD-PIPED, BREATHING AIR SYSTEM

Components:

- Breathing air compressors (2)
- Aftercooler (1)
- Breathing air purifier (1)
- Breathing air analysis system (1)
- Breathing air receiver (1)
- Pipe, valves, and fittings
- Portable breathing air stations (3), each capable of six connected respirators

Total cost for above components, including foundations and electrical work for a complete installation	$560,000
- Respirators (18), complete with full facepiece, emergency exit air supply, and harness for use with above system ($590 each)	10,620
Total	$570,620

5.2 OPTION 2 - SELF-CONTAINED BREATHING APPARATUS

- Thirty-minute-duration SCBA units (18), including respirators with full facepiece and harness ($1,200 each)	$ 21,600

It is assumed that, because of the short duration time, these would be used for initial entry into a suspected contaminated area for evaluation only, and would be available for emergency or accident rescue at the work locations. It is estimated that six units will be sufficient for these uses.

5.3 OPTION 3 - A SEMIPORTABLE SUPPLIED BREATHING AIR SYSTEM

5.3.1(a) Compressed Breathing Air Cylinders on Handcart

Components:

- Cradles to hold 12 cylinders (3 @ $250 each)	$ 750
- Manifolds for 12 cylinders (3 @ $260 each), each capable of six connected respirators	780
- Cylinders, 300 cu ft (36 @ $470 each)	16,920
- Respirators complete with full facepiece, emergency exit air supply, and harness for use with above system (18 @ $590 each)	10,620
Total	$ 29,070

5.3.2(b) Hand-Operated Blower

Not considered adequate.

5.3.3(c) Electrical-Powered Portable Breathing Air Pump

- Pump, including receiver and handcart (6 @ $1,680 each)	$ 10,800
- Respirators, complete with full facepiece, emergency exit air supply, and harness for use with above system (18 @ $590 each)	10,620
Total	$ 21,420

NOTE: Maximum number of personnel that can be supplied from one pump is three.

5.3.4(d) Gas (Air)-Powered Portable Breathing Air Pump

- Pump, including receiver and handcart (6 @ $1,770 each)	$ 10,620
- Respirators, complete with full facepiece, emergency exit air supply, and harness for use with above system (18 @ $590 each)	10,620
Total	$ 21,240

NOTE: Maximum number of personnel that can be supplied from one pump is three.

5.4 OPTION 4 - A COMBINATION OF PERMANENTLY INSTALLED MANIFOLDS AND A SEMIPORTABLE SUPPLIED BREATHING AIR SYSTEM

Pipe, valves, and fittings for permanently installed manifolds	$135,630
With Option 3(a) $29,070	$164,700
With Option 3(c) $21,420	$157,050
With Option 3(d) $21,240	$156,870

5.5 A STATIONARY AIR-CHARGING SYSTEM

System, 5 scfm at 4,000-psig compressor with purification system, air quality monitors, instruments and controls, etc., for use with Options 2 and 3(a)	$ 29,100

NOTE: Can also be used for Fire Station SCBA equipment

6.0 RECOMMENDATION

It is recommended that the following options be selected and combined to meet the MRS Facility Breathing Air System requirements:

Option 2 - Self-contained breathing apparatus (SCBA) (6)	$ 7,200
Option 4 with Option 3(a) - A combination of permanently installed manifolds and compressed breathing air cylinders on handcart	164,700
A stationary air-charging system	29,100
Total	$201,000

The above selection will provide three portable breathing air supply units, each capable of supplying six respirators simultaneously at a demand rate of 5 cfm.

The stationary air-charging system will recharge a 300-cu-ft cylinder at a rate of one per hour or recharge 45-cu-ft SCBA units at a rate of six per hour.

Spare parts are not included in the costs for any of the system.

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THE RALPH M. PARSONS COMPANY
of DELAWARE *Worldwide Engineers/Constructors*

100 WEST WALNUT STREET
PASADENA, CALIFORNIA 91124
(213) 440-2000
Telex WH 675-336

RJP

August 2, 1984

P-PNL-095

Pacific Northwest Laboratory
Battelle Memorial Institute
Post Office Box 999
Richland, Washington 99352

Attention: Mr. D. S. Jackson, Technical Administrator
A-E Services

Subject: Job 6440 - Monitored Retrievable Storage Facility
Central Boiler Plant Evaluation

Gentlemen:

In response to your 30% Review Comment concerning the economics of providing separate building heating systems in lieu of a Central Boiler Plant, we are transmitting herewith a cost evaluation to support our design decision.

If you have any questions concerning this evaluation, please advise.

Very truly yours,

W. D. Woods
MRS Project Manager

WDW:gp
Attachment

CC: R. B. Goranson
G. S. Rokkan
F. A. Pace
R. J. Hall
R. M. Gale
R. J. Steffen
J. A. Roll
J. W. Voss
A. K. Jowdy
C. H. Keehn
S. Dianat
W. L. Santo

DESIGN STUDY DS-23

CENTRAL BOILER PLANT EVALUATION

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
P-PNL-095	Central Boiler Plant Evaluation	Aug. 2, 1984

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC #076

To C. H. Keehn — Date June 13, 1984

From G. Hayase — Phone 3564 — Location EA-434

SUBJECT Job 6440 - Monitored Retrievable Storage
Basis for Design - Fire Water Supply

In accordance with IOC 065, the elevated water tank will be deleted and will be replaced with standby Diesel pump to assure fire protection water in the event of a complete power failure.

This change should be reflected by all disciplines, where applicable, in their Basis for Design.

G. Hayase

CC. D. S. Jackson (PNL)
D. W. Woods
A. K. Jowdy
Discipline Leaders

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE

IOC 065

To	C. H. Keehn			Date	May 22, 1984
From	G. Hayase	Phone	3564	Location	EA-434

SUBJECT Job 6440- Monitored Retrievable Storage
Function Design Criteria - Fire Water Storage

The functional design criteria requires a tank sized to accommodate both the facility process use and maximum credible fire water demand as well as a high tank to assure an adequate supply of fire protection water in the event of a complete power failure. The tank height needed to obtain the required minimum distribution pressure of 100 psi makes the high tank impractical. Assuming a flat site, the height requirements of the tank are on the order of 250 ft.

Based on the above, the civil section recommends a single tank sized for process use and fire water demand and a standby Diesel pump to assure fire protection water in the event of a complete power failure.

G. Hayase

DH:jf

cc: D. S. Jackson
F. X. Collins
J. T. Ang
W. D. Woods
A. K. Jowdy

CENTRAL BOILER PLANT EVALUATION

The basis for the selection of individual boilers in each facility was based on economics and past experience.

A steam generating plant is required in the Receiving and Handling Building to satisfy the demand for process steam and to preheat the incoming supply air because the HVAC System is a once through system. The remainder of the steam demand is for confort heating. Steam converters are provided to supply the hot water to the HVAC systems.

The support buildings are each provided with individual hot water boilers. There is no requirement for steam at the support buildings.

A centralized boiler plant would require steam generators with steam converters at each support building. In addition, a condensate pumping unit will be required in each building to return the condensate to the centralized steam plant. The steam is distributed to the support buildings via an insulated above ground piping system for both the steam supply and the condensate return.

Centralization does not save energy as compared with individually heated building. A study conducted by the Ralph M. Parsons Company for the Corps of Engineers in January 1984 found that heat losses from long runs of piping, traps and loss of condensate can run in the order of 30% of the transmitted heat load. Also the boiler efficiency of a central plant is not significantly different than the efficiency of individual boilers.

The capital cost difference between the two systems are shown below. Vendor budget prices for equipment were obtained and other costs were in-house generated.

Centralized Plant

Steam Boilers	3 @ $94,000 ea	=	$ 282,000
Steam Converters	6 @ $ 1,350 ea	=	8,100
Condensate Recovery	6 @ $ 1,500 ea	=	9,000
Distribution Piping			
Steam 6,600 ft @ $152/ft		=	1,003,200
Condensate 6,600 ft @ $91/ft		=	600,600
			$1,902,900

Individual Boilers

Steam Boilers (R&H)	3 @ $80,000 ea	=	$ 240,000
Hot Water Boilers	6 @ $14,500 ea	=	87,000
Oil Distribution	$28/ft		131,600
4,700 ft System			
			$ 458,600

DESIGN STUDY DS-24

FIREWATER SUPPLY

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-065	Firewater Storage	May 22, 1984
IOC-076	Firewater Supply	June 13, 1984

DESIGN STUDY DS-25

ALTERNATE EXHAUST RELIEF

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-267	Elimination of Alternate Exhaust Relief	Nov. 14, 1984

THE RALPH M. PARSONS COMPANY of DELAWARE

INTEROFFICE CORRESPONDENCE IOC #267

To A. K. Jowdy Date November 14, 1984

From J. T. Ang Phone 7095 Location EA-439

SUBJECT Job 6440 - Monitored Retrievable Storage Facility
Elimination of Alternate Exhaust Relief

Since the exhaust stack is now designed to meet both operating basis earthquake and tornado requirements, the need for an alternate relief/bypass damper is no longer necessary.

The new stack is located on top of a Category I exhaust air shaft, along with fresh air intake. It is not practical to provide any relief opening at this exhaust shaft with additional tornado shield over it.

NRC Regulatory Guide 3.32 stated that: "Provisions may be made for alternative release points.....in the event that flow through a stack is blocked due to structural failure."

Since there are no structural problems, we see no reason to spend money for things we don't really need. Therefore, the present concept of exhaust relief damper will be deleted from HVAC drawings.

J. T. Ang

JTA:gp

CC: W. D. Woods
C. H. Keehn
W. L. Santo
R. L. Jarvis

DESIGN STUDY DS-26

FIRE SUPPRESSION SYSTEM PLAN

FOREWORD

This study consists of the interoffice correspondence (IOC) listed below.

Document No.	Subject	Issue Date
IOC-592	Standby Generator Building Fire Protection	July 1, 1985
IOC-618 Rev. 1	R&H Building - Proposed Automatic Suppression Systems Plan	Aug. 5, 1985

INTEROFFICE CORRESPONDENCE IOC #592

To J. T. Ang Date July 1, 1985

From F. X. Collins/J. A. Boncich Phone 4717 Location B3-01-16

SUBJECT Job 6440 - Monitored Retrievable Storage Facility
Standby Generator Building Fire Protection

INTRODUCTION

The following fire protection design for the Standby Generator Building is based on an evaluation of Factory Mutual's loss prevention data sheets, electrical equipment considerations, building construction type, and National Fire Protection Association (NFPA) codes and standards.

The Standby Generator Building is a non-combustible Category 1 structure housing three diesel driven 1,400 KW emergency generators and 5 KV switchgear. The 5 KV switchgear including Bus No. 1, Transfer Bus and Bus No. 2 will be located in one large room. Each diesel driven generator unit along with a day's supply of fuel will be located in a separate cell. The generator compartments are isolated from each other by a 12 inch thick concrete wall and isolated from the switchgear room by a 24 inch thick wall.

IDENTIFICATION OF FIRE HAZARDS

a) Switchgear Room
Fire Hazard: Due to the lack of combustible materials (non-combustible wire insulation) and the fact that the entire room is isolated by fire rated barriers, there is no identified propagable fire hazard.

b) Switchyard Area
Fire Hazard: If the 14 MVA transformers stored in this area are of the oil insulated type, a fire hazard does exist. Fires in oil-insulated trasformers result principally from the breakdown of insulation. In the event of an electrical breakdown, sufficient pressure to rupture the transformer casing can be created. Considerable burning oil may be expelled and an intense fire may result.

c) Generator Compartments
Fire Hazard: The two flammable liquids, the day's supply of diesel fuel and the generator lube oil are the main fire hazards contained within the generator compartments.

RECOMMENDED FIRE PROTECTION

The selection of the fire suppression system for the Standby Generator Building is based on the fire hazard present, the system effectiveness and the effect of the extinguishing agent on the ability of the facility to provide standby power.

a) Switchgear Room
The fire protection for the Switchgear Room will consist of a smoke detection system, a fire alarm signaling system, (manual pull stations) and portable CO_2 fire extinguishers.

Since there are no physical separations within the Switchgear Room, the introduction of water into this area could be detrimental to the entire electrical system and is therefore not recommended.

The Switchgear Room will not be provided with an automatic fire suppression system. Since a fire hazard could not be identified in this area, an automatic fire extinguishing system would not be feasible. In the event of a fire, the aforementioned fire protection provisions would be adequate to extinguish the type of fires foreseen in this area.

This recommendation for not providing an automatic fire suppression system is in accordance with the recommendation obtained from Factory Mutual Systems' Loss Prevention Data, 19, 14-21, Switchgear page 14,#2 which states, "Modern switchgear installations located in a non-combustible room and not exposed to other combustibles would not require an automatic fire extinguishing system."

b) Switchyard Area

An automatic fire suppression system will not be provided. The fire protection for the 14 MVA transformers in the switchyard area will be in accordance with the recommendations obtained from Factory Mutual Systems' Loss Prevention Data Sheet, 5-4, "Transformers":

Transformer Protection:	Provide a 25 ft clearance between units and 2-1/2 inch hose with two portable spray nozzles.
Exposure Protection:	Locate at least 25 ft from exposed structures of non-combustible construction

c) Generator Compartments
The fire hazards identified in the generator compartments warrants that some type of automatic fire suppression system be provided. The types of extinguishing agents evaluated in the selection of the automatic system were Halon 1301, carbon dioxide and water. Halon 1301 and carbon dioxide are both electrically nonconductive and effective in the fire suppression of flammable liquids. However, the cost associated with the use of these agents and the requirement of attaining and maintaining a desired concentration of the agent within an environment makes them unattractive.

c) Generator Compartments (Contd)

Factory Mutual Loss Prevention Data Sheet, 5-23, "Emergency and Standby Power Systems," states, "Protect with automatic sprinklers those areas housing systems driven by internal combustion engines or existing installations of combustible construction."

An automatic fire sprinkler system poses few of the system components or problems associated with Halon 1301 or carbon dioxide suppression system, and are the simplest and the most reliable automatic system in use today. However, in order to confine the problems associated with water and an electrical system within a generator cell, we recommend the following provisions be made.

1. The ability to automatically shutdown and electrically isolate an emergency generator from the rest of the standby power supply prior to the activation of the sprinkler system.

2. Adequate drainage in each cell for the water from sprinklers and the fuel contained within each cell.

Incorporating the aforementioned provisions, our recommendation is that a preaction system be provided for these compartments. A preaction system would minimize the hazards to personnel and electrical equipment associated with leakages. The power shutdown and isolation requirements associated with the activation of a sprinkler system would be confined to a particular generator cell and would therefore not have a detrimental effect on the overall ability of the facility to provide standby power.

It is our opinion that with the above provisions made, a preaction system confined to the generator compartments would be in accordance with NRC-10, paragraph 72-73. General design conditions quoted as standby power systems important to safety must continue to perform their operation effectively under credible fire and explosion exposure conditions.

F. X. Collins

J. A. Boncich

FXC:JAB:fw

INTEROFFICE CORRESPONDENCE

IOC #618
Rev. 1 - 8/5/85

To W. L. Santo Date July 19, 1985

From J. T. Ang Phone 7095 Location EA-439

SUBJECT Job 6440 - Monitored Retrievable Storage Facility
R&H Building - Proposed Automatic Fire Suppression System Plan

---

1 Fire Protection Design Criteria

An automatic fire protection sprinkler system shall be provided throughout the building. It shall be designed in accordance with National Fire Protection Association (NFPA) and DOE 6430.1. In areas where water is unacceptable, a Halon System, or other acceptable systems, may be substituted.

2. Automatic Fire Suppression System Plan

Automatic fire suppression systems will be supplied throughout the process and non-process areas of the R&H Building. Non-process areas will be protected with standard automatic wet-pipe sprinkler system and critical areas such as the control room, electrical rooms, etc., will be provided with Halon 1301 total flooding system. A water spray system will be provided in all final HEPA filter plenums except Lag Storage HEPA filter plenums, and are actuated by a heat detection system.

A fire suppression system will not be required in the shielded hot cells. This is due to unoccupied area, massive will thickness of the cells (fire separation), proper equipment spacing and lack of any combustible materials within the cells. Criticality considerations preclude the use of a water suppression system. Contamination and HVAC requirements make impractical the application of a total flooding Halon 1301 system.

A. Automatic Sprinkler Systems

An automatic wet-pipe sprinkler system will be provided in designated areas and be complete, including piping, valves, fittings, sprinkler heads, and all required attachments and devices to provide a hydraulic water motor alarm, an electric alarm and supervisory signal to the main fire protection annunciator. Fire stopping material will be provided for closing pipe and conduit penetrations in fire resistive structural partitions.

Standpipe and hose cabinets will be provided in accordance with NFPA 14.

Fire Department connections will be provided to enable the installed sprinkler systems to utilize a secondary water supply.

B. Halon 1301 System

Areas of high valve or of high program importance (computer areas/control room) will be provided with a total flooding Halon 1301 system. The system will consist of fixed piping manifold racks, cylinders, detectors, circuits, alarms and controls, designed to provide detection, alarm and extinguishment of fire in accordance with NFPA 12A.

C. Dry Chemical System

Dry chemical will be used to extinguish flammable fires. Areas protected with dry chemical system will be determined after fire protection systems have been finalized.

D. Portable Fire Extinguishers

Portable fire extinguishers will be a part of the fire protection system provided for the R&H Facility. Portable fire extinguishers will be sized, located and installed throughout the facility in accordance with NFPA 10.

3. Sprinkler System Zoning

The Receiving and Handling (R&H) Building areas shall be divided into automatic sprinkler water flow zones based on the relative potential for exposure to radionuclides. The water flow zones will be similar to the ventilation zones to establish the hazard potential of the fire and fire water run-off.

The zones are depicted in Table 1 as follows:

Table 1

Ventilation Zones	Water Flow Zones	Total Area	Definition	Typical Location
1	None	(56,160 ft^2)	Process Zone Highly contaminated area, restricted access zones	Shielded hot cells Canyon cells High activity radwaste cell Remote handled maintenance room
2	1 & 2	(106,130 ft^2)	Limited Access Zones Potentially contaminated areas	Hot-cell service gallery Low level liquid radwaste area Shipping cask unloading rooms Contact handled maintenance areas Spent fuel and HLW transfer corridor(s) HEPA filtered exhaust filter room
3	3, 4, 5, 6 & 7	(250,400 ft^2)	Operating Zones Not normally contaminated	Operating galleries Process area corridors Airlocks Change rooms Counting rooms Filtered exhaust fan rooms Laboratories

Table 1 (contd)

Ventilation Zones	Water Flow Zones	Total Area	Definition	Typical Locations
4	8, 9, 10 & 11	(174,700 ft^2)	Unrestricted Access Zones	Receipt & Inspection areas Administrative areas Restrooms Mechanical and electrical equipment rooms (not UPS rooms) Unregulated storage areas Lunchrooms

4. Halon 1301 Total Flooding Systems Zoning

The Halon 1301 systems will be provided in electrical rooms, UPS rooms, and the main control room. Each room will be individually zoned and actuated independently.

5. Glove Box

Inert gas, such as nitrogen which is available in the facility will be provided for the glove boxes as required. Specific glove boxes requiring such protection will be determined during final design.

J. T. Ang

JTA:fw

cc: W. D. Woods
A. K. Jowdy
C. H. Keehn
H. W. de Angelis
F. X. Collins

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DESIGN STUDY 27

QUALITATIVE SAFETY ASSESSMENT FOR CONCRETE CASKS AND DRYWELLS

1.0 INTRODUCTION

A qualitative safety assessment of the concrete cask, the drywells, and their associated handling equipment has been performed. These assessments were performed to provide assurance that the conceptual designs could be further developed to ensure that no initiating events or accidents would cause an undue risk to the health and safety of the public during normal and off-normal operations or design basis accidents. These assessments were performed in parallel with that reported in the Regulatory Assessment Document and provide additional information on casks and drywells.

The cask, drywell, and handling equipment designs and operations were reviewed, and the most credible events and accidents, which had potential to result in an off-normal exposure to radioactivity or radioactive materials by operating personnel and/or the general public, were defined. To simplify the assessment, only the worst-case consequences of events were considered (e.g., spent-fuel canister rupture and contents release), rather than all possible combinations of less-severe consequences. In addition, the events and accidents were assessed relative to the casks and drywells only; the other facilities and structures are addressed in the Regulatory Assessment Document. The events and accidents that were judged to have no safety-related consequences for casks and drywells were not addressed.

The assessments presented in this study are based mainly on engineering judgment and past experience with casks and drywells. This is considered to be consistent with the advanced conceptual design phase, it being understood that further design effort and analyses will be required during the detail design phase to provide proof and justifications acceptable to the NRC.

2.0 CONCRETE CASK SAFETY ASSESSMENT

The following sections provide a description of potential concrete cask safety-related events and accidents, their consequences relative to onsite personnel and general public safety, and any mitigating and preventive features. The events and accidents assessed are those considered to be the most credible. The assessment considers the events from loading the casks with spent-fuel canisters to unloading the casks in the storage area, as well as long-term storage and natural phenomena.

The concrete cask designs, the associated handling equipment designs, and the operations associated with cask construction, handling, loading, and monitoring are described in Section 3.5.2 of the Design Report (Volume I, Book II). The concrete cask components, construction, and assembly details, along with the handling equipment, are shown on Drawings H-3-54985 through H-3-55008. The concrete cask storage area is shown on Drawings H-3-54979 through H-3-54981.

2.1 CONTAINER DROP INTO CONCRETE CASK

Spent fuel, high-level waste, and RHTRU waste are contained in steel canisters and the nonfuel-bearing component wastes (fuel assembly skeletons, hulls, etc.) are contained in sealed 55-gal drums. These filled canisters and drums are loaded from the Receiving and Handling (R&H) Building shielded process cell into concrete casks (located in the loadout/decontamination room below the shielded process cell). Equipment failure during loading, such as a grapple failure, could result in a 6,000-lb canister dropping 35 ft into the bottom the cask or dropping 10 ft onto the upper edge of the cask.

Such a drop could rupture the canister or drum. If the cask is partially filled with other canisters, the falling canister could hit another canister and cause damage to both canisters. Any contamination spread would be minimal; it should be contained within the sealed shielded process cell and cask, and within the contamination barrier provided between the two. The release of radioactive gases from a ruptured fuel rod would be routed through the HVAC system (see Regulatory Assessment Document).

Minimal damage would be sustained by the concrete cask. Any significant damage to the canisters or drums could be remedied by placing the waste into a new canister or drum, or by overpacking the damaged canister or drum. The shielded process cell has been designed not only to isolate the waste from the atmosphere and personnel during normal operations, but also to provide the necessary features to protect the surrounding areas if a canister or drum is dropped during loading. The design features to mitigate the consequences of a dropped canister or drum are the enclosed hot cell and HVAC system, the contamination barrier, "anti-drop" brakes on the hot cell crane, and the construction of the concrete cask, canister, and drums. In addition, the hot cell crane and grapples are designed with safety factors of 2 or 3, and are to be periodically inspected and load tested to 125% of their rated capacity. Safety interlocks, brakes on the crane, and a fail-safe design grapple are provided to prevent inadvertent container release.

2.2 CASK PLUG DROP ONTO CASK

The concrete plug is installed in a waste-filled concrete cask before it is moved from beneath the hot cell. This plug is lowered from the shielded canyon cell through the discharge port by the crane. The largest plug to be handled by the crane weighs 11.8 tons and could fall a maximum of 11 ft if the crane grapple failed.

A dropped cask plug would either hit the stepped edge of the discharge port before falling onto the top of the cask, fall directly onto the top of the cask, or fall into the cask. Impacts from a dropped plug would be expected to damage the discharge port, the cask, or the steel shell on the shield plug. Because the cask plug cannot fit through the cask opening at the stepped liner segment, it should not damage any of the cask contents; however, the potential exists for the plug diameter to fall below the step if the plug has rotated 90 deg from its normal handling orientation.

Any damage to the cask contents would be limited to the upper end of the waste containers. If damaged, these items could be removed after the shield plug has been removed. Any recovery operations from this accident would be expected to require contingency tooling, which would be brought into the hot cell through the maintenance port. Removal and repair/replacement of the waste containers would be done in one of the shielded canyon cells. Any releases from rupture of the containers would be contained within the hot cell and cask, as described in Section 2.1.

With a 0.5-in. radial clearance between shield plug and liner, a dropped plug could become wedged in the concrete cask. A shield plug that has become jammed into the cask is removable by using the crane and any contingency tooling required. Excess capacity is available in the overhead crane (20 tons) to remove the plug. Access for any off-normal equipment into the hot cell would be through the maintenance port. If the cask liner flange or the cask concrete is damaged, the contents can be removed into one of the shielded canyon cells and placed in lag storage, and the cask can be moved into the transfer/discharge corridor for repair. The cask flange can be repaired by the addition of weld-filler metal and grinding, and any damaged concrete can be replaced.

A damaged cask shield plug can be inspected and replaced or repaired, as needed. A replacement plug can be brought into the shielded canyon cell through the maintenance port, and a damaged plug can be removed through the same port. If the plug is too large (depending on cask type), the cask can be unloaded, the plug replaced in the cask, and the cask and plug removed from the R&H Building for repair/replacement operations. The steel shell on the plug prevents the contained concrete from becoming loose pieces (if broken), which could fall into the cask.

Dropping the concrete cask plugs is not expected to cause a safety problem, radiological release, or significant damage to the concrete cask. The solid construction of the cask allows it to take the impact of a falling cask plug without an impact on the contained waste. A damaged cask should be repairable after its contents are unloaded, or it could be replaced by a new cask. Shield plug drop should be prevented by the design of the lifting equipment (crane, grapple, and lifting fixture) and the periodic inspection and load testing (same as for the container drop discussed in Section 2.2).

2.3 CASK COVER DROP

After a concrete plug has been inserted into a waste-filled concrete cask, the cask is moved from the loadout/decon room into the transfer/discharge

corridor. The cask is positioned beneath an opening in a work platform, through which a metal cover is lowered onto the cask. Attached to this cover is the welding equipment to seal the cover to the cask. If the hoist cable were to break or the welder handling fixture were to fail, the cover and welding equipment would drop onto the cask.

The largest cover is 6.7 ft dia and 2 in. thick. The maximum distance this cover would drop is 6 ft. The potential result would be damage to the metal cover, the welding equipment, the shield plug, or the cask liner flange.

Dropping the cask cover should not cause a safety problem or unrepairable damage to the cask. The cover and welding equipment can be inspected for damage, and replaced if necessary. If the cask liner flange is dented by the impact, and this prevents the liner flange from properly sealing with the cover, it can be repaired by filler welding and grinding.

The transfer/discharge corridor crane and its hook, as well as the welding equipment handling fixture and its attachment to the cask cover, will be designed with sufficient structural margin to prevent failure from overloading. In addition, these components will be periodically inspected to ensure structural integrity. The crane hook and the handling fixture attachment to the cask cover will have positive engagement features that will prevent inadvertent releases. These features are provided to minimize the possibility of a cask cover drop.

2.4 TRANSPORTER START OR STOP LOADS ON CASK

The concrete cask will be transported from the R&H Building to the storage facility at a maximum speed of 3 mph. The acceleration or deceleration resulting from the starting or stopping of the transporter will be less than the acceleration exerted on the cask by the design basis earthquake. Therefore, the consequences of this event are enveloped by the seismic load analysis.

A ring is provided around the perimeter of the transporter load-bearing pad to restrict cask sliding. The combination of concrete cask weight, area in contact with the transporter, and pad ring can be expected to prevent the cask from sliding relative to the transporter.

Starting or stopping of the transporter when it is bearing a concrete cask should not generate a safety problem for the cask, its contents, or the transporter.

2.5 TRANSPORTER FIRE OR EXPLOSION

A cask transporter fire could result from ignition of the transporter's fuel tank. If a fire were to occur, the burning time of the limited amount of diesel fuel should not be long enough to threaten the cask's structural integrity.

The transporter is designed to isolate the fuel tanks and the engine compartments. Rupture of the fuel tanks is highly improbable because of the limited speed of the transporter and that of the other MRS vehicles.

Fire-detection and firefighting equipment will be provided on the transporter to ensure that the time to extinguish the flames is minimized to limit damage to the cask.

An explosion of the diesel fuel in the transporter is an extremely unlikely event. However, should an explosion occur, the amount of damage to the cask is not expected to cause a safety problem. The cask concrete bottom or walls may sustain some damage, but the massive, reinforced concrete cylinder of the cask should maintain sufficient structural and shielding integrity to allow it to be unloaded onto another transporter and returned to the R&H Building for unloading. The integrity of the liner and cover plate are not expected to be violated by an explosion.

2.6 CASK DROP

After a cask has been loaded with waste and sealed, it is transported to the storage area. At the storage area, a crane lifts the cask from the transporter, and places it in a designated location on a prepared concrete pad. During the transfer from the transporter to the storage pad, equipment failure could result in cask drop onto the transporter or the concrete pad.

The cask is lifted approximately 6 in. above the top of the transporter for movement onto the pad. If failure of the handling/lifting equipment occurs during the movement, the cask could fall onto the transporter, resulting in potential damage to the transporter (e.g., handling surface, crawler track, or motors). This could also result in the cask tipping over and falling onto the ground surface or pad. If the cask drop is assumed to be over the concrete pad, damage to the pad from the cask dropping approximately 6 ft would occur.

Neither of these drops is expected to damage the cask to any extent because of its structural capacity. Concrete may be chipped or broken from a small area at the cask surface. The cask may also tip over onto its side as a result. The weld between the cover plate and liner has sufficient strength to prevent the cover, shield plug, and/or cask contents from falling out of the cask if it tips over. Damage to the transporter or concrete pad (or handling/lifting fixture) is more likely if there is a cask drop accident. In all cases, the transporter or handling/lifting fixture can be replaced for further operation, and the damaged one repaired if deemed necessary. Damage to the pad can also be repaired. The cask can be upended (if tipped over) by using slings and the cask crane, and any concrete broken from the surface can be replaced (if needed).

The cask crane and handling/lifting fixture are designed with structural margins; their attachment together and to the cask is designed to be fail-safe. The cask handling/lifting fixture, a flanged hollow cylinder that uses a segmented circular shear block arrangement to transmit cask lifting

loads through the shear blocks to the flange, is designed so that shear block motion (release of the cask) is prevented as long as the cask load is on the fixture. The crane is equipped with dual brakes on the crane hoist drum, which are activated if there is power loss. The crane and fixture will be periodically load-tested and inspected to ensure continued structural integrity throughout their use. These measures are expected to prevent cask drops from occurring.

2.7 SEISMIC LOADS ON CASK

The concrete cask must withstand earthquake loads produced by a maximum horizontal ground acceleration of 0.25g and by a maximum vertical acceleration of 0.167g. These accelerations may be imposed on the cask during storage or during transport to or from storage. The casks have been assessed to determine whether tipping could occur during storage; the results show that the combined accelerations are insufficient to do so. The 12-ft-dia base, the 22-ft height, and the cask weight will keep the cask upright. If seismic accelerations are imposed on the cask and transporter, the larger base provided by the transporter and the stiff suspension system on the crawler units will prevent the cask from tipping. If the cask were to tip and fall over, the damage to cask, transporter, or ground should be no more severe than that for the cask-drop accidents considered above. Recovery from such a tip would be as described for the cask drops.

The concrete casks may be subjected to impact from other objects that have failed under seismic loads. These could include portions of the R&H Facility structure or other casks that have tipped over (these are only postulated accidents, as the R&H Building is designed to take seismic loads without failure and casks are designed not to tip over). Loads transmitted from the postulated impacts are not expected to cause excessive damage to the cask; i.e., damage would not result in safety problems such as radioactivity release, high radiation fields, etc. Recovery would include inspection of the cask and, if it is damaged, the cask could be returned to the R&H Building and unloaded.

The concrete casks will transmit seismic accelerations to the contained waste canisters. The designs for the spent-fuel and high-level-waste casks include internal support plates, which position the canisters and provide lateral restraints. The interaction between canisters and these restraints is expected to cause no significant damage to either, even under the worst horizontal accelerations. Seismic testing performed on similar spent-fuel canisters in similar support conditions (Ref. 1) showed that the impact loads did little more than produce shiny spots on the canister where insignificant localized surface yielding occurred.

2.8 NATURAL PHENOMENA AND MAN-MADE IMPACTS ON CASK

The concrete cask is susceptible to tornado wind loadings, missiles generated by tornadoes, lightning strikes, and impacts from aircraft while being transported and while in storage at the storage facility.

The strong winds of a tornado (approximately 80 mph) have the potential to make high-force missiles out of pipes, planks, rods, automobiles, utility poles, etc. These missiles can be hurled against the concrete cask with enough force to chip some of the concrete, but not with sufficient force to penetrate the cask wall. The walls of the concrete casks range in thickness from 42 to 21 in., are reinforced, and are backed up by the circular steel liner. The thick metal cask covers provide sufficient capability to prevent cask penetration or containment-barrier penetration by tornado missiles.

The wind-induced loads on the cask are partially dissipated by the circular shape of the cask. The loads are not sufficient to cause the casks to tip over while on the transporter or on the concrete pad.

The array of concrete casks or the cask on the transporter could be struck by lightning. The casks can be grounded on the storage area pads to prevent damage. The cask on the transporter could be grounded to the transporter, if needed. Should a cask be struck by lightning, an inspection of the cask would be performed, and subsequent replacement or repair operations would be initiated, as required.

The array of concrete casks and the cask on the transporter are also susceptible to impact loads from an aircraft crash. Although no such event has been identified in the Functional Design Criteria, the potential exists for such an accident to occur. Depending on the size of the aircraft, damage to the concrete casks could be minimal or it could be extensive (e.g., from a 747). The reinforced concrete cask walls, the shield plug, and the steel liner around the wastes provide protection against penetration to the wastes. The multiple casks also provide a limited amount of waste per cask, which could be released should the cask be ruptured and the containment barriers violated. The extent of damage to the casks and potential for radiological release need to be assessed, based on the location of the MRS Facility, the proximity of aircraft flight lanes, and the definition of the largest aircraft impact that a cask must withstand.

2.9 VOLCANIC ASH FALLOUT

If a volcano were to erupt, volcanic ash could be deposited on top of and around the sides of the concrete casks. This event is not a problem for the concrete casks because there are no ventilation ports or air filters to clog. If the ash were to pile to a depth of 5 ft, there would still be sufficient heat-transfer area around the cask to keep the contained waste temperature from rising above its temperature limit. No failure modes can be identified for a concrete cask covered with volcanic ash.

2.10 CANISTER FAILURE WITHIN CASK

Fuel assemblies are dismantled, and the rods (approximately 792 fuel rods from three 17 x 17 PWR fuel assemblies or approximately 441 fuel rods from seven 8 x 8 BWR fuel assemblies) are loaded into a 1-ft-dia by about 16-ft-long steel canister inside the hot cell. The canister is sealed, the

weld inspected, and the integrity of the canister checked before it is loaded into the concrete cask. The cask is sealed, and transported to an outside storage area.

A canister failure could be postulated to occur as a result of a cask drop, because of seismic accelerations, or because of undetected defects in the canister or its welds. Failure of the canister would release any contained gases (including any radioactive gases from failed fuel rods) into the cask interior. These gases would be contained inside the cask by the secondary containment barrier provided by the cask liner and seal-welded cover. Periodic cask gas sampling will detect the gases, and the cask would be returned to the R&H Building for removal of the canisters, canister inspection, and repair, replacement, or overpacking of the failed canister.

Because the canister is of stainless steel, corrosion of the wall does not appear to be a potential failure mechanism. The wall is the primary containment barrier; therefore, inspection of the base materials and welds will be performed to ensure that flaws in material or defects in welds beyond the prescribed limits do not exist in the storage canisters. The completed canister is also leak-checked to ensure integrity. The canister has been designed to take drop loads into the cask and to take loads transmitted by seismic accelerations. The canister has also been designed to withstand internal pressure loads from the assumed rupture of all spent-fuel rods. These features and preventive measures are provided to ensure canister integrity.

2.11 CASK CONTAINMENT BARRIER (LINER, COVER, AND WELD) FAILURE

The concrete casks are lined with a minimum of 0.50-in.-thick carbon steel and are sealed by a welded carbon-steel cover with a minimum thickness of 1.0 in. This containment barrier is intended to safely contain any gases that may be in the cask. Failure of this barrier can be postulated from undetected weld or material defects, or as a result of a large impact force (cask drop, tornado missile, etc.).

Failure of the cask containment barrier could result in release of any contained gases (this could include radioactive gases if failure of both canister and fuel rod cladding occurs) or could allow water to enter the cask interior. These have potential safety impacts. Cask barrier, canister, and fuel-rod cladding failure may have the potential to result in radiological releases greater than prescribed limits at the site boundary (no calculations have been made to assess this as yet). Water in the cask interior has the potential to result in a criticality incident.

The cask has been designed to take seismic loads, drop loads, tornado wind loads, and wind-generated missile loads without allowing the containment barrier to fail. Other potential impact loads should be absorbed by the reinforced concrete without affecting the barrier. With the design safety margins for canister and cask liners and covers, no single event is postulated to cause failure of these two containment barriers.

The liner and cover materials, as well as the welds on the liner barrier, are inspected to ensure that flaws or defects beyond the prescribed limits do not exist in the storage cask. The final seal weld is also inspected, and the cask is leak-checked to ensure barrier integrity before its placement into the storage facility. Exposed portions of the cask containment barrier are coated for corrosion protection; they will be inspected periodically, and repaired, recoated, etc., if needed. Periodic barrier pressure checks, as described in Section 3.5.2.A (Volume I, Book II), will be performed to ensure continued integrity. Should any leak be detected, the cask will be returned to the R&H Building, and unloaded.

For the conceptual design phase, criticality calculations have not been performed for water in the cask. Should calculations performed for the final cask configuration indicate the need for poison, poison rods or plates will be added to the cask interior to ensure fuel storage in a subcritical state under all conditions.

The above-described design features and activities are provided to ensure that the cask containment barrier is maintained in a leaktight configuration and that radiological releases are kept to a minimum.

3.0 DRYWELL SAFETY ASSESSMENT

The following sections provide a description of the events and accidents considered to be most credible for the drywell and that could affect onsite personnel or general public safety. These sections address the consequences of the worse-case safety-related events and accidents, along with any preventive features of the drywell design. As in the concrete cask safety assessment, this assessment covers the events from waste container loading into the transporter and unloading into the drywell to long-term storage and natural phenomena.

The drywells and associated equipment have been designed with mitigating and preventive features that will cover the safety-related events and accidents for this equipment. The drywell designs, the associated canister handling equipment and drywell operations equipment designs, and the operations associated with drywell installation, canister handling, loading, unloading, and monitoring are described in Section 3.5.4 of the Design Report (Volume I, Book II). The drywell components, installations, and handling equipment are shown on Drawings H-3-55035 through H-3-55056 (see Volume III, Book II). The drywell storage area is shown on Drawings H-3-55030 through H-3-55033.

3.1 CONTAINER DROP INTO TRANSFER SHIELD

Waste containers are individually loaded from one of the shielded canyon cells into the transfer shield in the loadout/decontamination room. The shielded canyon cell crane and grapple lower the canister, through the discharge port in the shielded canyon cell floor, into the transfer shield, which is parked below the port. If the grapple inadvertently releases or fails, the container could drop a maximum distance of 35 ft into the transfer shield.

If a loaded waste container weighing as much as 6,000 lb were dropped 35 ft into the transfer shield, the container would land on the lower shield gate of the transfer shield, potentially damaging the shield gate. A dropped canister or drum cage would be removed from the transfer shield, and inspected for damage. The canister or drum would be overpacked or the contained waste placed in a new canister or drum, as required. Because the transfer shield lower gate is a solid steel and lead structure, damage to it should be minimal. The gate is removable and replaceable. Should the subsequent inspection, following a drop accident, reveal unacceptable damage, the gate can be repaired or replaced. Such a drop could rupture the canister or drum. Any contamination spread would be minimal, and should be contained within the sealed shielded canyon cell and transfer shield (and within the contamination barrier provided between the two). The release of radioactive gases from a ruptured fuel rod would be routed through the HVAC system (see Regulatory Assessment Document).

To prevent a container drop, the crane and grapple will be periodically load-tested and inspected to verify integrity. Safety interlocks, brakes on the crane, and fail-safe grapple design are provided to prevent an inadvertent container release.

3.2 CONTAINER DROP INTO DRYWELL

Once positioned over the drywell, the waste containers are raised by the transfer shield hoist and grapple, the lower shield is opened, and the container is lowered into the drywell. If the hoist or grapple fails during this operation, the canister could drop to the bottom of the drywell.

In the unlikely event of hoist or grapple failure, the farthest distance any container will fall is approximately 22 ft. An impact of a canister with the bottom of the drywell after a 22-ft fall is not expected to damage the drywell or breach the integrity of the canister. If the canister contains spent-fuel rods, the rods may be damaged. This damage could release fission gases from the rods, but the gases would be contained by the intact canister.

The hoist and grapple are designed with a safety margin for the weight of the heaviest loaded canister consistent with requirements for the hot cell crane and grapples. This equipment, which will be periodically inspected, will contain load indicators and safety interlocks. The lower shield gate is also designed with a safety margin for the heaviest loaded canister, and will also be periodically inspected. Inadvertent release of the grapple is prevented by safety interlocks, and the grapple position is indicated to the operator. Likelihood of this equipment failing is very small.

A dropped waste container will be retrieved and returned to the R&H Building for inspection, overpacking, or replacement. Retrieval operations may include repair or replacement of the grapple, hoist, or cable assembly, depending on the cause of the drop. Emergency procedures will be developed for use in recovery from a container-drop accident. These would include use of supplementary shielding, replacement of the entire upper shield gate

(with grapple and cable assembly), or use of an auxiliary hoist. Following waste container removal from a drywell, the liner will be inspected for damage. If suspect, a damaged drywell will not be used.

3.3 SHIELD PLUG DROP INTO DRYWELL

After a drywell has been filled with a waste container, a shield plug is installed to reduce the radiation level at the ground surface to acceptable limits. The shield plug is a solid cast-iron or steel cylinder, tapered at one end, which fits into the upper flared end of the drywell. This plug could drop into the drywell during placement if the hoist and grappling equipment were to fail.

Inside the transfer shield, the shield plug rests on a small translating platform until it is placed into the drywell. After a waste container has been lowered into the drywell, the shield plug is moved into the center of the transfer shield on the sliding platform. The hoist is attached to the plug, and the plug is lowered into the drywell. If the winch or cable holding the plug breaks, or if the grapple inadvertently releases the plug after the translating platform has been retracted, the plug would fall approximately 4 ft into the drywell.

The shield plugs have a 0.25-in. diametral clearance with the upper end of the drywell liner. Near the bottom, the shield plug has a taper to interface with the flared upper portion of the drywell liner. The two tapered surfaces have a 1-deg difference in their angle. If dropped, the shield plug will fall only as far as the tapered surface of the liner because of the 6-in. difference in diameters of the plug and the liner below the taper. At this point, the plug will be in the same position as it would be if it had been properly placed in the drywell. It cannot have an impact on the waste container.

A dropped shield plug could dent the drywell liner or could become stuck in the liner. To assess the extent of damage, or to be able to make an inspection of the liner or shield plug, it is necessary to remove the shield plug and waste container. This may involve emergency procedures, depending on the cause of the drop (cable break, grapple failure, etc.). A plug that is improperly seated or is stuck in a cocked position can be removed by using the transfer shield hoist, cable, and grapple (structural capability allows sufficient margin to remove a stuck plug). Contingency tooling will be used if necessary to lift the plug.

The removed plug would be inspected (with the waste container in the transfer shield or returned to the R&H Building), and either repaired or replaced. The liner would also be inspected and repaired (if possible) or left unused. The design safety margins in the winch, cable, and grapple (designed for handling much heavier canisters), the periodic load-testing and inspections, and the safety interlocks on the equipment are provided to prevent a drop event.

3.4 INADVERTENT OPENING OR CLOSING OF SHIELD GATES

The transfer shield has movable gates at the top and bottom. These function as access ports to the interior of the shield and as radiation shielding. Also, the bottom shield gate supports the weight of a loaded waste container and the top shield gate supports the hoist and waste container when a container is being loaded into a drywell.

The top shield gate is opened and the bottom gate is closed when a canister is loaded from one of the shielded canyon cells into the transfer shield. The crane and grapple lower the canister until it rests on the bottom shield gate. If the top gate were to close before the canister is in the shield, the canister or the top gate mechanism could be damaged. The gate is safety-interlocked to the control panel to prevent gate actuation; during canister loading, the transfer shield is closed in the loadout/decontamination room without operator access. Overload trips on the gate drive motors will prevent damage to the canister or gate mechanism.

The bottom shield gate is closed during transfer shield loading, but it could be left open. If this happens, the shielded canyon cell hoist would lower the canister to the floor beneath the transfer shield. Some portion of the waste canister would then expose the surrounding area to a higher-than-normal radiation level. The canister can be raised back into the shielded canyon cell by the crane, and the bottom gate placed in the closed position. The loading operation is monitored visually, and the vertical position of the canister will be indicated to the crane operator. The bottom gate is safety interlocked to the transfer shield control panel, and its position is indicated in the cab. These features are provided to ensure that a failure of this type will not occur.

When a waste container is loaded into a drywell, the bottom shield gate is opened. If the gate should inadvertently close before the waste is in place in the drywell and the shield plug is in place, damage could occur to the canister, grapple, cable, or gate. If the bottom shield gate opens during container transport to the drywell, the container will be freely suspended in the hoist and grapple system. A failure of the hoist and grapple system would also have to occur for the canister to fall to the ground. Safety interlocks on the control system are provided to prevent inadvertent gate movement during container loading into the drywell or during container transport to the drywell.

3.5 DRYWELL COVER DROP

After the waste container has been installed in the drywell, a permanent cover is installed on the drywell. The permanent cover is attached to the welding equipment for handling and during seal welding. The cover and attached welding equipment could drop onto the drywell liner flange during the transfer operation if the hoist, hook, or welder handling fixture were to fail.

The largest cover for the drywells is 43 in. dia and 2 in. thick. After the waste has been stored in the drywell and the shield plug is in place, the cover is lowered onto the drywell. The maximum distance the cover could drop is 6 ft. If the cover drops on the drywell liner flange, the flange, the cover, or the attached welding equipment could be damaged. Because the shield plug is in place below the liner flange and the cover will not fit into the drywell, no damage to the shield plug is expected.

Dropping any of the drywell covers will not cause a safety problem or significant damage to the drywell. Any damage to the drywell liner will be repairable, and a damaged cover or welding equipment can be replaced. The crane and hook used to handle the covers and welding equipment will be periodically load-tested and inspected. The hook and any attachment features to the welding equipment and to the cover will be designed to prevent inadvertent release.

3.6 TRANSFER SHIELD/TRANSPORTER MALFUNCTION DURING CONTAINER LOADING

The waste containers are loaded from one of the shielded canyon cells into the transfer shield for transport to a drywell on the transport vehicle. The transfer shield is raised to seal with the bottom of the discharge port and provide a radiation and contamination barrier. After the container is lowered into the shield, the top shield gate is closed and the transfer shield is lowered to within 1 ft of the ground for transport to the drywell. At the drywell, the shield is lowered onto the concrete pad at the top of the drywell for container loading into the drywell. Transfer shield motion (lowering or raising) or transport vehicle motion during waste container loading can potentially damage the canister or transfer shield.

The transfer shield may be lowered before the canister is completely in the shield. This could result in high dose rates in the loadout/decontamination room. The following safety interlocks will prevent this:

- The discharge port plug in the shielded canyon cell floor will not be removed until the transfer shield is in place and the loadout/decontamination room is closed to operator access.

- The transfer shield cannot be lowered until the loadout/decontamination room is opened for operator access, which will not be allowed until the container is in the transfer shield and the discharge port plug is in place.

- The transfer shield is not lowered until the waste container rests on the bottom shield gate, the container is attached to the grapple, and the top shield gate is closed.

When the transfer shield and transport vehicle arrive at a drywell, they are positioned over an open drywell, and the transfer shield is lowered onto the concrete pad. The drywell liner flange fits into a recess in the transfer shield to prevent radiation streaming from the waste container as it is lowered into the drywell. If the transfer shield should be raised during

container lowering, or if the transfer vehicle should move, a personnel radiation hazard could result. Safety features are provided to prevent this:

- A panel indicator tells the transfer shield operator whether the shield is completely seated on the concrete pad.
- Electrical interlocks prevent the transfer shield from being raised or lowered when either of the two shield gates is open.
- The motor on the transport vehicle is shut off during container loading or unloading operations.

3.7 LOADS ON WASTE CONTAINERS IN TRANSFER SHIELD

The waste containers are transported to the drywell storage facility by a transport vehicle with a maximum speed of 12 mph. Lateral and axial loads on the container will result from transportation motion. The acceleration of the waste containers caused by the slowly moving transporter is expected to be less than the seismic accelerations. The spent-fuel canisters are designed to withstand the maximum dynamic seismic accelerations of 0.25g horizontal and 0.167g vertical generated by the Design Basis Earthquake (DBE) when the canisters are stored in a drywell. Because the transfer shield interior is of the same configuration as the drywell, it is concluded that the canisters will not be affected by the loads from the moving transporter.

3.8 TRANSPORTER LOADS ON DRYWELL LINER

The transfer shield and transport vehicle must be positioned over a drywell to load a waste container from the transfer shield into the drywell. If the driver inadvertently drives the vehicle tires over the drywell liner flange or a drywell cover, then some of the truck weight will be transferred to the drywell.

The drywells have been designed to support the combined weight of the transfer shield and transport vehicle. Only part of the total load will be transmitted to the liner or cover because, at most, only one set of tires could be on the drywell. The drywell liner is cast into the grout cylinder up to the underside of the liner flange. Therefore, the weight would be transferred directly to the ground below and around the drywell. The drywell covers (both temporary and permanent) have been designed to take the maximum load from the transfer shield and transport vehicle without causing damage to the cover or the cover seal weld.

3.9 TRANSPORTER FIRE OR EXPLOSION

The only volatile material on the transporter will be the fuel in the transporter fuel tank. This tank holds approximately 50 gal of diesel fuel. A fire from 50 gal of fuel would burn for approximately 10 minutes, and could reach a flame temperature of about 1,000°F. The short duration and low temperature of this fire are not expected to damage the waste containers or

the transfer shield. The shielding materials (lead and Bisco NS-3) of the transfer shield are completely contained in seal-welded steel, and would not be lost even if in a molten state.

If an event of this type should occur, the transporter operator and site emergency personnel would respond and quickly extinguish the fire.

An explosion on the transporter is considered an extremely unlikely event. However, should an explosion occur, the amount of damage to the transfer shield is not expected to cause a safety problem. The steel and lead walls and doors on the shield may sustain some damage, but the shield should still be able to provide necessary shielding and structural capacity to allow it to be returned to the R&H Building for waste container unloading. Should the explosion cause rupture or damage to the waste container within the shield, the potential releases would not be greater than those discussed for drywell containment barrier failure in Section 3.15.

3.10 SEISMIC LOADS ON DRYWELL

The drywells and contained waste containers are designed to withstand maximum accelerations of 0.25g horizontal and 0.167g vertical for the DBE. The drywell liners are solid structures, cemented into the ground. Drywells and containers of similar designs have been tested by exposing the storage configuration to seismic conditions (accelerations, frequencies, and amplitudes) up to 0.75g. No liner or waste container failures resulted.

3.11 TORNADO WIND LOADS AND MISSILE IMPACT ON TRANSFER SHIELD

The transfer shield and transport vehicle could be exposed to tornado-associated phenomena. These phenomena include differential air pressure loads, missile impact, and tornado wind loads. Missile impact loads or wind loads could potentially damage the transfer shield or its mechanisms. This could result in loss of radiation-shielding capability or damage to the waste container.

The transfer shield consists of several layers of material. The waste container cavity is surrounded by a 0.25-in.-thick steel shell. Surrounding that is a lead cylinder at least 7 in. thick and a 1-in.-thick, carbon-steel shell. The outside of the shell is covered with a 2.5-in.-thick layer of Bisco NS-3 and a 0.25-in.-thick steel shell. These thicknesses and types of materials (similar to those of the spent-fuel transportation cask) are considered to be sufficient to prevent penetration of the transfer shield by tornado missiles.

The shield gates are recessed into the transfer shield, and would not be directly susceptible to tornado missiles. However, the actuating mechanisms for the shield gates and the hoist and cable could be damaged by tornado missiles. In no case could the shielding integrity or the waste container support functions of the shield gates be compromised. Recovery from damage to the gate-actuating mechanisms, the hoist, or the cable would include replacement of damaged components, using auxiliary shielding (if needed) to

lower the overall worker exposure. All damageable components have been designed for removal and replacement with the transfer shield filled with a waste container.

Wind-induced loads or missile loads could be postulated to cause the transfer shield and transport vehicle to tip over. The wind loads would be partially dissipated by the circular shield shape; the overall footprint of the transport vehicle would be sufficient to keep the transfer shield upright. Should the transfer shield be tipped over, damage to the waste container and transfer shield are expected to be minimal. Recovery steps would include uprighting the shield, using the storage facility mobile crane. The shield and the housings surrounding the gates are designed to withstand tipping and to maintain the integrity of the radiation shielding.

3.12 TORNADO WIND LOADS AND MISSILE IMPACT ON DRYWELL

The drywells could also be exposed to tornado-associated phenomena. Because all but the liner flange and cover of a drywell are installed below ground level, only differential air-pressure loads and missile-impact loads can be imposed on the drywell. The drywell covers are designed to withstand missile impacts and the load caused by differential pressure between the drywell and the atmosphere without failure.

3.13 VOLCANIC ASH FALLOUT

If a volcano were to erupt, volcanic ash could be deposited on the ground surface around the drywells. Because there are no ventilation ports or air filters to clog in the drywells, this event is not considered to be a problem. The thermal insulation provided by the ash should not result in a noticeable increase in the waste temperature. Most of the decay heat is transferred through the sides of the liner into the surrounding soil, so the thermal mass of the soil allows waste temperature changes to occur at a very slow rate. The added thermal resistance at ground level resulting from the ash would not significantly affect the waste temperature for a period of weeks or perhaps months. The ash could be removed from the storage facility over a period of several weeks and would, therefore, have very little impact on drywell thermal performance (and the resultant container integrity).

3.14 CANISTER FAILURE WITHIN DRYWELL

Fuel assemblies will be dismantled, and the rods (approximately 792 PWR fuel rods from three 17 x 17 PWR fuel assemblies or approximately 441 fuel rods from seven 8 x 8 BWR fuel assemblies) will be loaded into a 1-ft-dia by about 16-ft-long steel canister inside the hot cell. The canister will be sealed, the weld inspected, and the integrity of the canister checked before the transfer shield is loaded for transport to the drywell.

A canister failure within the drywell could be postulated to occur as a result of seismic accelerations or because of undetected defects in the canister or its welds. Failure of the canister would release any contained gases (including any radioactive gases from potentially failed fuel rods)

into the drywell interior. These gases would be contained by the secondary containment barrier provided by the liner and seal-welded cover. Periodic drywell gas sampling will detect the gases. The drywell would be opened, and the canister would be returned to the R&H Building for inspection and replacement or overpacking.

Because the canister is of stainless steel, corrosion of the wall should not be a potential failure mechanism. It is the primary containment barrier; therefore, inspection of the base materials and welds will be performed to ensure that flaws in material or defects in welds are not present in the storage canisters. The completed canister is also leak-checked to ensure integrity. The canister has been designed to take loads transmitted by seismic accelerations. The canister has also been designed to withstand internal pressure loads from the assumed rupture of all spent-fuel rods. These features and preventive measures should ensure canister integrity.

3.15 DRYWELL CONTAINMENT BARRIER (LINER, COVER, AND WELD) FAILURE

The drywells are lined with a minimum of 0.50-in.-thick carbon steel, and are sealed by a welded carbon-steel cover with a minimum thickness of 1.0 in. This containment barrier is intended to safely contain any gases that may be in the drywell. Failure of this barrier can be postulated from undetected weld or material defects, as a result of large impact force on the drywell cover, or from corrosion of the liner.

Failure of the drywell containment barrier could result in release of any contained gases (this could include radioactive gases if failure of both canister and fuel rod cladding has occurred) or could allow water to enter the drywell interior. These have potential safety impacts. Drywell barrier, canister, and fuel rod cladding failure may have the potential to result in radiological releases beyond prescribed limits at the site boundary (no calculations have yet been made). Water in the drywell interior has the potential to result in a criticality incident.

The drywell has been designed to take seismic loads, drop loads, tornado wind loads, and wind-generated missile loads without allowing the containment barrier to fail. With the design safety margins for canister and drywell liners and covers, no single event is postulated to cause failure of these two containment barriers.

The liner and cover materials and the welds on the liner barrier are inspected to ensure that flaws or defects beyond the prescribed limits do not exist in the drywell. The final seal weld is also inspected, and the drywell is leak-checked to ensure barrier integrity. Exposed portions of the containment barrier are coated for corrosion protection, and will be inspected periodically and repaired, recoated, etc., if needed. The liner is protected from corrosion by a zinc-based paint primer, by the grout layer around it, and by a cathodic-protection system. In addition, for the spent fuel drywells, the soil around the liner has a temperature high enough to prevent moisture from reaching the liner. Periodic barrier pressure checks

will be performed to ensure continued integrity. Should any leak be detected, the drywell will be opened, and the canister returned to the R&H Building.

For the conceptual design phase, no criticality calculations have been performed for water in the drywell. Previous calculations, performed for intact fuel stored in water-filled drywells and for consolidated spent fuel stored in water, indicate that MRS drywell spent-fuel storage will be subcritical under all conditions. This would have to be confirmed by calculations during detailed design.

The above-described design features and activities should ensure that the drywell containment barrier is maintained in a leaktight configuration and that radiological releases are kept to a minimum.

4.0 SUMMARY TABLES

The evaluation of the concrete cask events and accidents, along with their effects on safety, have been summarized in the following four tables. These tables address concrete cask and drywell events and accidents, their causes and consequences, preventive or mitigating features or actions, and post-event actions for recovery. The tables have been separated into potential accidents (Tables 4-1 and 4-3) and events (Tables 4-2 and 4-4) that have the potential to result in failures. Each table defines the section of this design study in which that accident or event is discussed.

REFERENCE

1. Kurasch, D.H., et al., "Experimental Demonstration Package Program Canister Final Design Report," AESD-TME-3047, Westinghouse Advanced Energy Systems Division, Aug. 1980.

Table 4-1 - Concrete Cask Accident Assessment

Section No.	Accident	Potential Consequences	Possible Cause	Preventive Features	Postevent Action
2.1	Canister drops from shielded canyon cell during loading	1. Damaged shielded canyon cell discharge port 2. Damaged cask liner flange 3. Damaged canister (possible rupture and radiological release)	1. Handling and lifting equipment failure 2. Grapple release	1. Safety margins designed into equipment 2. Periodic equipment load testing and inspections 3. Safety interlocks on grapple 4. Canister designed for drop without rupture	1. Inspect damaged areas and equipment 2. Repair damaged areas 3. Repair or replace failed handling equipment as required 4. Inspect canister and replace or overpack as required
2.2	Concrete cask plug drops from shielded canyon cell during loading	1. Damaged shielded canyon cell discharge port 2. Damaged cask liner flange 3. Damaged plug	1. Handling and lifting equipment failure 2. Grapple release	1. Safety margins designed into equipment 2. Periodic equipment load testing and inspections 3. Safety interlocks on grapple	1. Inspect damaged areas and equipment 2. Repair damaged areas and equipment 3. Repair or replace failed handling equipment if required 4. Inspect plug and replace or repair as required
2.3	Cask cover and welding equipment drop onto cask liner flange	1. Damaged cask cover 2. Damaged welding equipment 3. Damaged liner flange	Handling and lifting equipment failure	1. Safety margins designed into equipment 2. Periodic equipment load testing and inspection	1. Inspect and repair handling equipment as required 2. Inspect cover and welding equipment 3. Replace or repair damaged cover and equipment 4. Inspect liner flange and repair as required

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Table 4-1 (Contd)

Section No.	Accident	Potential Consequences	Possible Cause	Preventive Features	Postevent Action
2.5	Fire and/or explosion on transporter	1. Heat load on cask resulting in exceeding waste temperature limit 2. Damaged cask 3. Damaged transporter	1. Fuel leakage 2. Collision with another vehicle	1. Periodic inspection and maintenance of transporter 2. Fire detection and firefighting equipment on transporter 3. Limited transporter fuel capacity and speed 4. Cask designed to take impact loads (from explosion)	1. Extinguish fire rapidly 2. Gas sample cask interior and leak check containment barrier 3. Move to storage or return to R&H Building for unloading as required 4. Repair or replace transporter as required
2.6	Loaded cask drops during transfer to storage pad	1. Damaged cask (possible liner rupture and radiological release) 2. Damaged transporter 3. Damaged storage pad	Handling and lifting equipment failure	1. Safety margins designed into equipment 2. Periodic equipment load testing and inspection 3. Handling equipment safety interlocks 4. Cask designed for drop-impact loads without rupture	1. Inspect handling equipment, cask, pad, and transporter 2. Repair or replace equipment as required 3. Repair storage pad as required 4. Leak check cask containment barrier; store or return to R&H Building for unloading as required

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Table 4-2 - Concrete Cask Event Assessment

System No.	Event	Possible Cause	Potential Consequences	Preventive Features	Postevent Action
2.4 2.7 2.8	External loads on cask	1. Start/stop of transporter 2. Earthquake 3. Tornado winds and missiles	1. Cask tips over 2. Penetration of cask containment barrier (possible radiological release)	1. Transporter speed limited to 3 mph 2. Cask designed with margin to take loads without barrier rupture	1. Upright cask 2. Gas sample cask interior and leak check containment barrier 3. Move cask to storage or return to R&H Building for unloading as required
2.9	Volcanic ash on and around cask	Volcanic eruption	Heatup of cask contents caused by increased resistance to heat flow	1. Thermal mass of cask prevents rapid heatup 2. Margin designed into cask	1. Clean ash from cask and storage area 2. Gas sample cask interior and leak check containment barrier 3. Move cask to storage or return to R&H Building for unloading as required
2.11	Cask containment barrier failure	1. Impact loads 2. Undetected material or weld defects	1. Possible radiological release (if canister and fuel-rod cladding failed) 2. Cask susceptible to water inflow	1. Periodic load testing and inspection of handling equipment 2. Cask designed to take all design basis (Category I) loads without barrier rupture 3. Periodic leak check of cask containment barrier 4. Inspection of liner, cover, and weld before assembly	1. Gas sample cask interior and leak check containment barrier 2. Return cask to R&H Building for unloading if required

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Table 4-2 (Contd)

Section No.	Event	Possible Cause	Potential Consequences	Preventive Features	Postevent Action
2.12	Canister failure	1. Impact loads 2. Undetected material or weld defects 3. Corrosion	1. Contamination spread inside cask 2. Possible radiological release inside cask	1. Inspection of canister after construction and after sealing 2. Periodic gas sampling check of cask interior for canister leakage	1. Gas sample cask interior and leak check containment barrier 2. Return cask to R&H Building for unloading if required 3. Repair or overpack failed canister

Table 4-3 - Drywell Accident Assessment

Section No.	Accident	Possible Cause	Potential Consequences	Preventive Features	Postevent Action
3.1	Canister drops from shielded canyon cell into transfer shield	1. Damaged canister (possible rupture and radiological release) 2. Damaged transfer shield	1. Handling and lifting equipment failure 2. Grapple release	1. Safety margins designed into equipment 2. Periodic testing of hoist and grapple 3. Safety interlocks	1. Inspect canister and replace or overpack as required 2. Inspect transfer shield and replace or repair as required 3. Inspect handling equipment and repair as required
3.2	Canister drop into drywell	1. Damaged canister (possible rupture and radiological release) 2. Damaged drywell liner	1. Handling and lifting equipment failure 2. Grapple release	1. Safety margins designed into equipment 2. Periodic testing of hoist and grapple 3. Safety interlocks	1. Return canister to R&H Building 2. Inspect drywell liner and repair as required 3. Repair or replace failed handling equipment as required
3.3	Shield plug drop into drywell	1. Damaged shield plug 2. Damaged drywell liner	1. Handling and lifting equipment failure 2. Grapple release	1. Safety margins designed into equipment 2. Periodic testing of hoist and grapple 3. Safety interlocks	1. Inspect and repair handling equipment as required 2. Remove canister and return to R&H Building 3. Inspect drywell and repair as required 4. Inspect shield plug and repair or replace as required
3.4	Opening or closing of shield gates during canister loading/unloading or transfer	1. Radiation exposure to workers 2. Damage to canister, gate, or lifting equipment 3. Canister drop into drywell	1. Shield gate fails to open or close when actuated 2. Interlocks fail	1. System interlocks 2. Periodic equipment inspections and maintenance	1. Return canister to R&H Building, inspect, and replace or overpack 2. Inspect shield gate and repair or replace as required 3. Check interlocks and repair or replace components as required

le 4-3 (Contd)

Section No.	Accident	Possible Cause	Potential Consquences	Preventive Features	Postevent Action
3.5	Drywell cover and welding equipment drop onto drywell liner flange	1. Damaged liner flange 2. Damaged cover 3. Damaged welding equipment	Handling and lifting equipment failure	1. Safety margins for equipment 2. Periodic load testing and inspections	1. Inspect handling equipment and repair or replace as required 2. Inspect liner flange and cover 3. Repair liner flange as required 4. Repair or replace cover as required
3.6	Transfer shield or transporter malfunction during canister loading	1. Radiation exposure to workers 2. Damage to canister (possible rupture and radiological release) 3. Damage to transporter or handling and lifting equipment	1. Operator error 2. Actuation of transfer shield gates during transport 3. Transporter movement during transfer shield unloading	1. Safety interlocks 2. Position indicators and electrical interlocks 3. Transporter inoperative during loading and unloading of shield	1. Inspect transfer shield and repair or replace as required 2. Return canister to R&H Building and inspect, replace, or overpack as required 3. Inspect safety interlock system and replace or repair as required
3.9	Fire and/or explosion on transporter	1. Heat load on waste will possibly exceed temperature limits 2. Damaged transfer shield 3. Damaged transporter	1. Fuel leakage 2. Collosion with another vehicle	1. Periodic inspection and maintenance of transporter 2. Fire detection and firefighting equipment on transporter 3. Limited transporter fuel capacity and speed 4. Transfer shield designed to take heat load and impact load from explosion	1. Extinguish fire rapidly 2. Inspect transfer shield and transporter for damage 3. Repair or replace transporter or transfer shield as required 4. Return canister to R&H Building and inspect, replace, or overpack as required

Table 4-4 - Drywell Event Assessment

Section No.	Event	Possible Cause	Potential Consequences	Preventive Features	Postevent Action
3.7 3.7 3.11	External loads on canister in transfer shield	1. Transporter start or stop 2. Earthquake 3. Tornado winds and missiles	1. Transfer shield tips over 2. Penetration of shield by missile	1. Transporter speed limited 2. Transfer shield designed to take impact loads without canister damage	1. Upright transfer shield 2. Return canister to R&H Building and inspect, replace, or overpack as required 3. Inspect transfer shield and replace or repair as required
3.13	Volcanic ash on drywell storage area	Volcanic eruption	Heatup of waste container caused by increased resistance to heat flow	1. Thermal mass of soil prevents rapid heatup of drywell 2. Margin designed into drywell	Clean ash from drywell storage area
3.14	Canister failure	1. Undetected material or weld defects 2. Corrosion	1. Contamination spread inside drywell 2. Possible radiological release inside drywell	1. Canisters will be leak checked and inspected for material and weld integrity 2. Completed canister integrity monitored periodically by drywell gas sampling	1. Remove canister and return to R&H Building 2. Inspect canister and replace or overpack as required
3.15	Drywell containment barrier failure	1. Impact loads on cover 2. Undetected material or weld defects 3. Corrosion	1. Possible radiological release (if canister and fuel-rod cladding failed) 2. Water in drywell	1. Liner leak checked and inspected before installation 2. Drywell leak tested after initial sealing and periodically 3. Drywell designed to take impact loads	1. Remove canister and return to R&H Building 2. Inspect drywell and cover, and repair or replace as required
3.10 3.12 3.8	External loads on drywell	1. Earthquake 2. Tornado missiles 3. Transporter	Failure of drywell containment barrier (possible radiological release if canister and fuel-rod cladding failed)	Drywell designed to take loads and missiles without barrier rupture	1. Gas sample drywell interior and leak check containment barrier 2. Remove canister to R&H Building as required 3. Inspect drywell and repair as required

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DESIGN STUDY DS-28

FISSION GAS DIFFUSION IN A CASK OR DRYWELL

1.0 INTRODUCTION

The purpose of the investigation discussed in this study was to determine whether the presence of a leak of fission gas out of a fuel rod stored within a cask or drywell could be detected and measured by a conventional monitoring device attached to a sampling port near the top of a drywell or the bottom of a cask within a reasonable time. The analysis is based on the simple diffusion of the fission gas through the backfill gas (helium or air). The alternative could be to install a flow system of some kind so that any leakage gas within the storage unit could be moved toward the detector by forced convection.

2.0 THE DIFFUSION MODEL

2.1 ASSUMPTIONS

(1) The applicable diffusion problem can be stated as follows:

The region $0 < x < \ell$. Zero initial concentration. No flow of matter at $x = 0$ (insulation condition). Constant flow Q into the region at $x = \ell$.

The detector is assumed to be at $x = 0$, and the leak at $x = \ell$.

(2) An isothermal condition was assumed. However, calculations were made for three temperatures: 300, 400, and 500°K, so that the general effect of temperature is made explicit. Thermal-gradient-generated convection (or, indeed, any convective process) would only speed up the movement of fission gas; therefore, the isothermal diffusion model is conservative.

(3) The leak occurs at one end of the storage unit and the gas sampling port and the detector are at the other end. This is obviously the most conservative situation, and sets the full inside depth of the storage unit as the diffusion distance; the value 600 cm was assumed.

(4) The diffusion path is unrestricted; i.e., there are no regions between the leak and the detector where any dimension of the flow cross section is less than the molecular mean free path. This includes pathways through the shield plug at the top of the drywell, where channels at least several millimeters in diameter are assumed.

(5) The effective initiation time of the leak is assumed to be the time at which the fission gas concentration in the neighborhood of the leak is twice the detection limit of the detector. On this basis, an arbitrary time can be calculated for what might be called the detection lag: the time between effective initiation time and the time when the local concentration at the detector just becomes detectable, that is, is one-half that at the leak. (Although the calculations allow for other assumptions about detection lag and detection limits, the foregoing were found to be convenient for the present analysis.)

2.2 CALCULATIONS

Reference 1 presents the solution to the heat flow problem corresponding to the diffusion model presented above as follows:

$$\nu = \frac{2Q\sqrt{\kappa t}}{K} \sum_{n=0}^{\infty} \left\{ \text{ierfc} \frac{(2n+1)\ell - x}{2\sqrt{\kappa t}} + \text{ierfc} \frac{(2n+1)\ell + x}{2\sqrt{\kappa t}} \right\} \quad (1)$$

where ierfc(x) is the integral of the complementary error function, erfc(x):

$$\text{ierfc}(x) = \int_x^{\infty} \text{erfc}(\zeta) d\xi \quad (2)$$

erfc(x) is defined as

$$\text{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-\xi^2} d\xi \quad (3)$$

Both functions are extensively tabulated. In Equation (1), ν is the temperature, t is the time in seconds, Q is the heat flux at $x = \ell$ in cal/sq cm-s, K is the thermal conductivity in cal/cm-s-deg, and κ is the thermal diffusivity in sq cm/s. K and κ are related by

$$K = \kappa \rho c_p \quad (4)$$

where c_p is the specific heat in cal/g-deg and ρ is the density in g/cubic cm. To convert Equation (1) to a diffusion equation solution (the partial differential equations for heat flow and for diffusion are identical in form, but their parameters are dimensionally different), one can reinterpret the parameters as follows: (1) set the thermal diffusivity κ equal to the diffusion coefficient D; both constants have the same dimensions, (2) allow the dimensions of the product ρc_p to be unity; thus, the thermal conductivity K also becomes equal to D, and (3) allow ν to become a molar concentration C in moles/cu cm. The dimensions then become consistent if Q is expressed in moles/sq cm-s. Equation (1) then becomes:

$$C = 2Q\sqrt{t/D} \sum_{n=0}^{\infty} \left\{ \text{ierfc} \frac{(2n+1)\ell - x}{2\sqrt{Dt}} + \text{ierfc} \frac{(2n+1)\ell + x}{2\sqrt{Dt}} \right\} \quad (5)$$

It is sufficient, however, to calculate the ratio $C(x=0)/C(x=\ell)$ as a function of time. This ratio is:

$$\frac{C(0)}{C(\ell)} = \frac{2 \sum_{n=0}^{\infty} \text{ierfc} \frac{(2n+1)\ell}{2\sqrt{Dt}}}{\sum_{n=0}^{\infty} \left\{ \text{ierfc} \frac{n\ell}{\sqrt{Dt}} + \text{ierfc} \frac{(n+1)\ell}{\sqrt{Dt}} \right\}} \quad (6)$$

Equation (6) can be simplified by making use of the identity

$$\text{ierfc}(x) = \frac{1}{\sqrt{\pi}} e^{-x^2} - x \, \text{erfc}(x) \quad (7)$$

and shifting index in the first summation in the denominator. The result is

$$\frac{C(0)}{C(\ell)} = \sum_{n=0}^{\infty} \text{ierfc} \frac{(2n+1)\ell}{2\sqrt{Dt}} \Bigg/ \left\{ \frac{1}{2\sqrt{\pi}} + \sum_{n=0}^{\infty} \text{ierfc} \frac{(n+1)\ell}{\sqrt{Dt}} \right\} \quad (8)$$

Finally, we can consolidate the dimensionless group $1/2\sqrt{Dt}$ into constant α :

$$\frac{C(0)}{C(\ell)} = \sum_{n=0}^{\infty} \text{ierfc}\,(2n+1)\alpha \Bigg/ \left\{ \frac{1}{2\sqrt{\pi}} + \sum_{n=0}^{\infty} \text{ierfc}\, 2(n+1)\alpha \right\} \quad (9)$$

Using Equation (9), $C(0)/C(\ell)$ is plotted as a function of α in Figure 2-1. Values of ierfc(x) were taken from the tabulation in Reference 1.

To use Figure 2-1, appropriate values of the diffusion coefficient D are needed. These were calculated by the method of Reference 2 for the systems helium-krypton, helium-xenon, air-krypton, and air-xenon at each of the temperatures 300, 400, and 500°K. The results are presented in Table 2-1. A value of the parameter α was then calculated for every system-time-temperature combination, using 600 cm for the value of ℓ, and the corresponding value of $C(0)/C(\ell)$ from the curve in Figure 2-1. The results are all tabulated in Table 2-1. Finally, the data of Table 2-1 were plotted for each gas system as $C(0)/C(\ell)$ versus time, one curve for each temperature. The resulting graphs are presented as Figure 2-2. A horizontal line on each of these graphs at $C(0)/C(\ell) = 0.5$ cuts the diffusion curves at times corresponding, according to our leak initiation time assumption, to the incidence of detectability at the monitor. These times, therefore, correspond to the detection lag times defined in Section 2.1. They are also tabulated in Table 2-1.

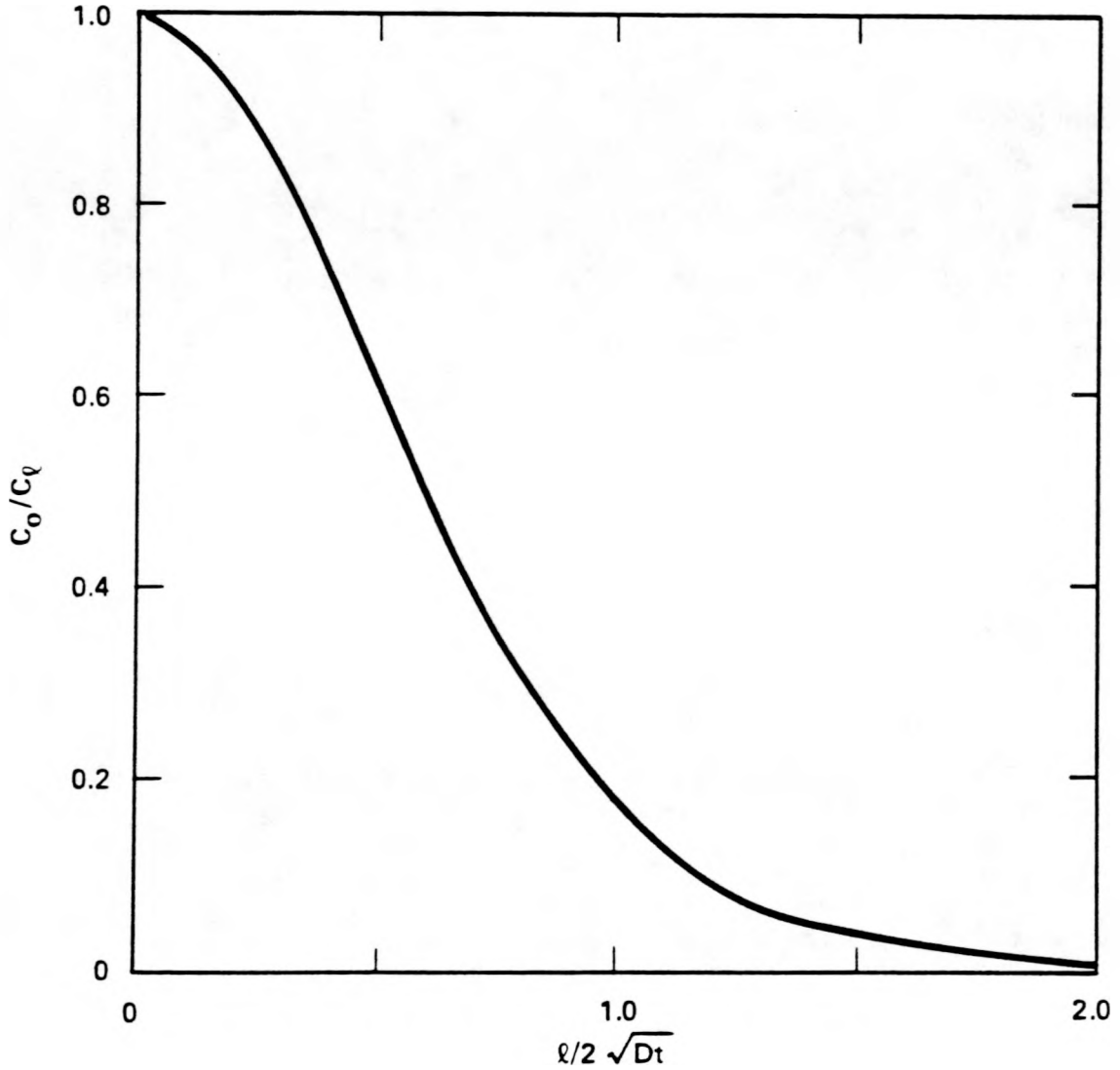

Figure 2-1 - Concentration Ratio at Each Face of the Region $0 < x < \ell$ (With No Flow at $x = 0$, flux Q at $x = \ell$)

Table 2-1 - Fission Gas Diffusion in an MRS Cask
(a) The Systems He-Kr and He-Xe

System	Temperature (°K)	Diffusion Coefficient (cm^2/s)	Time (days)	α	$C(0)/C(\ell)$	Detection Lag (days)
He-Kr	300	2.011	1	0.720	0.39	1.5
			3	0.416	0.72	
			10	0.228	0.90	
	400	3.258	1	0.565	0.55	0.8
			3	0.326	0.81	
			10	0.179	0.93	
	500	4.694	1	0.471	0.65	0.5
			3	0.272	0.86	
			10	0.149	0.95	
He-Xe	300	1.829	1	0.755	0.25	1.8
			3	0.436	0.69	
			10	0.239	0.88	
	400	2.965	1	0.593	0.52	1.0
			3	0.342	0.80	
			10	0.187	0.92	
	500	4.296	1	0.492	0.63	0.5
			3	0.284	0.86	
			10	0.156	0.94	

Table 2-1 (Contd)
(b) The Systems air-Kr and air-Xe

System	Temperature (°K)	Diffusion Coefficient (cm^2/s)	Time (days)	α	C(0)/C(ℓ)	Detection Lag (days)
Air-Kr	300	0.569	1	1.35	0.06	5.3
			3	0.781	0.34	
			10	0.428	0.71	
	400	0.950	1	1.05	0.16	2.9
			3	0.604	0.51	
			10	0.331	0.81	
	500	1.40	1	0.862	0.28	1.8
			3	0.498	0.62	
			10	0.273	0.86	
Air-Xe	300	0.496	1	1.45	0.05	6.3
			3	0.837	0.29	
			10	0.458	0.66	
	400	0.833	1	1.12	0.12	3.5
			3	0.646	0.46	
			10	0.354	0.79	
	500	1.23	1	0.920	0.23	2.0
			3	0.531	0.59	
			10	0.291	0.83	

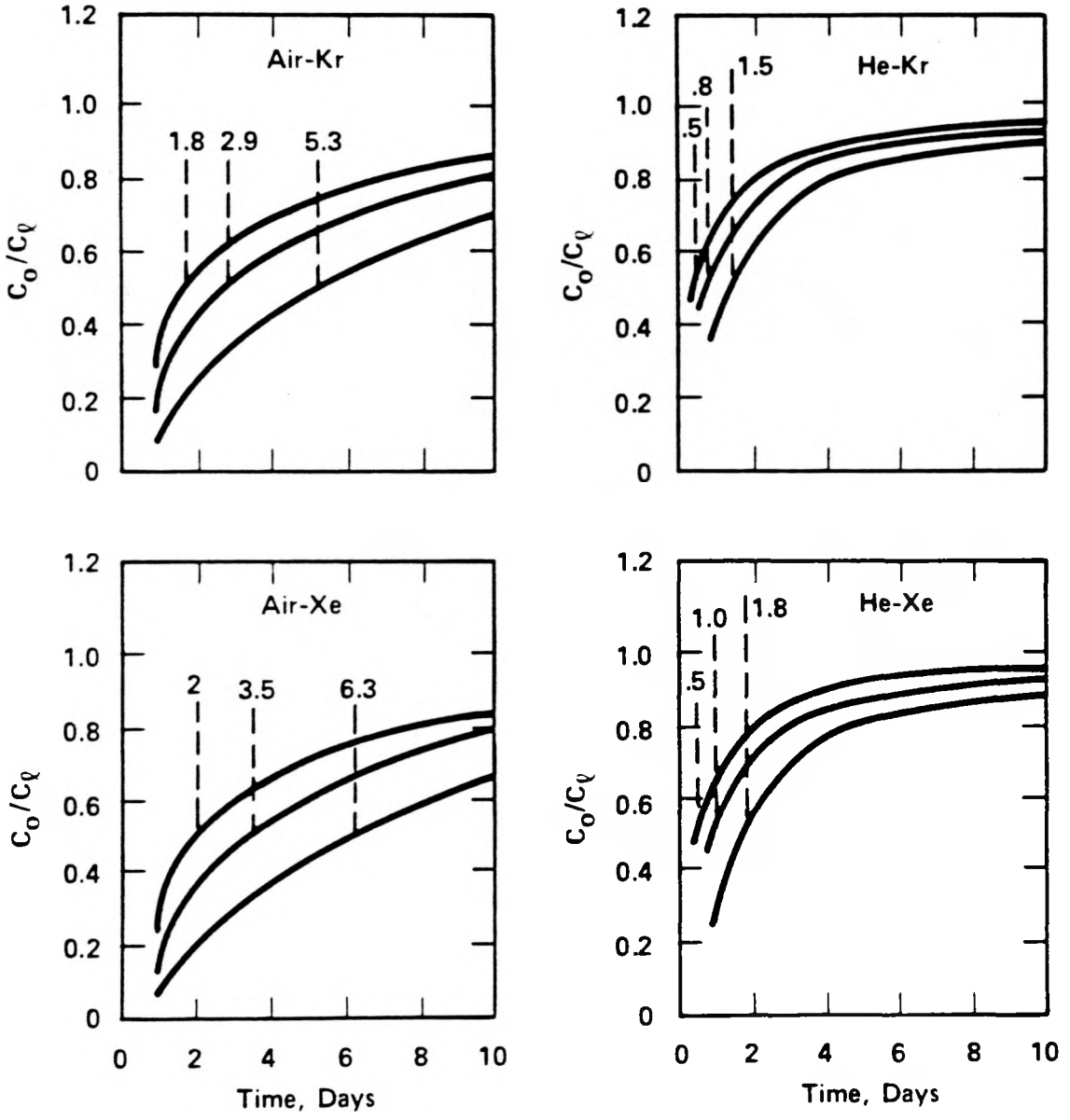

Figure 2-2 - Calculation of Detection Lag Times

3.0 RESULTS AND CONCLUSIONS

The detection lag times vary from system to system in a predictable way, being least in the He-Kr system and greatest in the air-Xe system; He is a small atom/molecule and displays the less resistance to diffusion by a solute molecule (Kr or Xe) than air, whereas Xe is a larger atom/molecule than Kr, and its progress through either solvent gas (He or air) is slower. Likewise, the effect of increasing temperature in increasing diffusion rates is well known.

The significant result here is the magnitude of the lag times. For the worst case, air-Xe at 300°K, the lag is just a little more than 6 days. Any thermal convection, an effect almost certain to supplement the isothermal diffusion actually investigated, could only reduce that time. Moreover, the gas temperature during most of the cask lifetime, in the case of spent fuel, will be higher than 300°K. Therefore, positive detection of a leak is ensured, under these conditions, for any monitoring schedule that implies reviewing each cask at intervals not less than 5 or 6 days. Alternatively, if continuous monitoring of all casks is undertaken, any leak would be detected within 5 or 6 days of its inception. If the backfill gas were helium rather than air, the maximum lag time would decrease to about 2 days.

Based on the quoted results, it appears that a sweep gas system or other form of forced convection system for moving any fission gas toward the detector is unnecessary, and it is recommended that none be installed.

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1. Carslaw, H.S., and Jaeger, J.C., Conduction of Heat in Solids, First Edition, Clarendon Press, Oxford, 1950.

2. Hirschfelder, J.O., Curtiss, C.F., and Bird, R.B., Molecular Theory of Gases and Liquids, John Wiley, New York, 1967.

FOREWORD

The following is a generic study that is applicable to the site, wherever it may be located. The only difference between the site characteristics used in this study that would make any difference in the results and the site characteristics now defined in Revision 3 of the Functional Design Criteria (FDC) is the soil thermal conductivity.

This study uses a conductivity of 0.8 W/m-K versus 1.2 W/m-K in the Revision 3 FDC. The concrete cask surface temperature change would be minimal for a soil thermal conductivity of 1.2 W/m-K (approximately 1°C) and only at the base of the concrete cask.

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DESIGN STUDY DS-29

CONCRETE CASK THERMAL ANALYSIS

1.0 INTRODUCTION

The concrete cask thermal analysis was performed to assist in the conceptual design of concrete casks for the Monitored Retrievable Storage (MRS) Facility, and to verify that the concepts for storage of spent fuel or high-level waste (HLW) in concrete casks were acceptable from a heat-transfer standpoint. The specific purpose of the analysis was to predict critical peak temperatures (peak cladding temperatures for the spent-fuel cases and peak canister and glass temperatures for the HLW cases), and compare them with specified limits: 375°C for both spent-fuel cladding and HLW canisters. Additionally, parametric analyses were performed to provide a functional understanding of the thermal interaction between the heat-generating waste forms and the cask components. Analyses were performed of a variety of waste forms and cask geometries.

The purpose of this design study is to describe and document the thermal analysis performed in support of the conceptual concrete cask designs, and to discuss the results that were obtained. The analyses performed for this design phase were based on the analysis approach and methods developed from spent-fuel drywell testing and analyses at the E-MAD Facility (Ref. 13) and from repository waste-package analyses (Ref. 14 and 15). Brief justifications for assumptions made in the models and in parameters used in the analyses are presented in this design study, with further details available in the noted references.

In Section 2, the waste forms considered are identified. Section 3 provides a description of the concrete cask. The approach to the thermal analysis is outlined in Section 4, and the applied computation methods are described in Section 5. Relevant properties of involved materials are discussed in Section 6. The results of the analysis are discussed in Section 7. Section 8 provides conclusions.

2.0 WASTE FORMS

As indicated above, two basic waste forms have been considered: spent-fuel and high-level waste. Within these two categories, waste-form variations were also considered. These variations and the reference waste forms are described below.

2.1 SPENT FUEL

The reference spent-fuel waste form consists of a bundle of spent-fuel rods in a sealed, stainless steel canister. Pertinent data relative to the fuel rods and canister configuration are identified in Figure 2-1. The bundle was assumed to contain 792 fuel rods from three Westinghouse 17 x 17 PWR, spent-fuel assemblies. Only the PWR case was analyzed because of its higher heat load per canister. In waste-package design, it is generally accepted that an acceptable design for PWR spent-fuel rods will also be acceptable for BWR rods. The spent-fuel canister was assumed to have no internal partitions, which could enhance heat transfer from the bundle interior to the canister, and the rods were assumed to be in loose bundle form and arranged on a triangular pitch. Although the bundle is not banded, the packing would still be fairly tight; the minimum average spacing between adjacent rods is estimated at approximately 0.05 cm. All calculations for this reference case assumed that the fuel had been discharged from the reactor with 33,000-MWD/MTU burnup, and that it cooled 10 yr before being placed in dry storage. The heat-generation rate corresponding to these conditions is 1,650 W per canister. Thermal performance calculations for the reference waste form were also made for burnup/cooling period-combinations of 33,000/5 and 55,000/10, corresponding to heat-generation rates at dry storage emplacement time of 2,520 and 3,150 W per canister, respectively.

The alternate spent-fuel waste form for MRS is an intact PWR spent-fuel assembly encapsulated in the reference canister. Because the heat-generation rates at dry storage emplacement time for 33,000/10, 33,500/5, and 55,000/10 intact spent fuel are assumed to be 550, 840, and 1,050 W per canister, respectively, which are lower than that for the consolidated 33,000/10 spent-fuel case, no intact-fuel calculations were made.

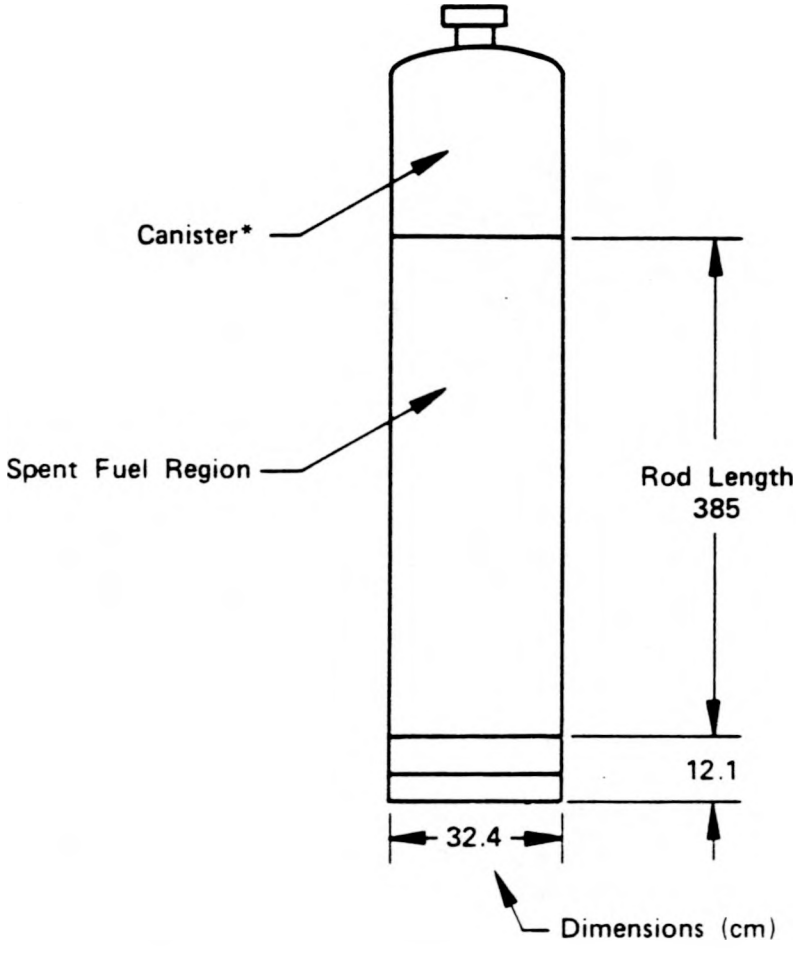
2.2 HIGH-LEVEL WASTE

2.2.1 Reference High-Level Waste Form

The HLW forms considered during the study are identified in Figure 2-2. In each case, the waste form was assumed to consist of a borosilicate glass matrix containing the nuclear waste material installed in a stainless steel canister. In the reference case, the waste-form heat-generation rate at dry storage emplacement time was assumed to be 2,200 W, as specified in Reference 1 for HLW 10 yr out of reactor. This corresponds to a volumetric heat-generation rate of 0.01055 W/cm^3.

2.2.2 Alternative High-Level Waste Forms

Alternative HLW forms 1 and 2 were assumed to employ the same glass/waste composition and volumetric heat-generation rate as the reference case. Thus, the heat-generation rates at emplacement time for these alternatives were 3,300 and 19,100 W, respectively.



* Canister Wall Thickness – 0.635 cm
Canister Material – Stainless Steel

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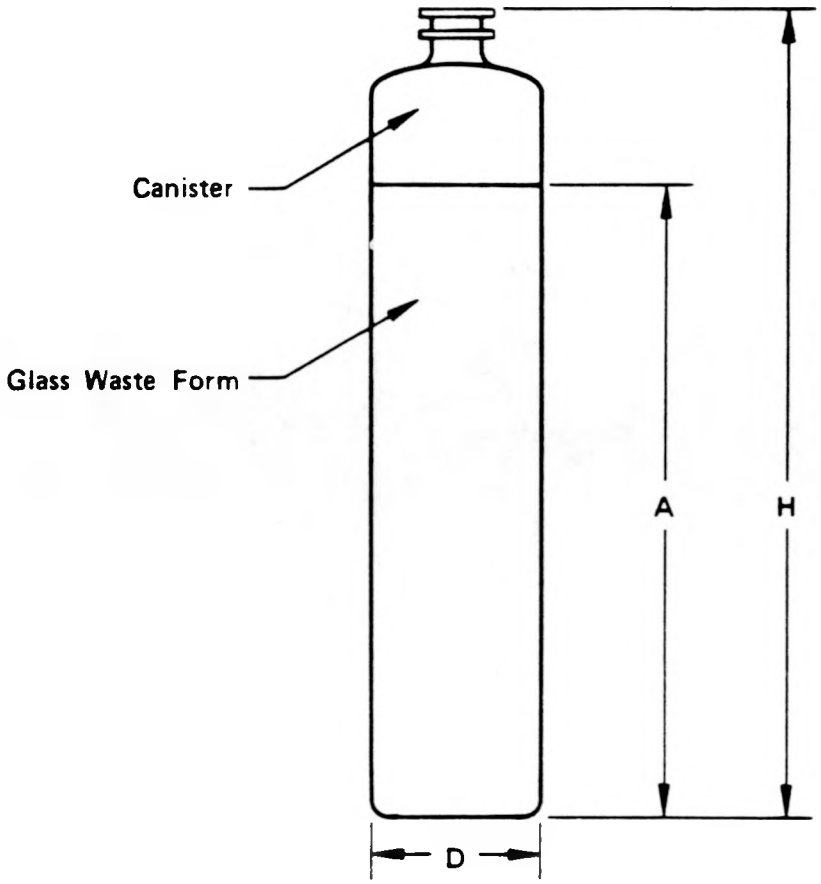
Figure 2-1 - Spent-Fuel Waste Form Physical Data



Dimensions (cm)*

Case	D	A	H
Reference	32.4	274.3	304.8
Alternate 1	32.4	411.5	457.2
Alternate 2	76.2	411.5	457.2
West Valley	61.0	274.3	304.8

*Canister Wall Thickness – 0.635 cm
Canister Material – Stainless Steel

Figure 2-2 - High-Level Waste Form Physical Data

2.2.3 West Valley High-Level Waste Form

The West Vally (WV) HLW waste form was also assumed to be based on borosilicate glass. However, the total waste-form heat load specified by Reference 1 is only 220 W, corresponding to a volumetric heat-generation rate of 0.00029 W/cm^3.

2.3 DECAY-HEAT CHARACTERISTICS

Decay-heat data in normalized form are presented in Table 2-1 for spent fuel and HLW. Data are not provided for WV HLW because a transient analysis was not required to demonstrate acceptable thermal performance.

3.0 DESCRIPTION OF CASK

For this analysis, two similar cask designs were considered. These designs are alike except for the adjustments necessitated by the different radiological, thermal, and geometric characteristics of the waste forms each design is expected to store. The basic cask design is shown, and dimensions important to the determination of peak temperatures are given, in Figure 3-1. The spent-fuel cask is designed to store fuel rods in 12 cylindrical storage canisters; the high-level waste cask is designed to store up to nine canister-encased "logs" of glass-encapsulated waste. These general arrangements of canisters within these casks are shown schematically in Figure 3-2.

The casks are composed primarily of concrete (which is necessary as a shield to maintain safe radiological conditions near the cask surface). The casks are cylindrical in shape, and are set on concrete pads in a triangular pitch array. The center-to-center cask spacing was assumed to be 17 ft-0 in.

As discussed in Section 6, the thermal analysis included the examination of vertical and radial rebar as possible cask components. Rebar for the cask would be composed of concrete-embedded, radially conductive segments placed to provide more efficient removal of waste-generated heat. The amounts of radial rebar were varied in the analysis, but were always assumed to be composed of carbon steel. The vertical rebar was of the same material, but the rebar content was fixed so that there were 45 vertical rebar segments running closely along the height of the liner (8-deg spacing) and 90 vertical segments along the height of the outer surface (4-deg spacing). The direct effect of various amounts of radial rebar is discussed in Section 7.

4.0 ANALYSIS APPROACH

Analyses of the concrete casks were performed in two steps. These steps represent a natural division in the thermal and geometric characteristics of the cask. This two-step approach also reduced the complexity of the analysis, and permitted the creation of a flexible matrix of results that could be integrated to provide evaluations for a variety of design combinations.

Because temperatures of interest occur separately in the cask wall and in the heat-generation region, these were considered independently with two analysis

Table 2-1 - Waste Form Normalized Decay-Heat Data

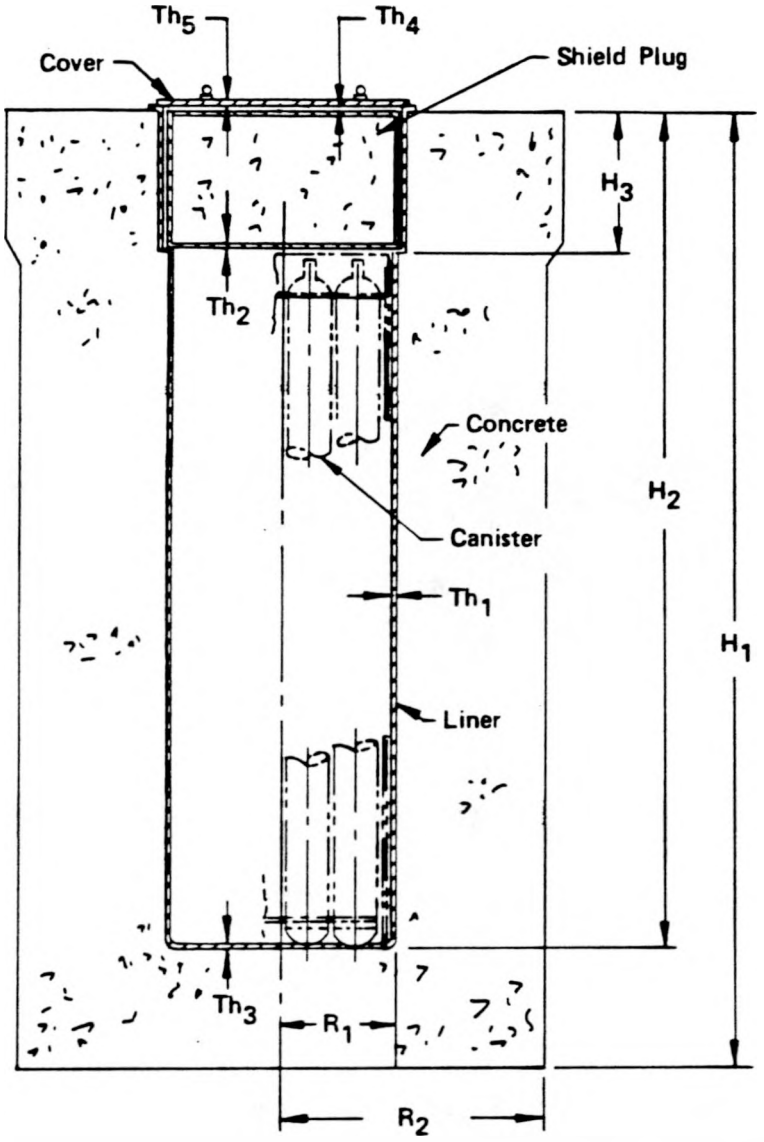
Time After Emplacement (yr)	HLW	SF(1)	SF(2)	SF(3)
0	1.0	1.0	1.0	1.0
5	0.83	0.84	0.85	0.65
10	0.72	0.75	0.76	0.56
15	0.66	0.68	0.69	0.50
20	0.60	0.63	0.63	0.46
30	0.48	0.52	0.53	0.39

Specifications

HLW: 10 yr out of reactor
SF(1): 33,000 MWD/MTU, 10 yr out of reactor
SF(2): 55,000 MWD/MTU, 10 yr out of reactor
SF(3): 33,000 MWD/MTU, 5 yr out of reactor

Data Sources

HLW: Reference 2
SF(1): Reference 3
SF(2): Reference 4
SF(3): Reference 4



Dimension	Component	S. Fuel (cm)	CHLW (cm)
R_1	Liner (Outside)	91.4	76.2
R_2	Concrete (Outside)	182.8	182.8
H_1	Concrete (Height)	670.5	670.5
H_2	Liner (Length)	588.0	570.2
H_3	Shield Plug	95.2	105.2
Th_1	Liner (Thickness)	5.0	5.0
Th_2	Plug Liner (Thickness)	0.6	2.5
Th_3	Liner Bottom (Thickness)	1.2	2.5
Th_4	Air Gap (Thickness)	1.9	1.9
Th_5	Cover Plate (Thickness)	5.0	5.0

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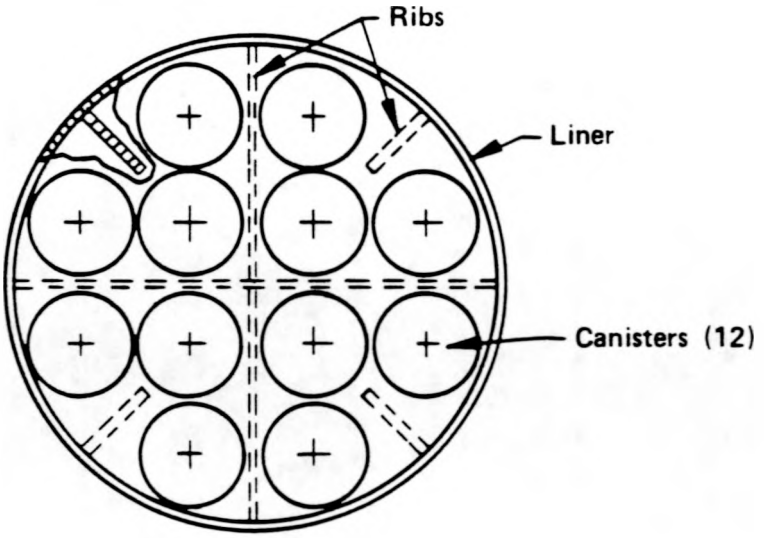
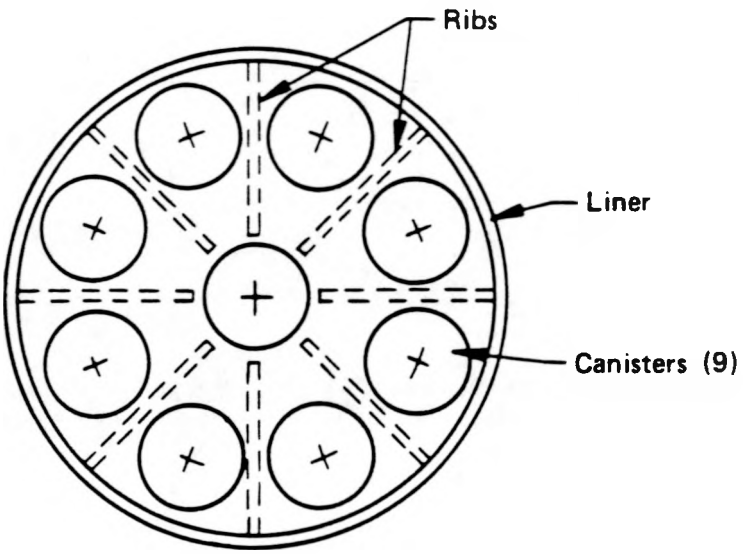
Figure 3-1 - MRS Concrete Cask Conceptual Design



(a) Spent Fuel Canister Array



(b) HLW Canister Array

Figure 3-2 - Cask Internal Arrangement

models: the overall cask model and the cask internal model. The liner separating the concrete cask wall and the heat-generation region acts as the common boundary. The cask wall and liner temperature distributions were determined by treating the region containing the waste canisters as a single, homogeneous material with a heat-generation rate determined by the heat output of the waste and the volume of the designated heat-generation region (see the two-dimensional cross section of this axis-symmetric "overall" cask model in Figure 4-1). With this, the dimensions of the cask, and the thermal properties of the materials involved, it was possible to determine the peak liner temperatures as a function of time.

These peak temperatures were then applied as a boundary condition in a two-dimensional (r, θ) thermal-analysis model of the cask interior. Because this is the region of greatest interest, the two-step analysis is especially advantageous. Many different internal configurations can be analyzed by using the liner temperatures secured by a single overall cask analysis.

Where the overall cask model employed a simple heat-generation region, the internal model applied a structure that reflects the geometry of the waste canisters in the interior region of the cask. Figure 4-2 illustrates the interior model configurations used for spent fuel and HLW.

The models are two-dimensional sections of the internal region of the cask that take advantage of the 45-deg symmetry of the arrangement within the spent-fuel cask interior and the 22.5-deg symmetry of the HLW cask interior. The ribs shown were included in the design for thermal purposes. In the spent-fuel case, each modeled section had two ribs, one half as long as the other, where the shorter rib could be modeled with an optional end plate.

5.0 FINITE-ELEMENT MODELING

The models described in the following sections were created for solution by use of the ANSYS finite-element transient thermal analysis computer program (Ref. 5). The models are described as they were used with the ANSYS program, along with a brief summary of the model verification.

5.1 OVERALL CASK MODEL DESCRIPTION

The finite-element overall cask model developed for this study contained 189 four-noded, axis-symmetric elements and 224 nodes (see Figure 5-1). It was generally intended for the examination of temperature distributions throughout the cask, and primarily for determination of peak liner temperatures. Mainly because of the inherent flexibility of finite-element modeling, the analysis provided useful comparative data on many variations of the cask design. As indicated in Section 3, the same cask model was used for the analysis of both spent-fuel and HLW cask systems. Primary components of the cask model include the heat-generation region, liner, concrete cask wall, support pad, and the soil base. The liner step and cask outer-diameter step were not modeled because their impact on peak waste-form temperature predictions should be negligible.

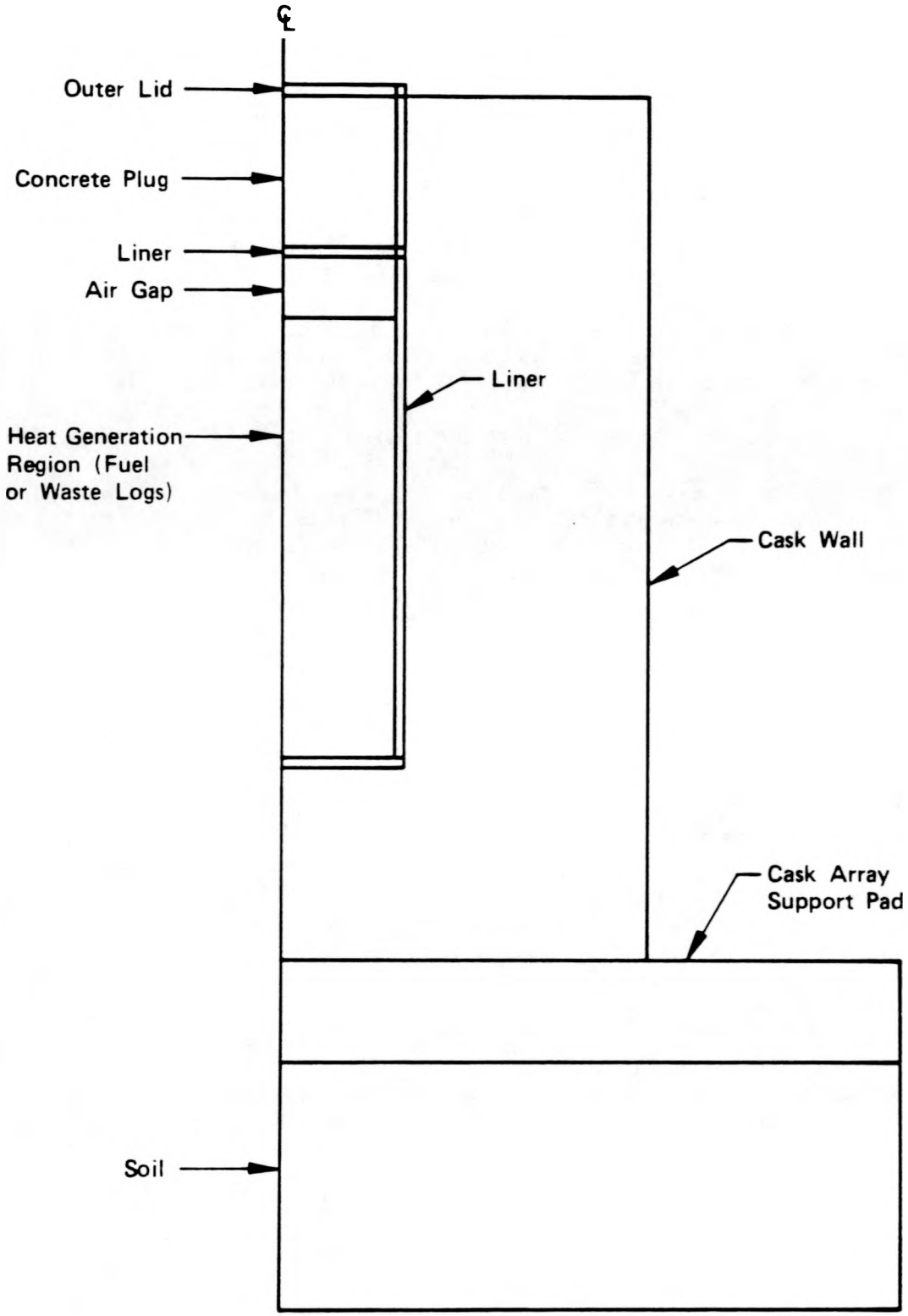
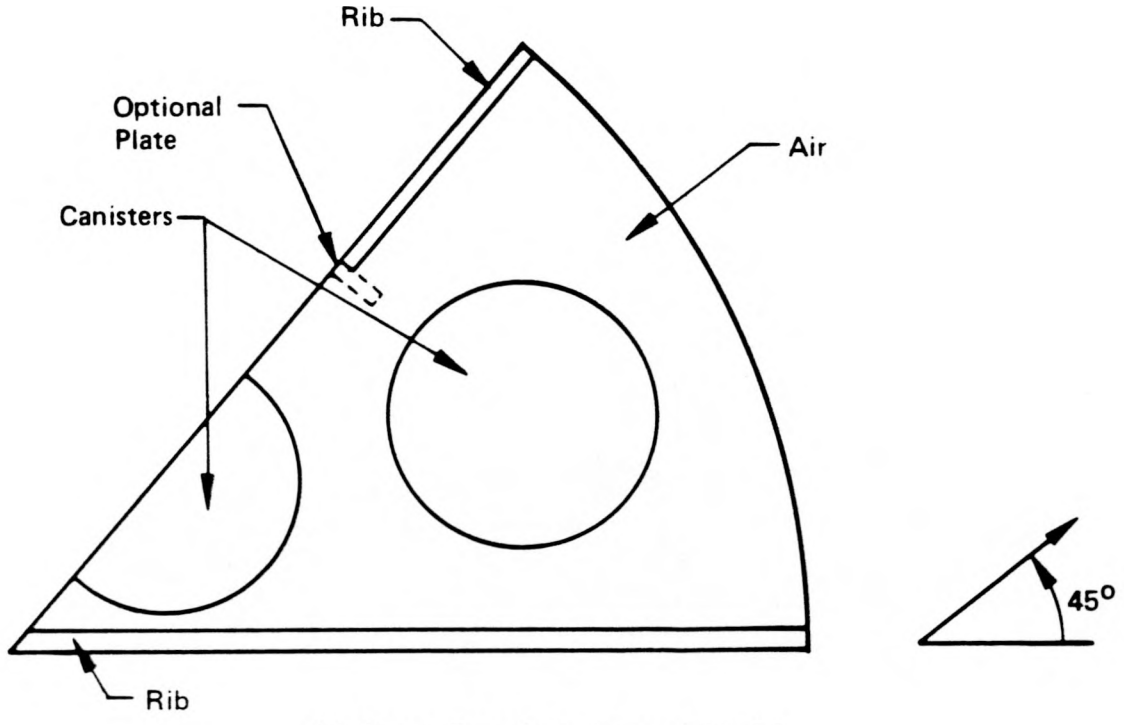
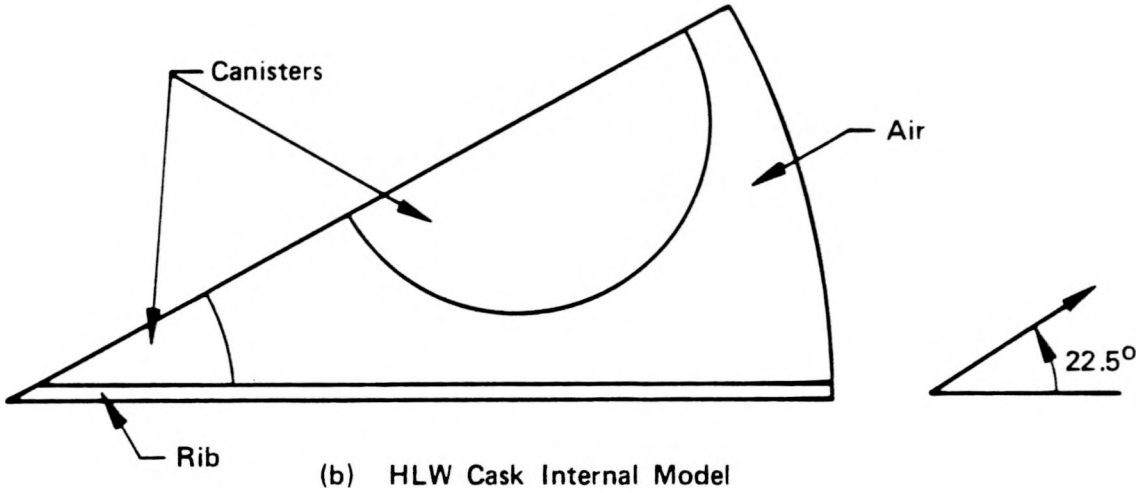


Figure 4-1 - Overall Cask Model



(a) Spent Fuel Cask Internal Model



(b) HLW Cask Internal Model

Figure 4-2 - Cask Internal Model Components

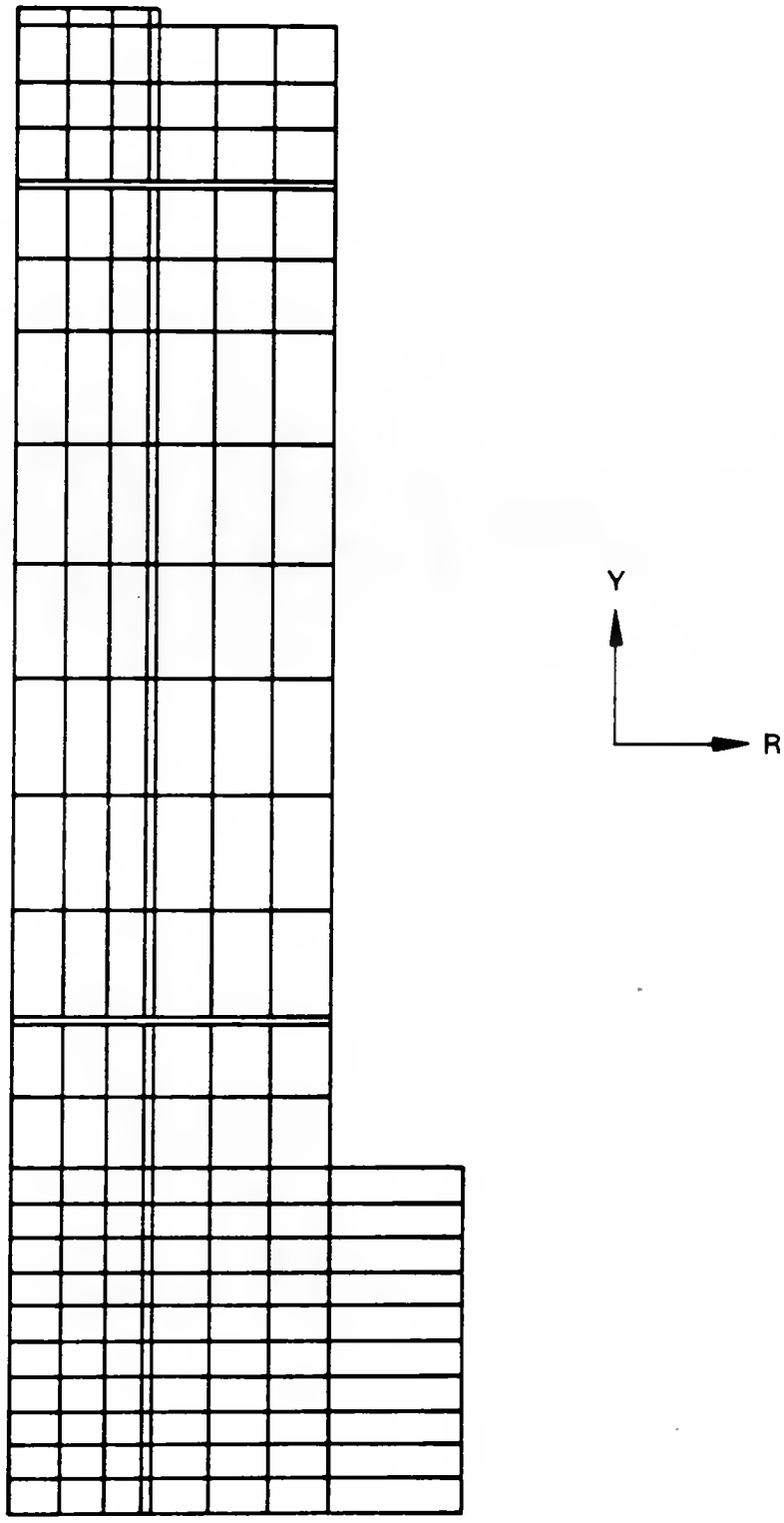


Figure 5-1 - Overall Cask Finite-Element Model

The waste-form region in the overall cask thermal model was viewed as a homogeneous heat-generating zone in contact with the liner. Internal detail was not assigned to the waste-form model because the primary purpose of the calculation was to predict peak temperatures at the cask liner, not within the waste form itself. Thus, correctly representing the radial-direction heat flux in the waste form was important, and this involved establishing a heated length for the waste form.

In the consolidated spent-fuel analysis, the heated length was set at 407 cm. This value included 385 cm for the rod length plus allowances at each end for conduction in the canister wall. In the HLW case, this length was set at the waste-form length plus an additional 10 cm to allow for axial heat conduction in the canister wall above the waste.

Recognizing that the selection of the effective heated length was based in part on judgment, calculations for the spent-fuel case were made to estimate peak liner temperature sensitivity to variations in heated length. A calculation was made with a heated length of 365 cm, which is the active fuel length. The results indicated that this change would alter the peak liner temperature by approximately 12°C. Slight inaccuracies in the heated length and the resulting errors in the peak liner temperatures are viewed as being acceptable, considering the conceptual design purpose of the analysis. For detailed design studies, however, it may be required to treat the waste-form region more rigorously, and in a way that would avoid the need to establish an effective length of the heat-generating zone.

The region between the shield plug and the waste form was modeled with an effective thermal conductivity in the vertical direction that represented the combined effects of conduction and radiation; convection was neglected. Peak liner temperatures depend primarily on concrete, rebar, and liner conditions, and relatively little on the system of resistances above the waste form. Therefore, treating the region beneath the shield plug with an approximate model was found to be satisfactory; large modeling inaccuracies in this region could be tolerated without having a significant impact on the predicted peak liner temperature, as noted in Reference 13.

All model parametric studies were performed with the cask radiological requirements in mind. As an example, Figure 5-2 shows the effect of variations in steel liner thickness on the concrete cask wall thicknesses for the spent-fuel cask design to maintain a constant cask surface dose rate. The increases in steel liner thickness provide added shielding, allowing the concrete wall thickness to be reduced and permitting more desirable thermal conditions. The concrete/steel tradeoff was approximated by using a fixed-mass model of the composite wall, based on the densities of these materials (see Table 5-1).

The fins on the outer surface of the liner are in the design primarily to support the concrete rebar structure. They have been included in the overall cask model. The analysis assumed that 16 carbon-steel fins (1.9 x 8.9 cm) were spaced uniformly around the liner, and that their lengths equaled the cask height. Thermally, their effect was included through average

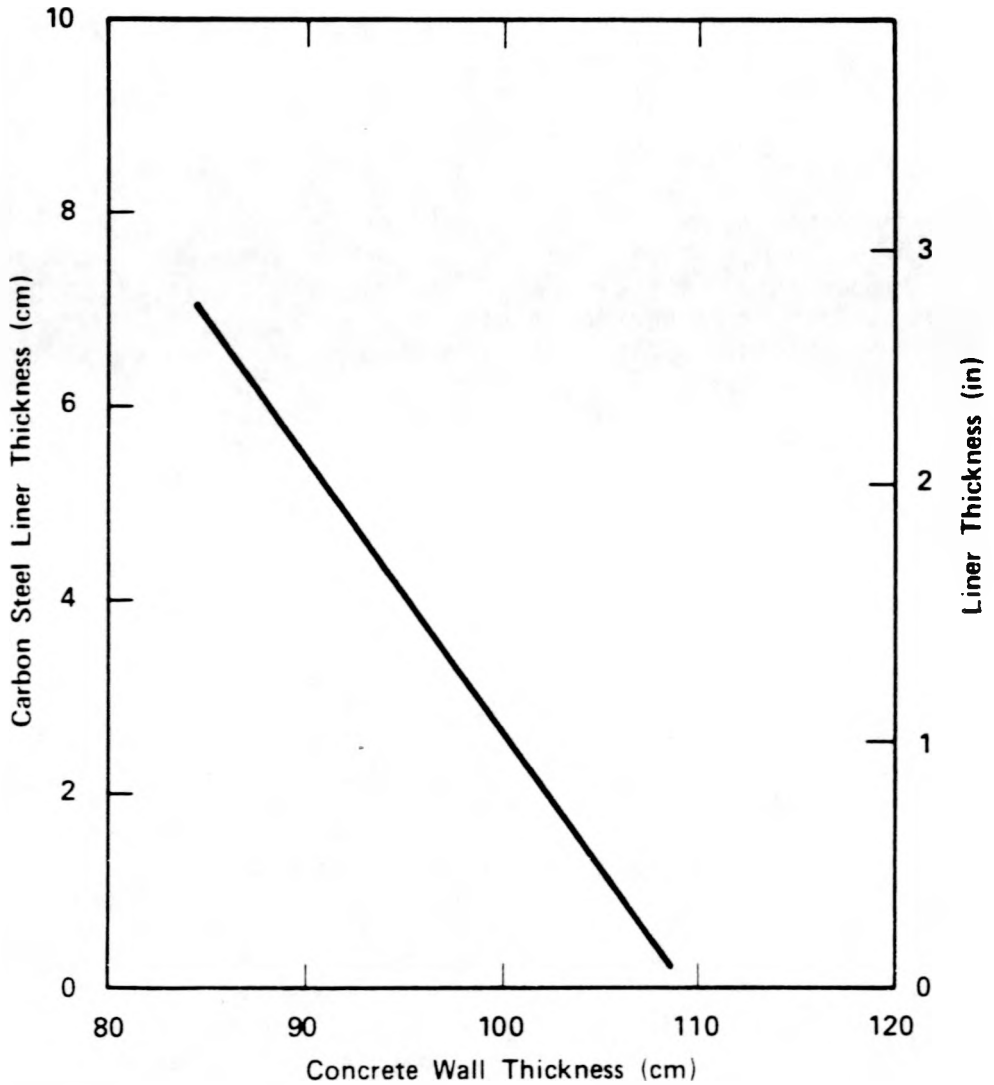


Figure 5-2 - Liner/Cask Wall Relationship for Constant Cask Surface Dose Rate

Table 5-1 - Material Properties for Concrete Cask Thermal Analysis

Material	Thermal Conductivity (W/cm-K)	Density (g/cm^3)	Specific Heat Capacity (j/g-k)	Emissivity
Soil	0.008[a]	1.68[b]	1.05[b]	--
Carbon steel (liner)	0.40[c]	7.84[c]	0.46[c]	0.5[d]
Stainless steel (canister)	0.17[c]	7.84[c]	0.46[c]	0.5[e]
Spent fuel	f	9.28[g]	0.26[g]	0.8[f]
High-level waste	h	3.1[i]	0.75[i]	--
Concrete	0.0182[c]	2.28[c]	0.84[c]	--
Air	0.0003[c]	j	j	--
Aluminum (liner ribs)	2.16[c]	2.7[c]	0.87[c]	0.5[k]

[a]Reference 6.
[b]E-MAD soil properties (Ref. 13, p. 93).
[c]Typical handbook values; analysis used air conductivity as a function of temperature.
[d]Reference 9, p. 4-110.
[e]Reference 8, p. 475.
[f]See Section 5.2.2 for discussion of effective spent-fuel thermal conductivity modeling.
[g]Reference 3, p. 35-A.
[h]$K(W/cm\text{-}K) = 0.0085 + 7.5 \times 10^{-6}\ T(°C)$ over the range T = 0 to 600°C (Ref. 2).
[i]Reference 3, p. 36-A.
[j]Neglected.
[k]Assumed treated; e.g, see Reference 11 (pp. 15-18) data for anodized-aluminum surfaces.

conductivity values in the radial and axial directions. In each case, the conductivity calculation was based on a model that viewed heat transfer as occurring in parallel paths of carbon steel and concrete, with equal temperature differentials across the paths.

The percentage rebar term, as used in this thermal analysis, identified the fraction of the radial cross-sectional areas that must contain carbon-steel rebar. This term was then used to develop a radial-direction thermal conductivity for the cask wall. The model for that development assumed parallel heat flow through concrete and carbon steel, with equal temperature differentials imposed across the two paths. The resulting conductivity was assumed to be constant with radius.

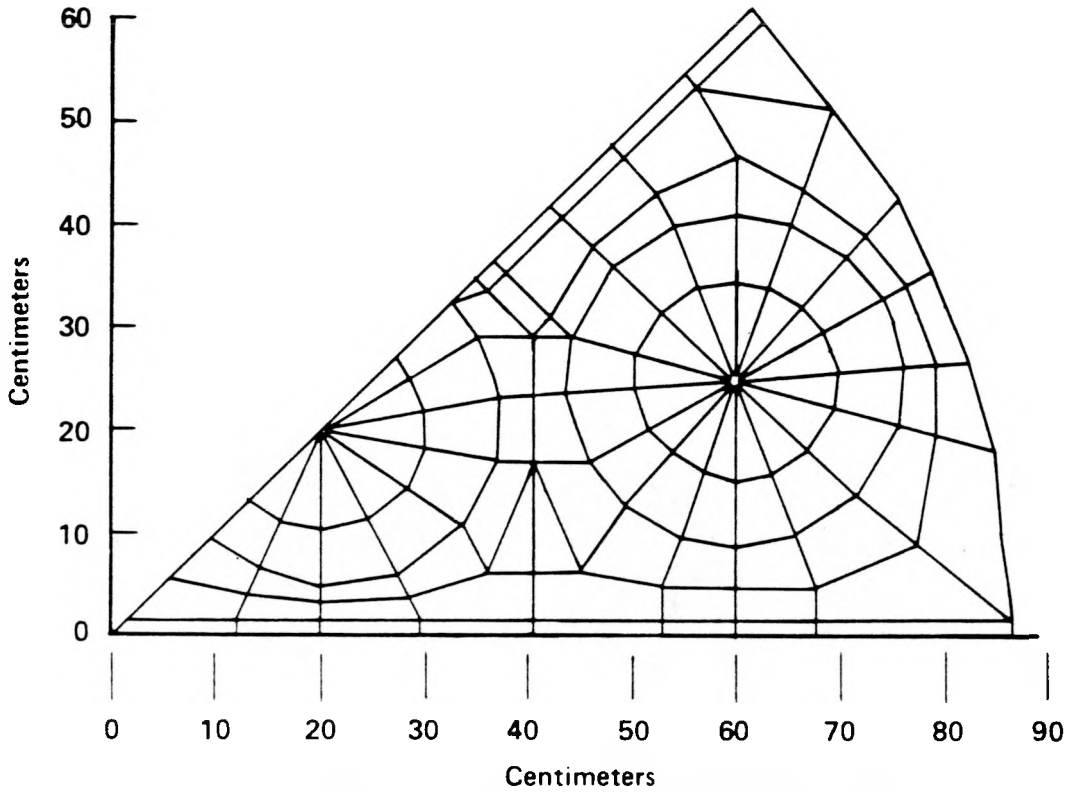
Radiation and convection heat losses from the cask were included in the models by the use of an effective convection model. Atmospheric temperature was assumed to be constant at 38°C. This ambient temperature is considered to be conservative enough to account for solar-insolation effects, based on the analysis of E-MAD cask thermal data (Ref. 13).

The concrete pad below the cask was assumed to be in perfect contact with the cask bottom surface. The pad was modeled as being 45.7 cm deep and having a 259-cm radius. The soil below the pad was given an appropriate depth for this analysis. The criterion for selecting the model depth for the soil base was that no temperature change should occur at the lowest boundary during the time period of interest. An adiabatic boundary was imposed at that location. This approach effectively simulated the heat sink provided by the soil. The depths required for cask modeling were found to be in the 5- to 10-m range.

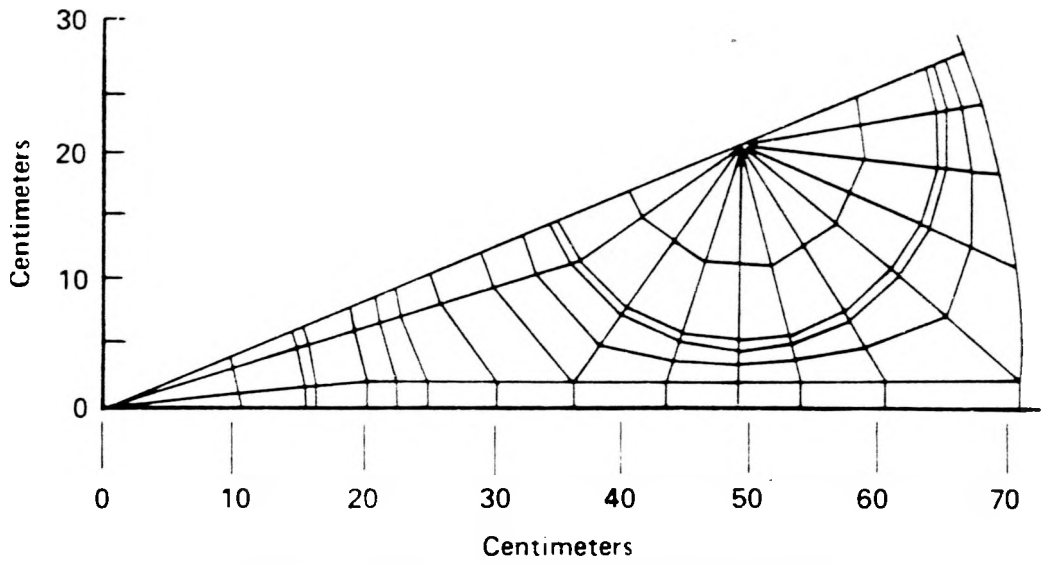
Verification was provided by using the described ANSYS model to calculate the radial temperatures in successive material layers resulting from defined boundary conditions in a steady-state system. These temperatures compared very well with hand calculations, which applied well-understood heat-transfer equations.

5.2 MODEL INTERNAL DESCRIPTIONS

The model used to predict temperatures in the interior of the spent-fuel cask contained 112 two-dimensional plane elements, of various geometries, and 115 nodes (see model in Figure 5-3a); the analysis of the nine-canister HLW systems required the application of a separate model (see Figure 5-3b). This HLW model used 84 elements and 96 nodes. Both models contain three major components: heat-generation regions, conductive ribs, and air-filled regions. Heat transfer in the air-filled regions was simulated by an effective thermal conductivity model (with appropriate temperature dependence) that represented the combined effects of conduction, convection, and radiation.



(a) Spent Fuel Cask Internal Finite-Element Model



(b) CHLW Cask Internal Finite-Element Model

Figure 5-3 - Internal Finite-Element Models

5.2.1 Effective Thermal Conductivity External to Canisters

An effective thermal conductivity method was used to model heat transfer across the air-filled regions between canisters and between canisters and the liner/rib assembly. This approach - which considers thermal radiation, conduction, and convection - was used because the method was judged to provide a satisfactory model of the process. Also, it significantly simplified the modeling process because radiation and convection did not require explicit treatment. Peak waste-form temperatures were found not to be strongly dependent on variations in the effective conductivity. With this simplification, more time and effort were available to parametrically examine the effect of various cask design features on cask thermal performance.

Heat transfer from a canister (containing either spent fuel or HLW) to its surroundings in the cask occurs primarily in the radial direction across an air-filled gap. In deriving the effective conductivity, those surroundings were simulated by a cylindrical surface (concentric to the canister) having a radius of 9.0 in. (canister radius = 6.375 in.). This provided a reasonable representation of the actual gap that will exist around each canister. Then, considering the spent-fuel case, a canister heat load of 1,650 W (distributed uniformly over a heated canister length of 407 cm[1]) was assumed, and the temperature differential across the radial air gap was calculated for a range (50 to 350°C) of outer surface temperatures. The calculation considered the three heat-transfer modes; the resulting temperature differentials were then used to derive effective thermal conductivity values that could be expressed as a function of the average temperature in the air gap. This calculation was done by using the relationship for radial heat conduction in the wall of a hollow cylinder. Thus,

$$k_e = \frac{Q}{2\pi l \Delta T} \ln \frac{r_o}{r_i}$$

where

k_e = effective thermal conductivity

$\frac{Q}{l}$ = heat load per unit axial length

r_i, r_o = inner and outer radii

ΔT = gap temperature differential $(T_i - T_o)$

Modeling of the radiant heat transfer across the annulus was based on the following expression:

[1]The 407-cm heated length led to a low estimate of canister wall heat flux and a conservatively small effective thermal conductivity. The heated length used for the internal model analysis was 365 cm.

$$Q = \frac{\sigma A_i}{\frac{1}{\varepsilon_i} + \frac{r_i}{r_o}\left(\frac{1}{\varepsilon_o} - 1\right)}\left(T_i^4 - T_o^4\right)$$

where

σ = Stefan-Boltzmann constant
ε_i, ε_o = emissivities at inner and outer radii
A_i = inner surface area
T_i, T_o = inner and outer surface temperature, °K

Conduction and convection calculations across the radial gap were based on a well-known effective thermal conductivity approach (Ref. 7, pp. 330-331). The method considers two concentric cylindrical surfaces, separated by a gas and operating at different temperatures. Heat transfer from one surface to the other occurs by conduction through the gas and by local convection cells. The gap is assumed to be closed at each end, so there is zero net gas throughput. The effective conductivity describing the combined effects of conduction and convection is related by a correlation to the gas thermal conductivity and to its Grashof and Prandtl numbers. Properties are evaluated at the average gas temperature; the length term in the Grashof number is the gap thickness. The Grashof number and gap thickness ranges covered by data supporting the correlation bracket the values involved in the effective conductivity calculations for this study. The correlation is, therefore, applicable.

In the radiation calculation, a value of 0.5 was assigned to both emissivities. As indicated in Reference 8 (p. 475), this is a typical value for stainless steel (canister material), and is probably a conservative value for oxidized carbon-steel plate (cask liner). This conservatism is indicated by emissivity data provided, for example, in References 9 (p. 4-110) and 10 (p. 192). Generally, an emissivity of 0.5 for an aluminum surface (cask ribs) would be an excessively high value; however, there is evidence - e.g., Reference 11 (pp. 15-18) - that surface effects such as anodizing could elevate the emissivity into the 0.4 to 0.6 range. A heat-resistant surface preparation could certainly provide even higher values. Because the aluminum ribs are in the design primarily to enhance heat transfer, it would appear unreasonable for the design to accept the low emissivity of an unconditioned aluminum surface, thus compromising the performance gain offered by the high thermal conductivity of aluminum

The effective thermal conductivity resulting from this process is depicted as a function of air temperature in Figure 5-4. The curve shows an exponential effect that becomes stronger at the higher temperatures, and that is caused, of course, by the radiation component. The function was input directly into the cask internal finite-element model. Because the model represents an approximation, it was of interest to determine the effect on peak cladding temperature of variations in the conductivity model. The results of this sensitivity study are presented in Figure 5-5. They show that a 30% reduction in the conductivity values would increase the predicted peak fuel cladding temperature by only 11°C. This is viewed as a small

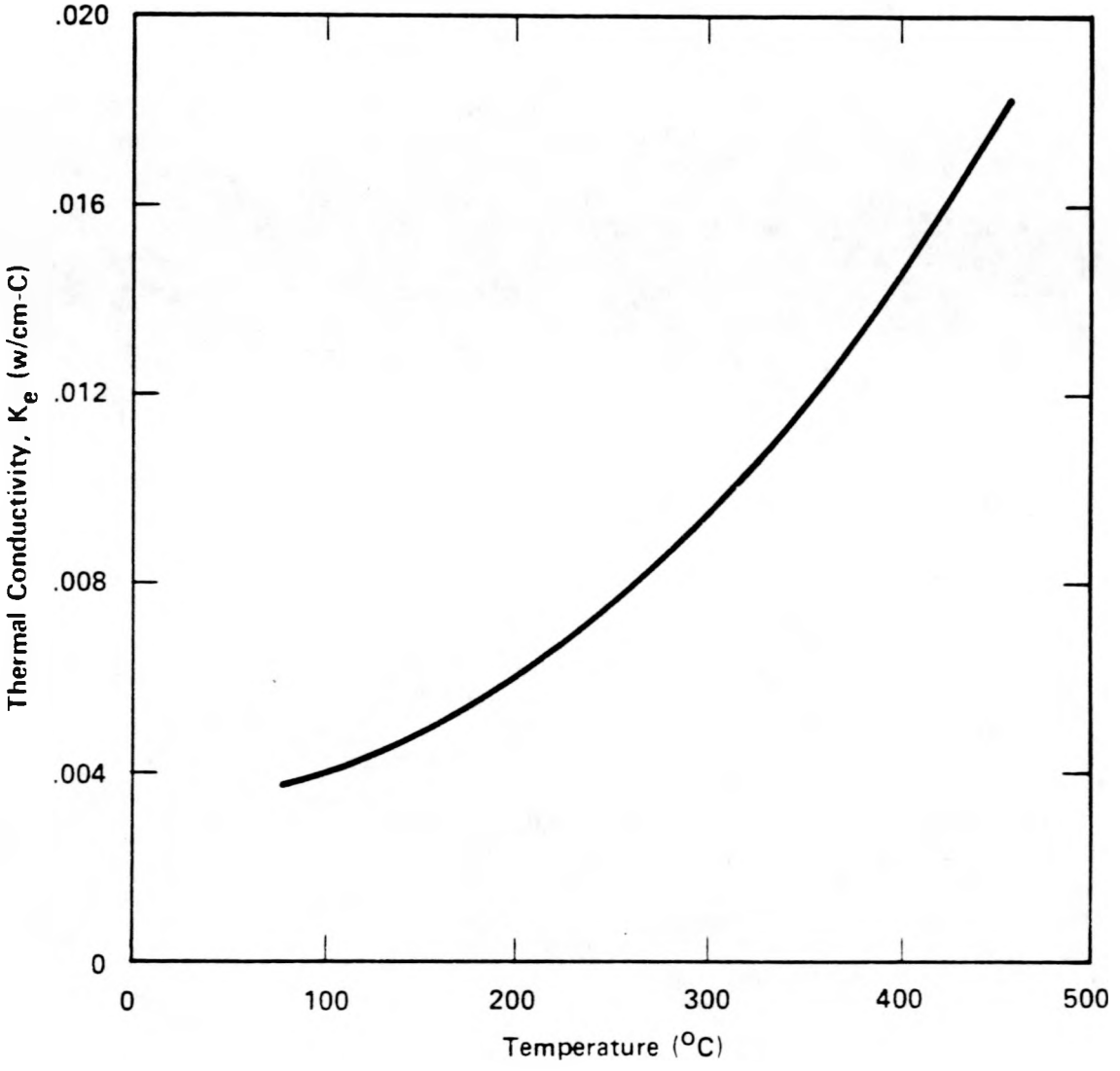


Figure 5-4 - Air Zone Effective Thermal Conductivity Model - Cask Internal Model

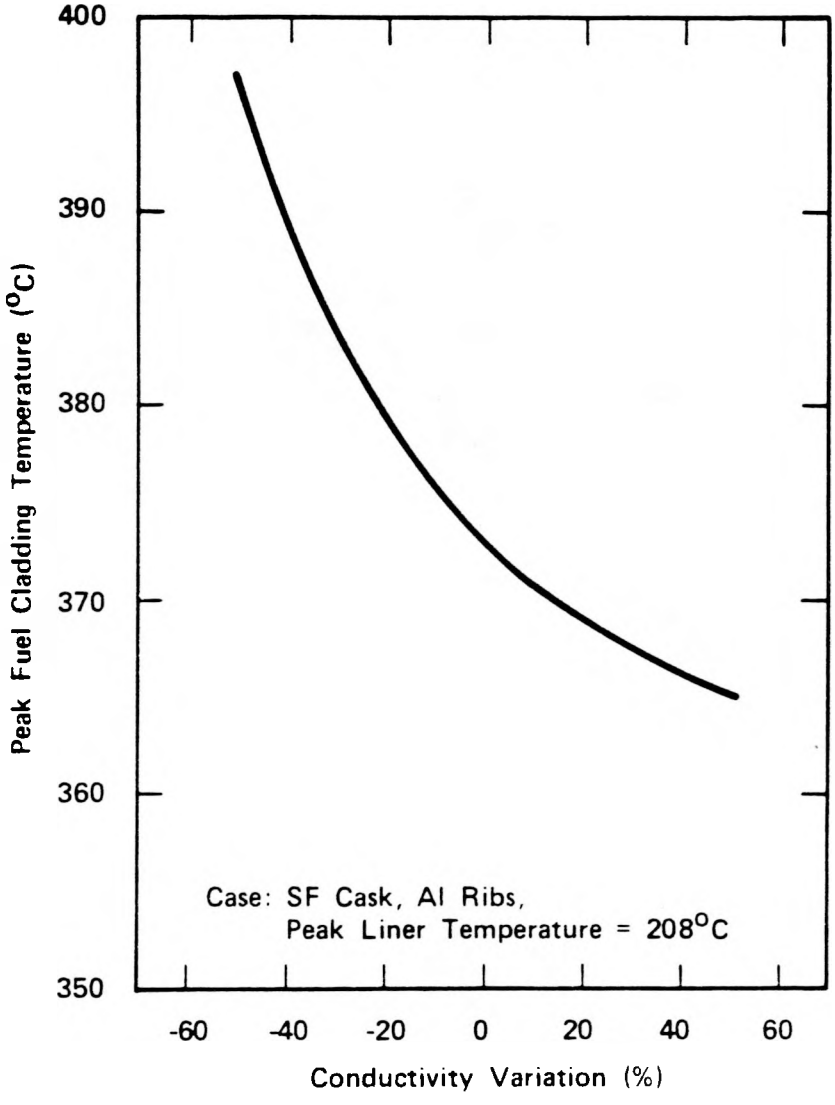


Figure 5-5 - Sensitivity of Peak Fuel Cladding Temperature to Variations in Air Zone Effective Thermal Conductivity

effect resulting from a rather large uncertainty in this part of the model, and is taken as evidence that use of the effective thermal conductivity approach is appropriate for conceptual design analyses.

A significantly larger effect would indicate the greater importance of the heat-transfer process occurring in the air-filled zones and the need to model it with better accuracy. Later stages of the cask design process, beyond the present conceptual design phase, may require a more detailed analytical model to ensure that all effects on thermal performance are considered and understood. It is noted that the above modeling approach was also applied in the HLW cask analysis. Slightly higher values of the effective thermal conductivity were calculated because of the higher canister wall heat flux, its increasing effect on gap temperature and temperature differentials, and their positive effects, in turn, on the effectiveness of the heat-transfer modes.

5.2.2 Effective Thermal Conductivity Model for Canister/Rod Bundle Region

In Reference 12, a theoretical expression is developed that relates the peak temperature in a bundle of heat-generating rods to the temperature of the bundle perimeter, the rod emissivity, and certain physical parameters of the individual rods and the bundle. The expression appears as follows:

$$T^4 = T_o^4 + \frac{Q_1}{A_1 \sigma}\left[Z + \left(\frac{1-\varepsilon}{\varepsilon}\right)\left(1 + \frac{n\,A_1}{A}\right)\right] \qquad (1)$$

where

T = peak rod surface temperature
T_o = bundle perimeter temperature
Q_1 = heat-generation rate per rod
A_i = heat-transfer area per rod
A = bundle perimeter heat-transfer area
n = number of rods
ε = rod emissivity
σ = Stefan-Boltzmann constant
Z = a correlation constant

The Z parameter is given in Reference 12 as a function of rod arrangement (square or triangular pitch), number of rods in the bundle, and the rod pitch-to-diameter ratio (P/d). It is noted that Eq. (1) was developed from thermal-radiation theory, and takes no credit for rod-to-rod contact or for conduction/convection in the gas-filled spaces between the rods. Thus, the model should involve some inherent conservatism, particularly in the consolidated bundle case (P/d = 1.0), that makes it appropriate for conceptual design. For this reason, the theoretical method developed in

Reference 12 was adopted for use in the MRS Facility design study to predict peak fuel-rod cladding temperatures, and it was applied in both the concrete cask and drywell (see Design Study 25) calculations.

When the fuel-rod region is part of a finite-element heat-conduction model, as in the cask interior analysis, it is convenient to have an effective thermal conductivity function for the rod region that can be supplied directly as input to the finite-element model. Such a function was developed for use in the cask analysis. Its development, based on Eq. (1), is described as follows:

Consider the radiative heat transfer between parallel surfaces 1 and 2, situated Δr apart.

The net heat flux q is proportional to $(T_1^4 - T_2^4)$. Thus,

$$q \propto (T_1^4 - T_2^4) = (T_1^2 + T_2^2)(T_1 + T_2)(T_1 - T_2) \approx -4T_{av}^3 \Delta r \frac{\Delta T}{\Delta r} \qquad (2)$$

where

T_{av} = average of temperatures T_1 and T_2

and

$\Delta T = T_2 - T_1$

Comparing Eq. (2) with the heat-conduction equation,

$$q = -k_e \frac{\Delta T}{\Delta r} \qquad (3)$$

suggests that the equivalent thermal conductivity k_e should have the form

$$k_e = cT^3 \qquad (4)$$

where the constant c would depend on the radiation characteristics of the rod surfaces and the geometric pattern of the rod array.

To determine the constant c, consider the radial conduction of heat in a solid cylinder having a uniform conductivity k_e and a volumetric heat-generation rate Q. In the steady state, neglecting the end effects, the heat balance around any cylindrical surface of radius r gives

$$Q \pi r^2 = -k_e 2 \pi r \frac{dT}{dr} \qquad (5)$$

Substituting cT^3 for k_e and integrating Eq. (5) yields the following radial temperature distribution:

$$T^4 = T_s^4 + (Q\ R^2/c)\ [1 - (r/R)^2] \quad (6)$$

where

T_S = cylinder surface temperature
R = cylinder radius

The temperature T_O at the center of the cylinder is then given by

$$T_o^4 = T_s^4 + Q\ R^2/c \quad (7)$$

Equation (7) has the same functional form as Eq. (1), obtained from Reference 12, and a comparison of Eqs. (1) and (7), noting that $Q = nQ_1/\pi R^2 L$, gives the following expression for c:

$$c = nd\sigma \left[Z + \left(\frac{1-\varepsilon}{\varepsilon}\right)\left(1 + \frac{nd}{D}\right)\right]^{-1} \quad (8)$$

where

d = diameter of an individual spent-fuel rod
D = rod bundle diameter

and the effective thermal conductivity for the rod bundle region is, therefore, given by

$$k_e = nd\sigma \left[Z + \left(\frac{1-\varepsilon}{\varepsilon}\right)\left(1 + \frac{nd}{D}\right)\right]^{-1} T^3 \quad (9)$$

To obtain the effective conductivity function for a cask canister containing 792 consolidated rods, the following parametric values were applied:

n = 792
d = 0.95 cm (typical PWR fuel rod OD)
Z = 220
ε = 0.8
D = 31.15 cm (canister ID)

The resulting function is plotted in Figure 5-6. The Z value (220) was obtained directly from Reference 12 (Figure 27, p. 88), assuming a triangular pitch and a pitch-to-diameter ratio of 1.0. The emissivity of 0.8 was judged to be a reasonable value for the coated surfaces of spent-fuel rods. Figures 5-7 and 5-8 present peak cladding temperature data collected by

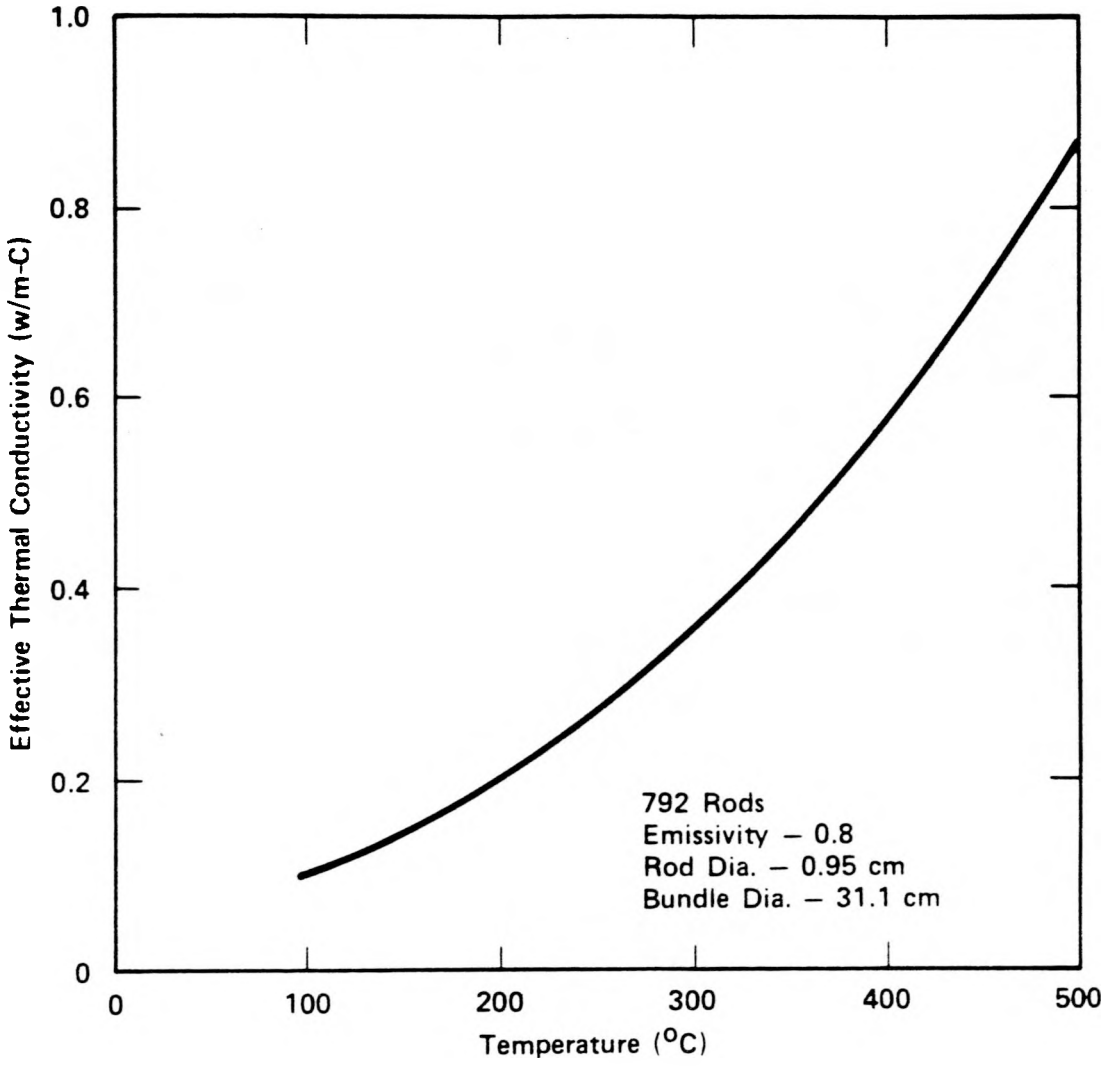


Figure 5-6 - Effective Fuel Rod Region Thermal Conductivity - Consolidated Rods, Triangular Pitch

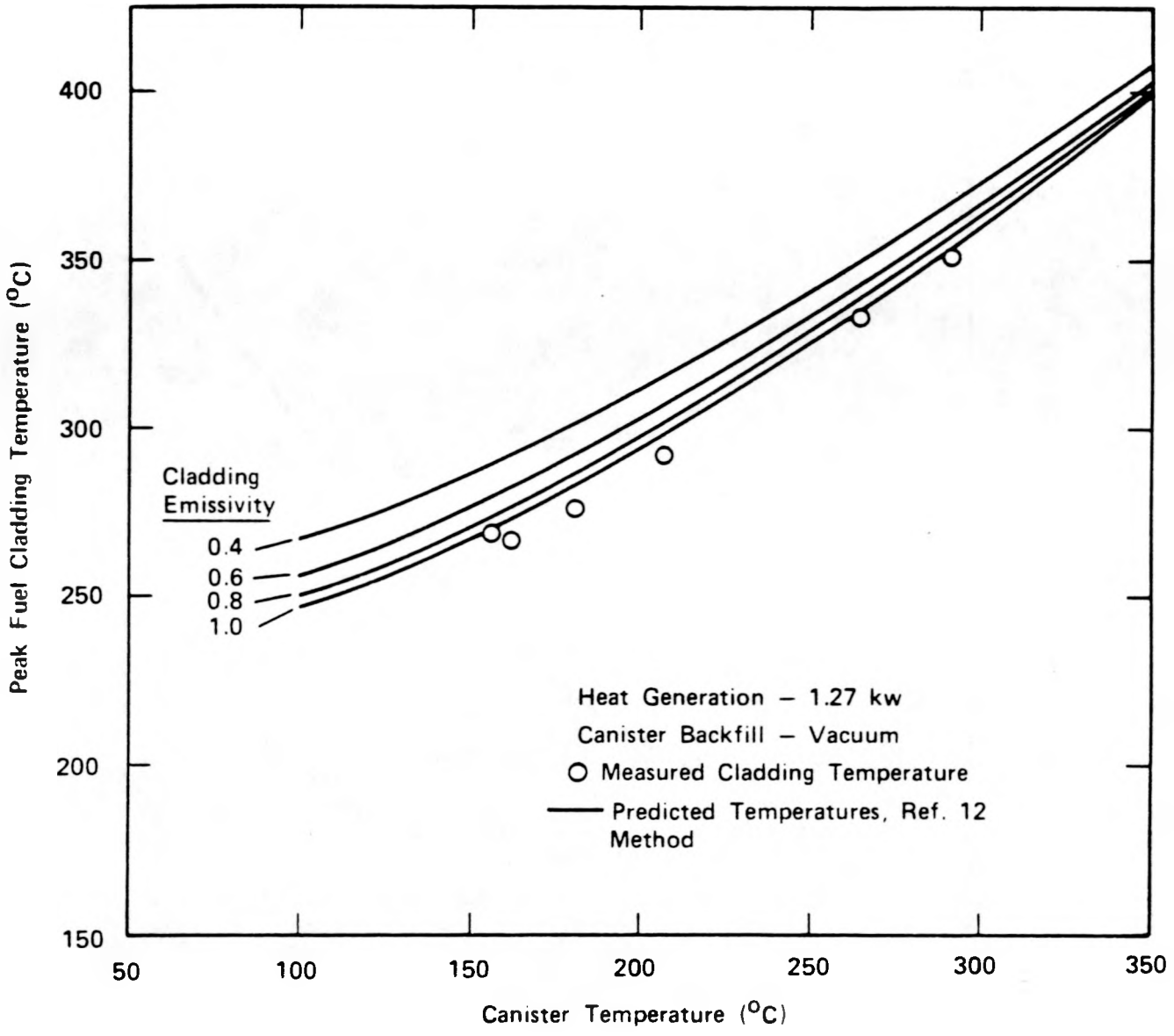


Figure 5-7 - Comparison of Predicted Fuel Cladding Temperatures With Measured Values From E-MAD Test Program, Fuel Assembly D15

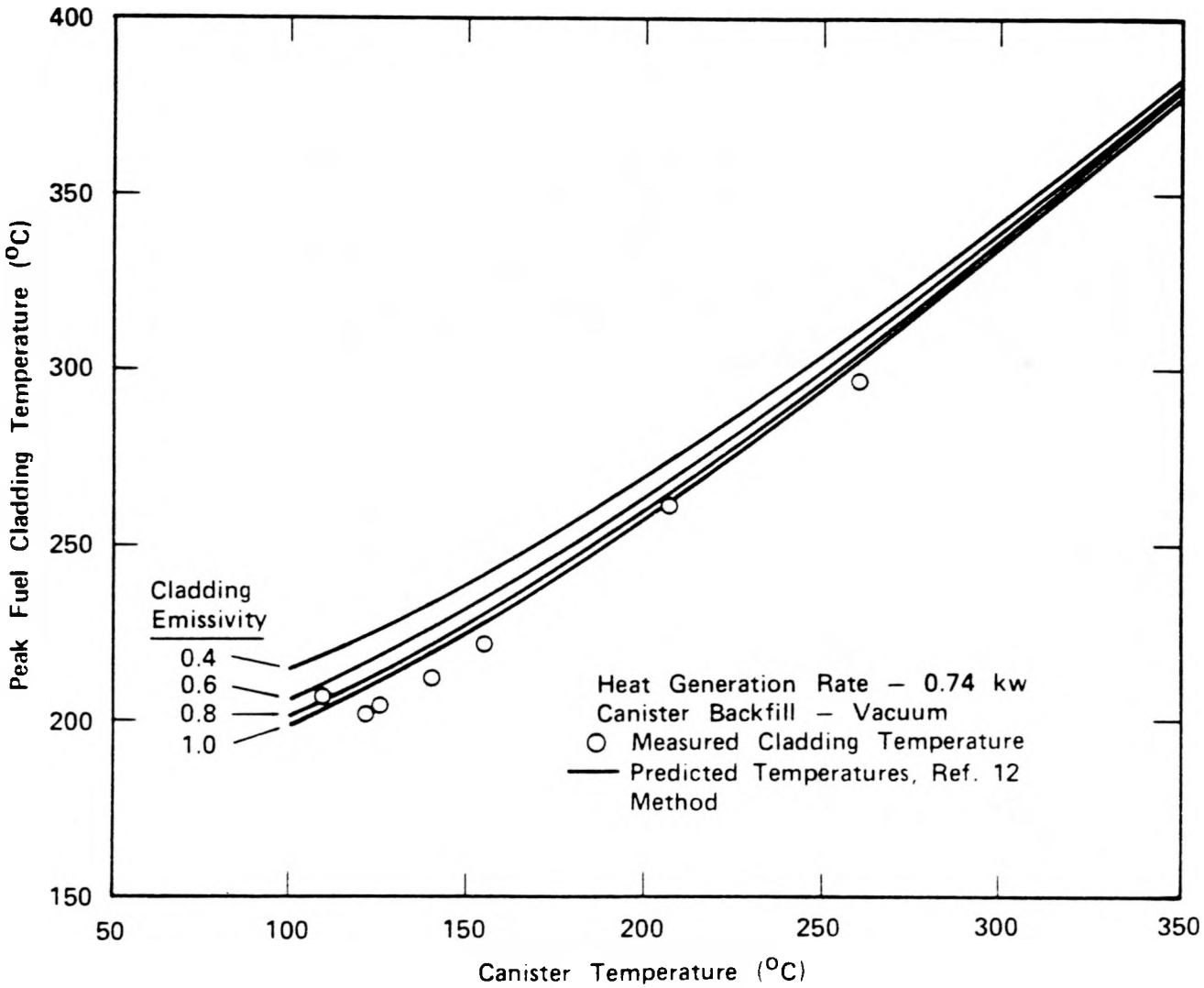


Figure 5-8 - Comparison of Predicted Fuel Cladding Temperatures With Measured Values From E-MAD Test Program, Fuel Assembly B43

Westinghouse during performance of the Fuel Assembly Internal Temperature Measurement Test program at the E-MAD Facility. The test program and results are described in detail in Reference 13. The tests used intact PWR spent-fuel assemblies of the Westinghouse 15 x 15 design. Also shown in the figures are peak cladding temperature predictions that were obtained by using Eq. (1). The predictions are plotted for several values of rod-surface emissivity, and the curves indicate that an 0.8 emissivity, in addition to being a reasonable value, could be expected to yield some conservatism when used in conjunction with Eq. (1). This was taken as evidence that the 0.8 emissivity, together with Eq. (1), are suitable for conceptual design analysis purposes.

As to the validity of the Reference 12 method for application to consolidated rod bundles, experimental work does not exist at present to satisfactorily verify any analysis method. Until such work is available, conservative methodology must be applied to rod-bundle analysis. The method described herein is believed to provide that conservatism because of its performance in predicting measured temperatures (with = 0.8), and particularly because it takes no credit for rod-to-rod contact or for gas conduction and convection effects.

As further evidence of its acceptability for MRS Facility conceptual design analysis purposes, it is noted that the method described above has been applied to consolidated rod-bundle analysis in several previous waste-package conceptual design studies. Two of these studies, and the thermal analysis performed in each case, are documented in References 14 and 15.

6.0 MATERIAL PROPERTIES

Material properties applied during the concrete cask thermal analysis are identified in Table 5-1. Included are the properties used for the soil base; concrete; stainless steel; carbon steel, as used in the liner, the radial and vertical rebar, and in the external and internal ribs; and aluminum (considered for internal ribs). Air was used to fill gaps above the overall cask heat-generation region and between the canisters and liner components in the internal model.

7.0 RESULTS OF ANALYSES

Parametric analyses were performed by using the overall cask model and the cask internal model to determine the effects of varying cask component configurations and to define the combination of these component configurations that would yield a thermally acceptable conceptual design. Results from the various parametric studies are presented, along with cask temperature distributions for the acceptable cask configurations. A brief synopsis of how the analyses were done follows.

Generally, the analytical process consisted of employing the cask interior models to determine curves that, for given interior cask configurations, gave the peak spent-fuel cladding temperatures or peak HLW canister

temperatures for a range of liner temperatures. Analysis was done for various rib materials and structures to determine the system most efficient for the transfer of heat from the cask center to the liner. After specific peak liner temperatures were found (using the overall cask model), they were applied to the interior model curves, and peak waste or peak canister temperatures were determined.

In the overall cask analysis, the major task was to vary those parameters that most affect the temperature distribution of the cask, and to predict the thermal effects of their alteration. One such analysis was the liner-thickness study. The results found for the spent-fuel cask (with no radial or vertical rebar and containing the reference spent-fuel waste form) are presented in Figure 7-1. This figure shows the peak liner temperature sensitivity to liner thickness, using the constant-mass model discussed in Section 5.1. The same qualitative behavior is expected for the HLW cask. From these results, the 2-in.-(5.08-cm)-thick, carbon-steel-lined cask was chosen as the reference case for both spent-fuel and HLW designs. This liner thickness, which is considered the largest practicable, was used in all subsequent analyses.

Another study was performed to determine the relationship between the peak liner temperature and the extent of cask-wall radial rebar. Results for the spent-fuel case (with a 2-in. liner and containing the reference spent-fuel waste form) are shown in Figure 7-2. The results indicate that there is a significant advantage to having some amount of radial rebar. Even a cask wall with 2% radial rebar content operates nearly 50°C cooler than the same cask without radial rebar.

7.1 SPENT-FUEL RESULTS

7.1.1 Spent-Fuel Parametric Analysis Results

Figure 7-3, showing the predicted peak liner temperature for various times, displays the results for the spent-fuel cask with 10-yr-old, 33,000-MWD/MTU fuel, no radial rebar, and with 2 and 4% radial rebar. Temperatures rise quickly in the first days, until the cask is hot enough to facilitate efficient heat transfer to the outer surfaces. The apex of each curve indicates the peak liner temperature for that configuration. Typically, the peak temperature occurs at a point along the liner that is near the center of the heat-generation region.

From the curves in Figure 7-3, the peak liner temperatures for the three external cask cases have been indicated in Figure 7-4 (with, for purposes of completeness, the 8% rebar liner temperature, similarly determined) as lines cutting across the internal model-generated curves. These curves refer to various internal region configurations (with the same waste-form characteristics). All configurations are variations of the reference interior design case, with one long and one short 1.5-in.-thick, carbon-steel rib (see Figure 4-2a).

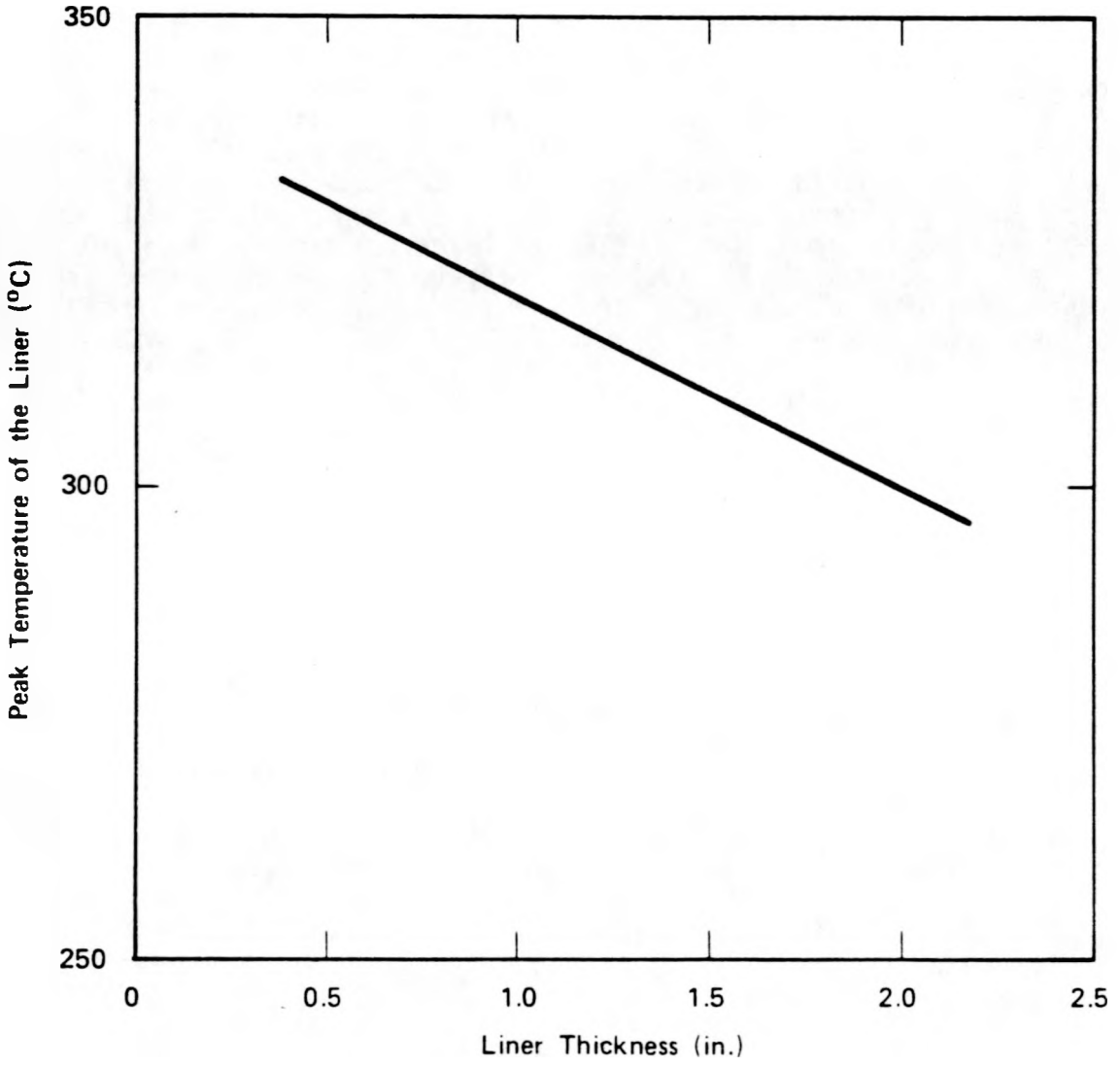


Figure 7-1 - Effect of Liner Thickness on Peak Liner Temperature
(Spent-Fuel Cask; 10-yr-old, 33,000-MWD/MTU Fuel;
No Vertical or Radial Rebar)

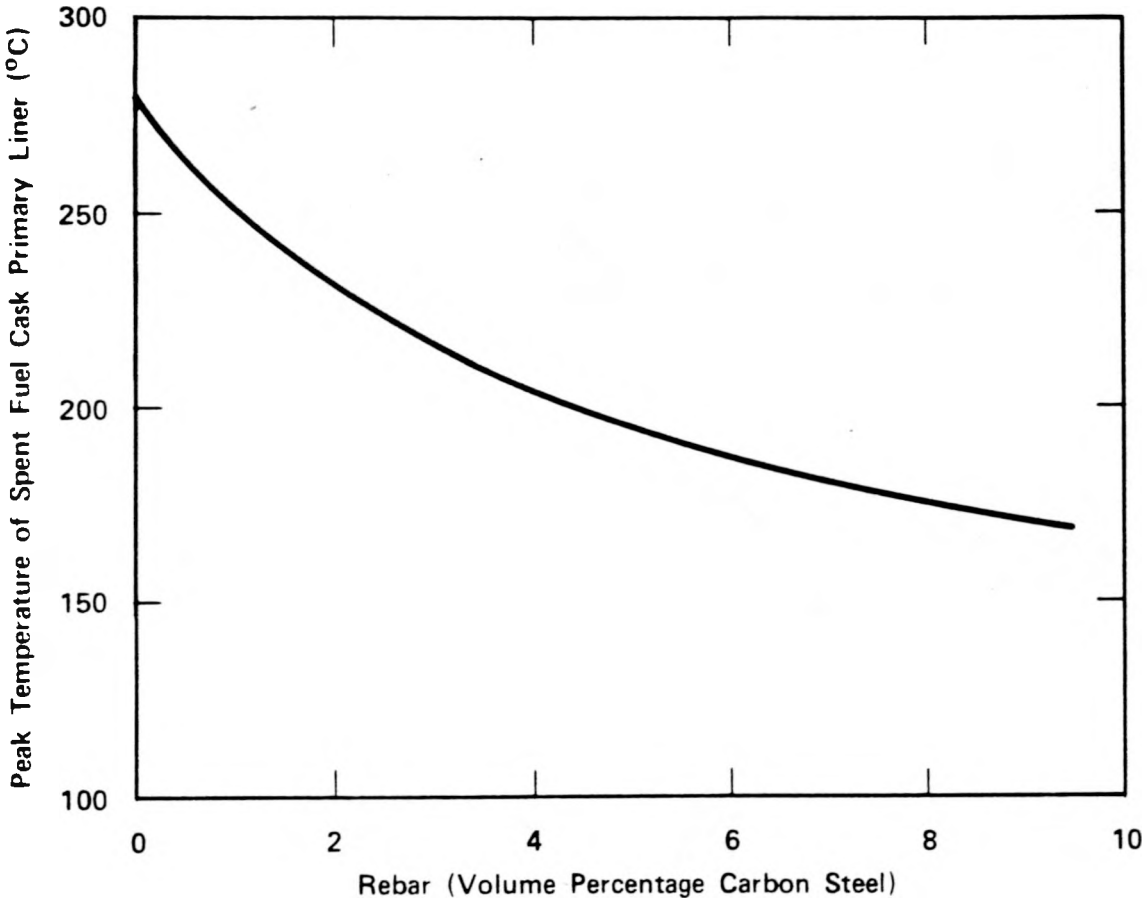


Figure 7-2 - Thermal Effect of Rebar on Peak Liner Temperature (Spent-Fuel Cask; 10-yr-old, 33,000-MWD/MTU Fuel; 2-in. Liner)

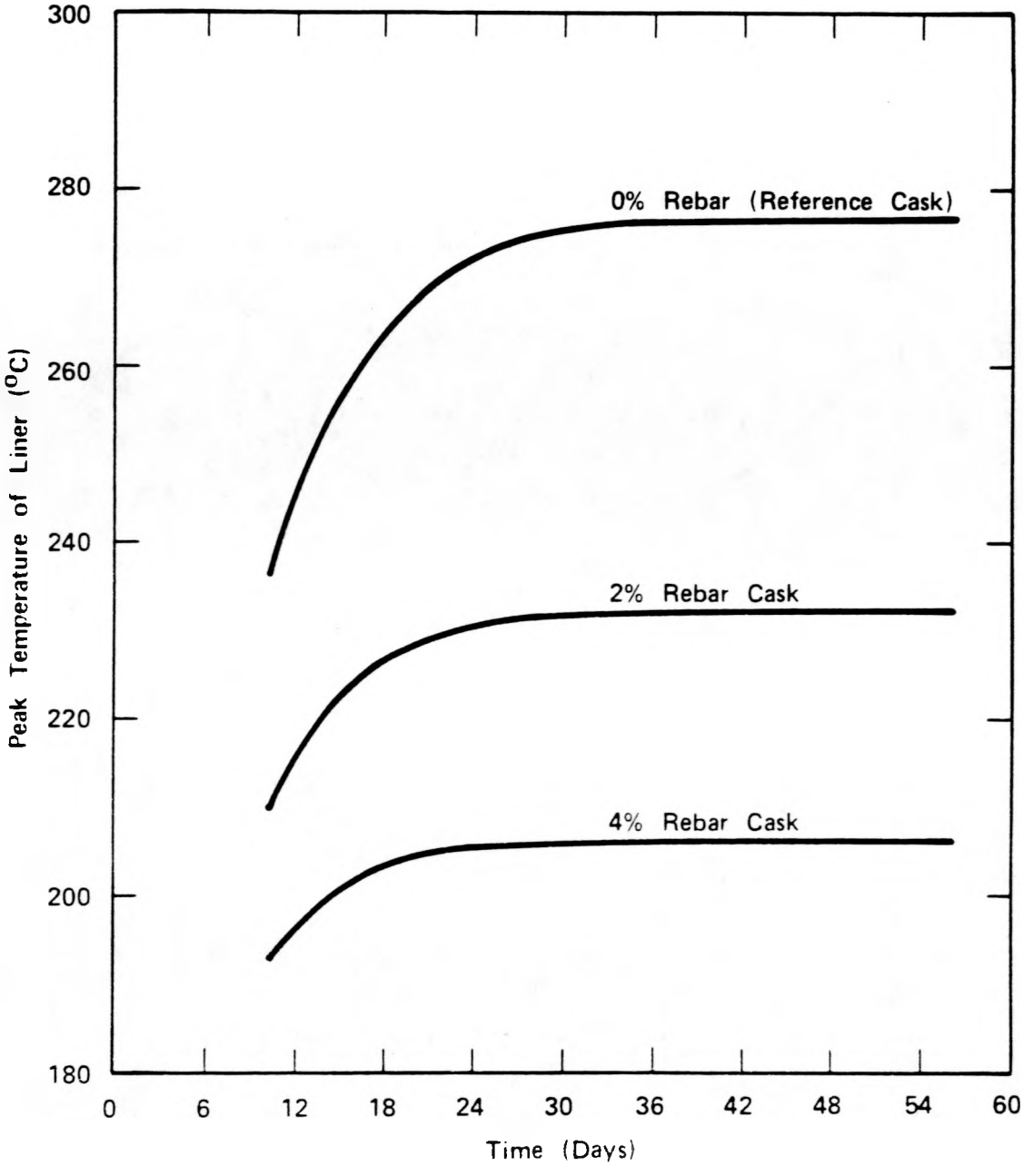


Figure 7-3 - Thermal Effect of Rebar on Transient Peak Liner Temperature (Spent-Fuel Cask; 10-yr-old, 33,000-MWD/MTU Fuel; 2-in. Liner)

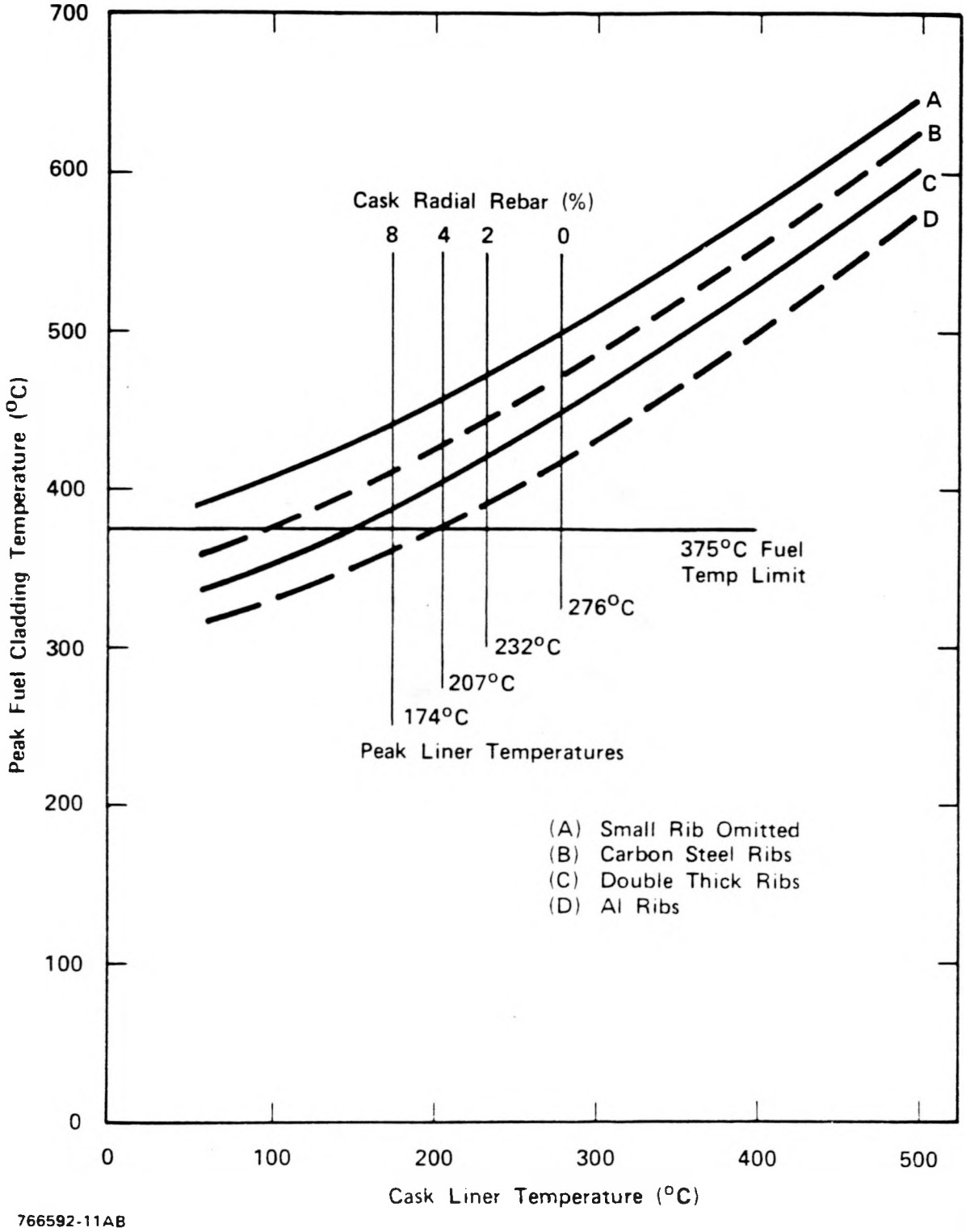


Figure 7-4 - Spent-Fuel Cask Internal Model Results

The intersection points of the peak temperature lines with the interior model curves show the predicted peak fuel temperature. The figure also includes a line that indicates the 375°C limit that has been established for the fuel (Ref. 3). Design combinations that have intersection points above this line must be considered unacceptable from a thermal standpoint.

Two other consolidated spent-fuel cases were also considered. The first used 5-yr-old, 33,000-MWD/MTU fuel. This case used a modified version of the spent-fuel cask model; only eight waste canisters, rather than twelve, were placed in the interior model. This was because of the high temperatures expected to be caused by the relatively high thermal output of the waste form. The spent-fuel internal model was adjusted by assigning to the elements designated to represent the inner four canisters (see Figure 5-3) the material and thermal properties of air. This was also done with the second spent-fuel case examined, that with 10-yr-old, 55,000-MWD/MTU fuel.

The analytical process applied to these additional spent-fuel cases was as described above for the reference spent-fuel analysis. A cladding temperature/liner temperature curve was derived by using the cask internal model, and this was overlaid with a peak liner temperature from the cask overall model to identify a predicted peak cladding temperature. Results of this process are presented in Figures 7-5 and 7-6 for the 33,000/5 and 55,000/10 cases, respectively. In both instances, the peak cladding temperatures exceed the prescribed limit, and cask design modification would be needed to reduce them. In these additional spent-fuel analyses, the cask material and dimensional input were from the thermally acceptable cask configuration for a reference spent-fuel case. The cask liner was composed of 2-in.-thick carbon steel, and the cask wall contained 4% radial rebar.

7.1.2 Spent-Fuel Cask Temperature Results

Isotherms in the cask for the 10-yr-old, 33,000-MWD/MTU fuel, 2-in. liner, and 4% radial rebar case at the time when peak liner temperature occurs are shown in Figure 7-7.

7.2 HLW RESULTS

7.2.1 Reference HLW Cask Parametric Analysis Results

The reference HLW waste-form cask analysis was patterned directly after that discussed above for the spent-fuel cask. The curves derived from the HLW overall cask model (see Figure 7-8) show that the HLW cask tends to operate at considerably higher temperatures than does the spent-fuel cask. This is because of the higher radial-direction heat flux at the cask wall.

The peak liner temperatures (each caused by various cask-wall radial rebar contents), indicated in Figure 7-9, intersect the internal model curves and show predicted values of peak canister temperatures. A 375°C line indicates the maximum allowable canister temperature (see Ref. 1). The intersection of the canister temperature limit line with the curves and the peak liner temperatures identifies workable combinations of cask design features.

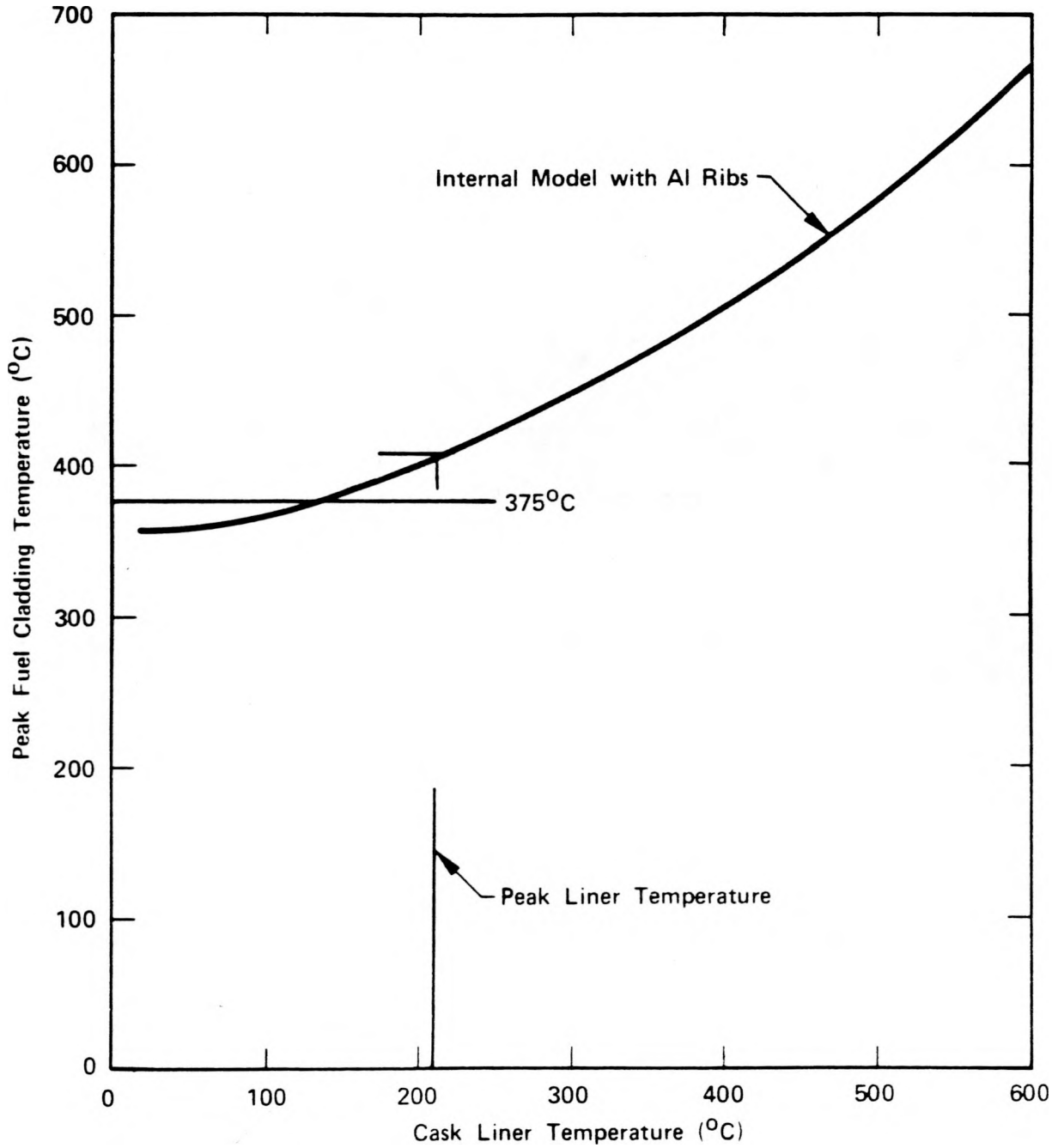


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Figure 7-5 - Spent-Fuel Cask Thermal Results With Eight Canisters of 5-yr-old, 33,000-MWD/MTU Fuel

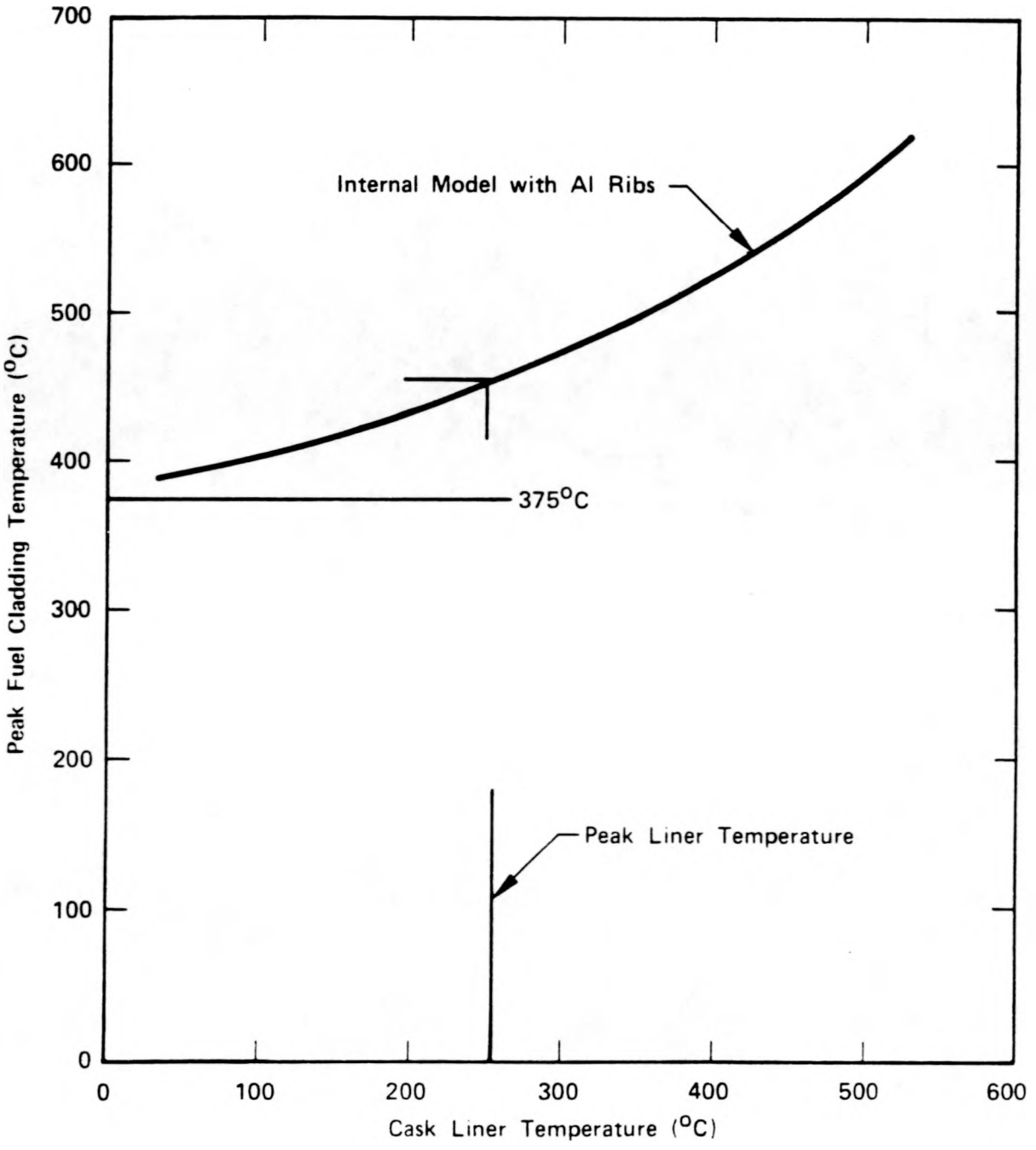

Figure 7-6 - Spent-Fuel Cask Thermal Results With Eight Canisters of 10-yr-old, 55,000-MWD/MTU Fuel

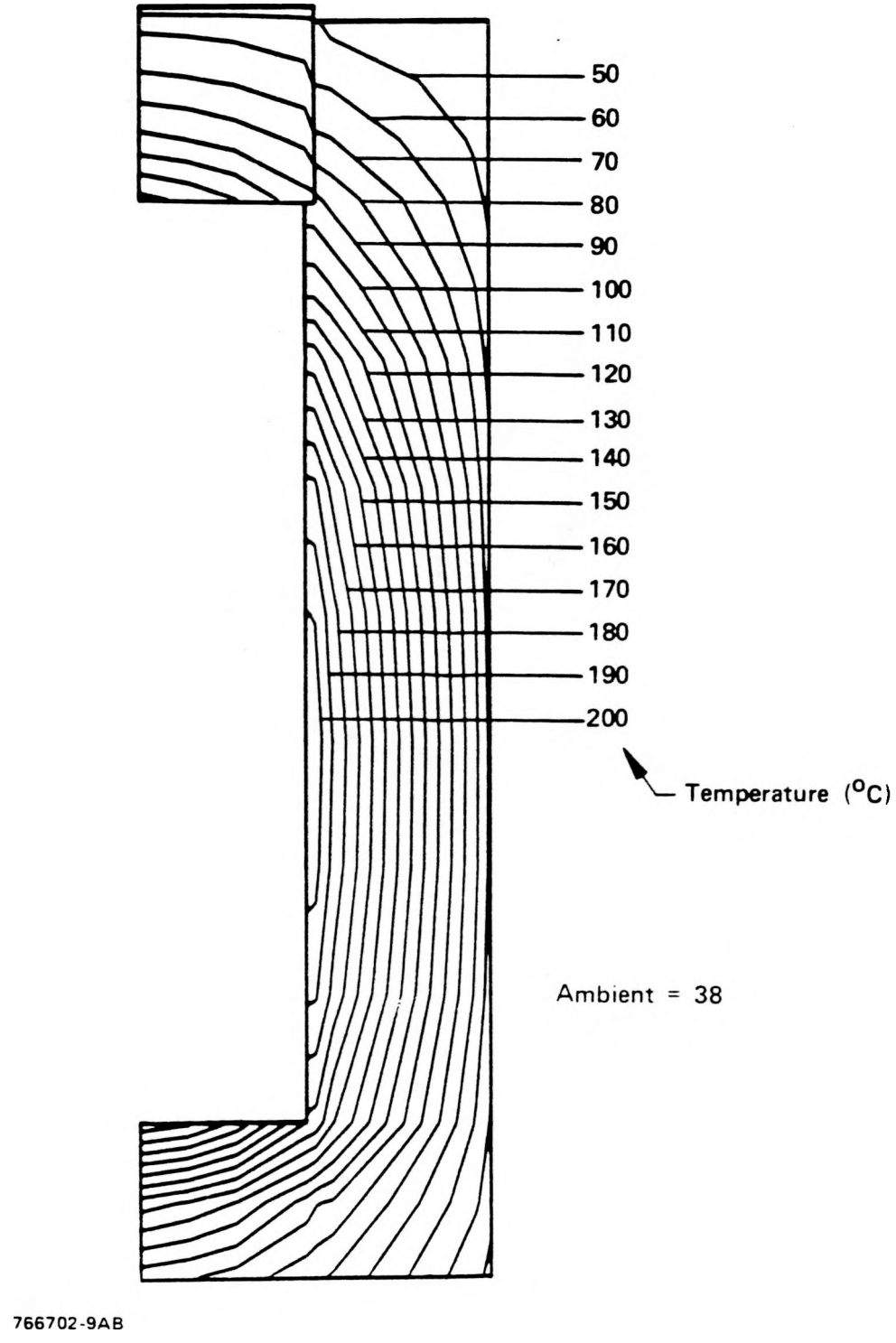

Figure 7-7 - Spent-Fuel Concrete Cask Isotherms (10-yr-old, 33,000-MWD/MTU Fuel; 2-in. Liner, 4% Radial Rebar)

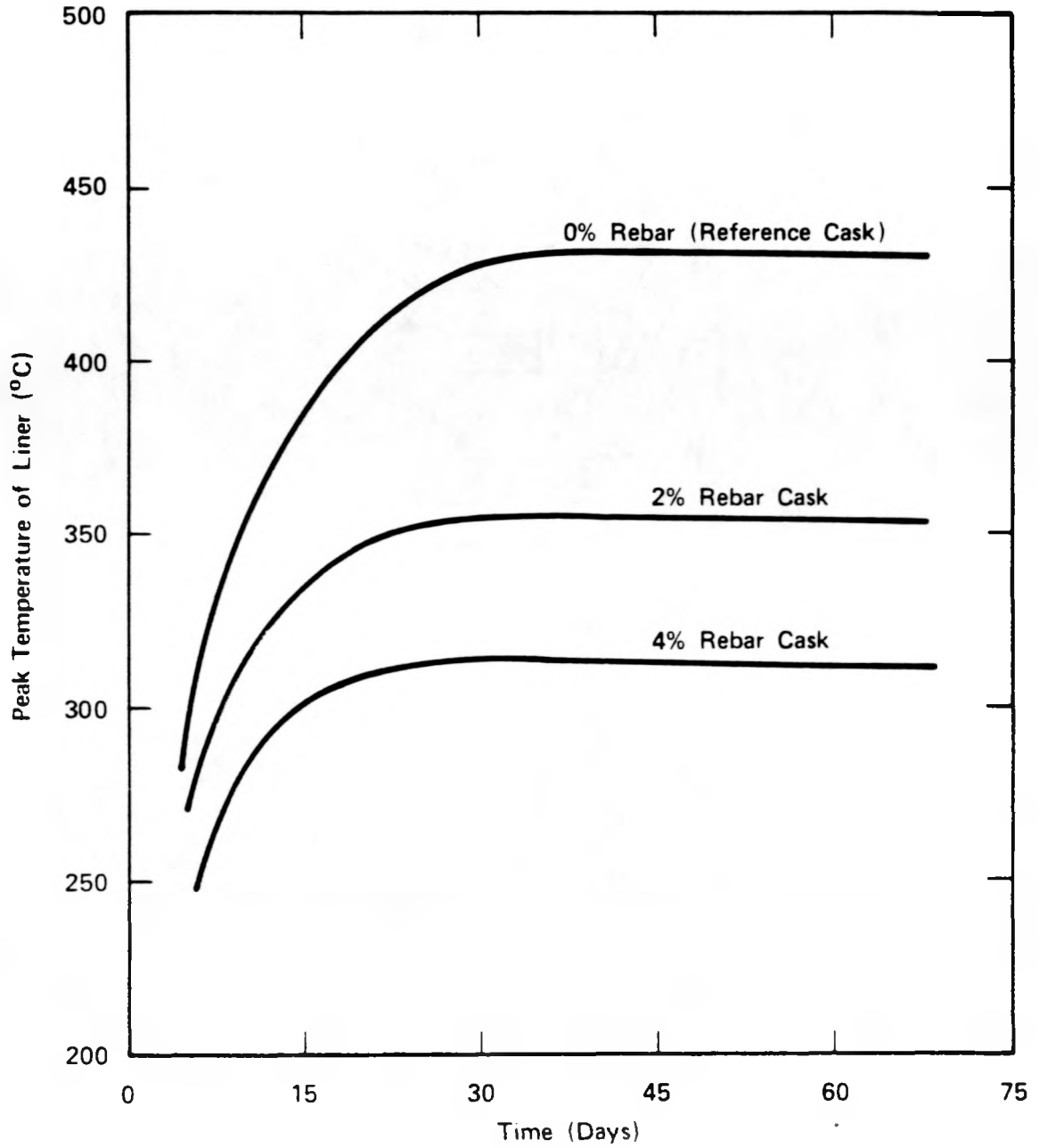

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Figure 7-8 - HLW Cask Transient Peak Liner Temperature

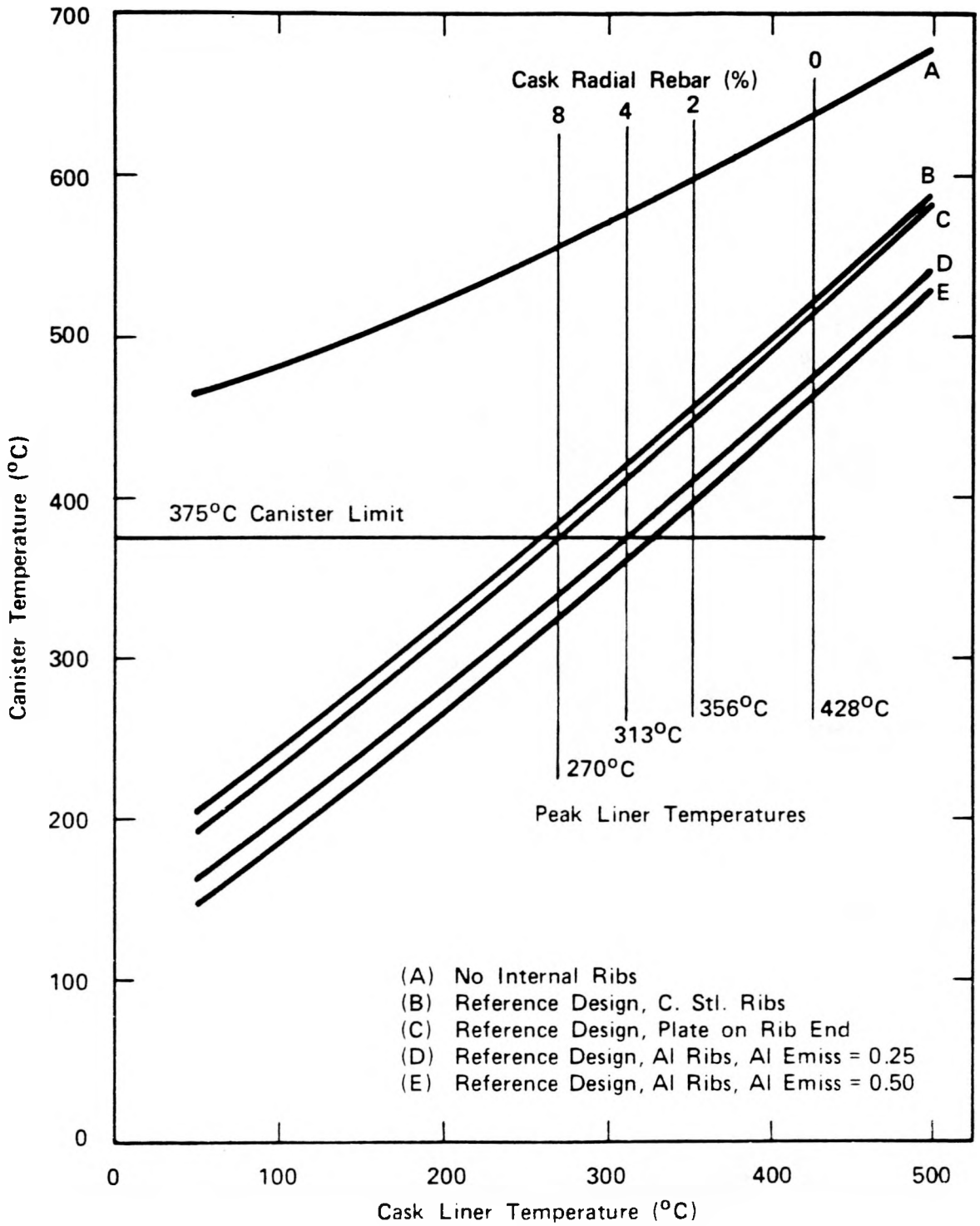

Figure 7-9 - HLW Cask Internal Model Results

7.2.2 Additional HLW Analysis

Analysis was also made for an HLW cask with eight waste canisters (rather than nine) of the Alternative 1 HLW waste form, which has higher heat output than the reference waste form and a greater heat-generating height. Because the same glass-waste mixture is maintained, the larger glassified log produces a proportionally greater heat output. As with all prior cases, the liner temperature was determined and indicated on the appropriate liner-waste temperature curve (determined by a corresponding interior model; in this example, the aluminum rib case). The results for the Alternative 1 HLW cask are shown in Figure 7-10.

The last HLW case examined involved the placement of a single, large glassified waste log (30 in. dia, 162 in. high, 19,100-W power output) into the center of a cask. The purpose of this study was to determine whether the reference glass-waste mixture was workable and, if not, to determine what adjustments would be required. Figure 7-11 displays the results of this analysis.

The first step of this study was to determine whether the glass log could be stored in an open-air environment and meet the waste-form temperature-limit criterion (500°C for HLW). It was found that, with the reference glass-waste mixture, the peak temperatures at the center of the log would exceed the limit. Therefore, as indicated in Figure 7-11, a lower heat-generation rate (0.91 of the reference value) was determined, one that would maintain the centerline temperature below the 500°C limit.

To analyze the large-diameter HLW log in the cask storage configuration, calculations were first performed to derive the curve of peak liner temperature versus relative heat-generation rate (see Figure 7-11). Then, based on these data, a one-dimensional (radial) analysis of the cask interior was made to produce the peak centerline and peak canister temperature curves. Figure 7-11 indicates that a further reduction (to 0.69) in the relative heat-generation rate would be required to facilitate cask storage. It is believed, however, that cask design modifications could be implemented (internal ribs, for example) that would enable operation at higher heat-generation rates up to 0.8.

It should be observed that the large-diameter HLW log would be thermally limited by centerline temperature, whereas the thermal design of the narrow logs would be controlled by peak canister temperature.

7.2.3 Reference HLW Cask Temperature Results

Isotherms of calculated temperatures throughout the reference HLW cask, with a 2-in. liner and 4% radial rebar, are shown in Figure 7-12.

8.0 SUMMARY AND CONCLUSIONS

Spent-fuel peak cladding temperatures and peak HLW canister temperatures were predicted for a variety of cases involving storage of these waste forms

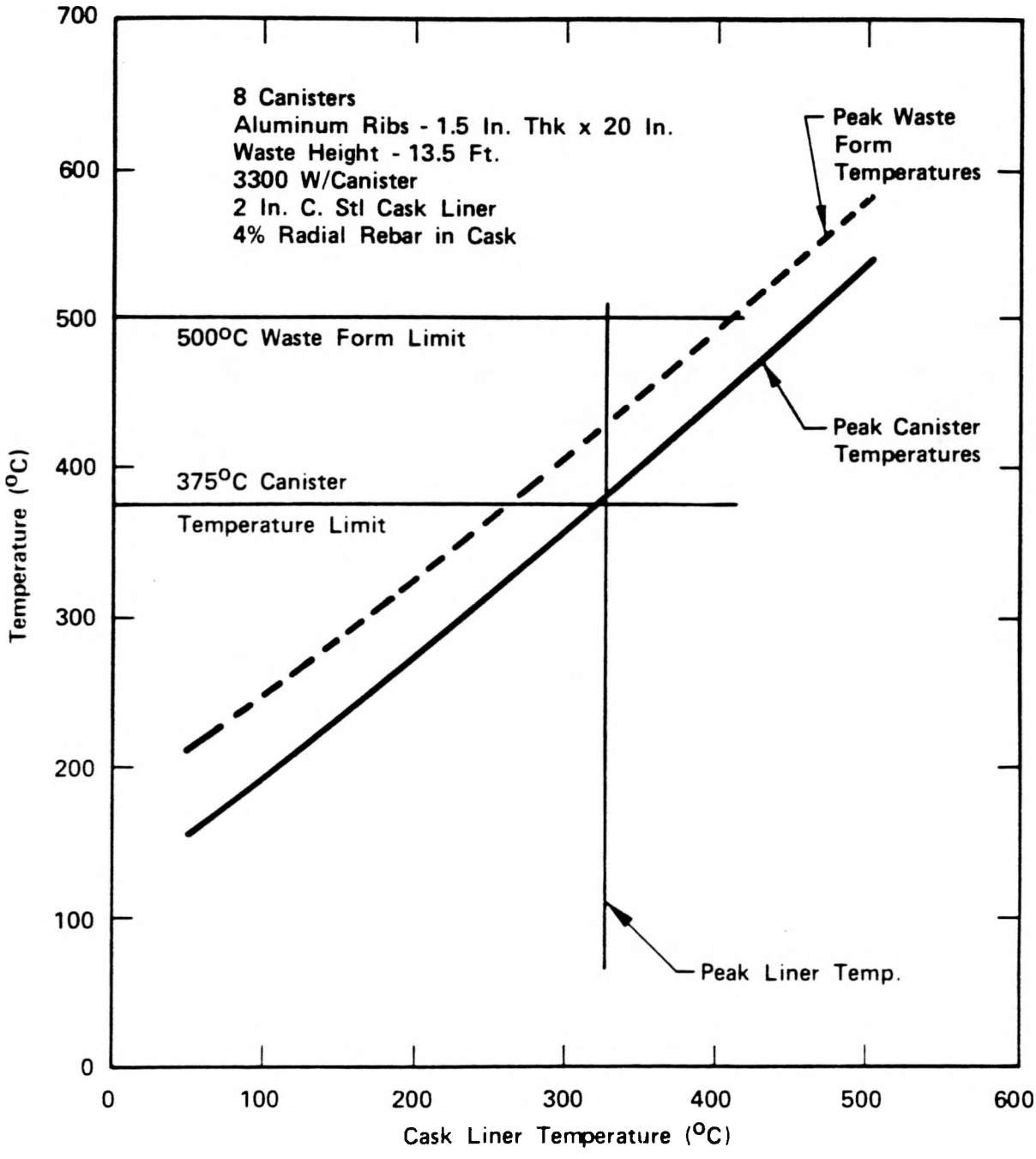

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Figure 7-10 - HLW Cask Internal Temperatures for 12-in.-dia by 15-ft-long HLW Canisters

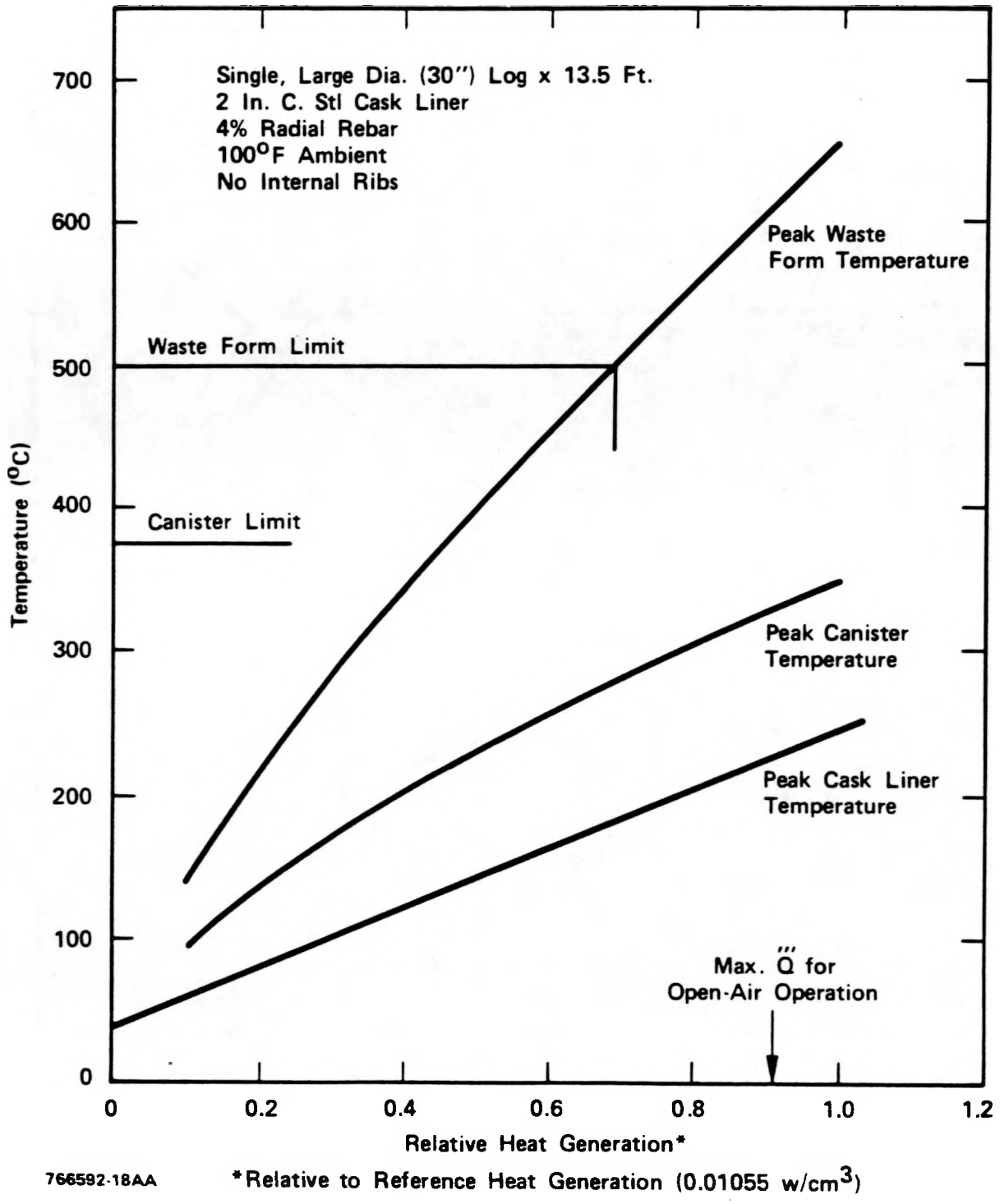

Figure 7-11 - HLW Cask Internal Temperatures for 30-in.-dia by 15-ft-long HLW Canisters

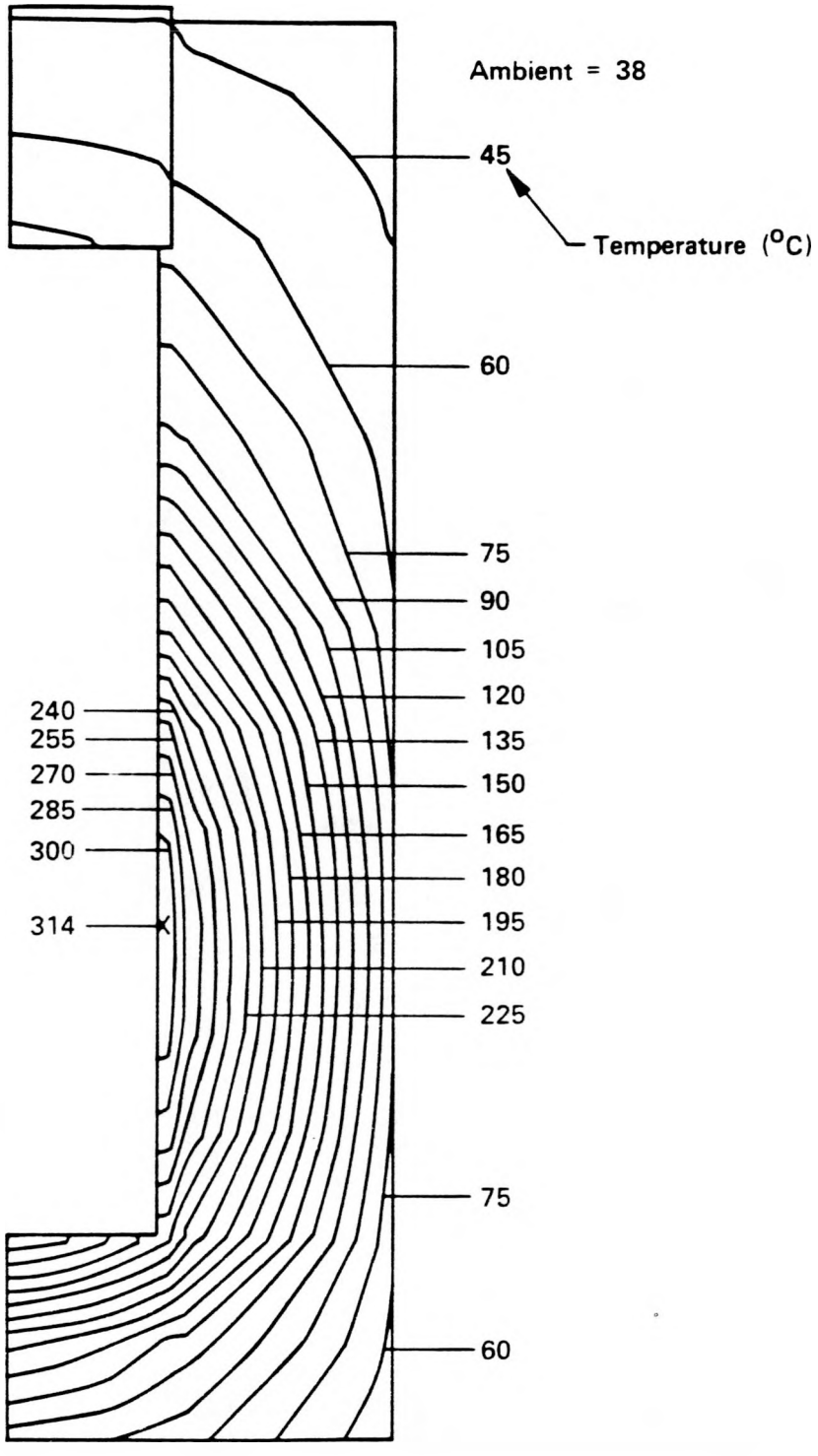

Figure 7-12 - HLW Concrete Cask Isotherms (Reference HLW Waste Form, 2-in. Liner, 4% Radial Rebar)

in vertical concrete casks having an outside diameter of 365.6 cm (12 ft) by 670.5 cm (22 ft) high. The reference MRS Facility concrete cask advanced conceptual design, evaluated for spent fuel, had 91.4-cm-(36-in.)-thick concrete walls with a 5-cm-(2-in.)-thick liner. The corresponding thicknesses of the cask for HLW were 106.6 cm (42 in.) and 5 cm (2 in.). As a result of the conceptual design analyses, the following conclusions may be drawn:

(1) The principal thermal resistances are those that exist in the cask wall and between the waste canisters and the cask liner.

(2) The cask thermal resistance can be reduced to an acceptable level by a design that incorporates radial rebar and/or by addition of conductivity-enhancing material to the concrete mix.

(3) The internal thermal resistance (waste canister to cask liner) can be controlled by proper selection of internal rib (fin) materials and geometry.

(4) The peak fuel cladding temperature can be maintained below 375°C for cask storage of the reference spent fuel (12 canisters, each containing 792 fuel rods from three Westinghouse 17 x 17 PWR spent-fuel assemblies having burnups of 33,000 MWD/MTU with 10 yr cooling before dry storage), provided that:

   (a) The heat transfer through the cask wall is enhanced through the use of radial rebar or other means.

   (b) Appropriate (geometries and material) fins or ribs are used within the cask cavity to enhance the flow of heat from the canisters to the cask liner.

(5) To store consolidated fuel (from three assemblies in a single canister) having burnup/cooling-period combinations of 33,000/5 and 55,000/10, the number of canisters must be reduced from 12 to 8 for the first case and to less than 8 for the latter case; special designs must also be developed to enhance the canister-to-liner heat transfer to keep the peak clad temperatures within the 375°C limit. For the particular cask design geometries investigated in this study, the temperature limits were exceeded for both of these burnup/cooling-period combinations.

(6) The analysis indicates that nine of the reference HLW canisters can be stored in the HLW cask without exceeding the 375°C canister temperature limit, provided that the design includes high-conductivity ribs between the canisters and that the concrete cask is designed to include an equivalent of 4 vol% radial rebar.

(7) Similarly, it was found that the other HLW canisters, producing 50% more heat (but with the same volumetric heat-generation rate), can be stored without exceeding the canister temperature limit if the number of canisters is reduced from nine to eight.

(8) To store a single, large HLW canister (75.2 cm dia and 411.5 cm high), the canister of HLW must have a volumetric heat-generation rate that is between 69 and 80% of the reference value of 0.01055 W/cm^3 to limit the peak waste-form temperature to 500°C. This value is a function of the specific design of cask internals designed to enhance the transfer of heat from the canister to the cask liner.

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FOREWORD

This study is based on the emplacement of 1,800 MTU/yr in concrete casks located in the storage area. Section 7 of the study addresses an estimate of the total worker radiation exposure assessment for concrete casks. In increasing the throughput rate from 1,800 to 3,600 MTU/yr, the estimate of the total worker radiation exposure would double. However, the individual worker radiation exposure need not double if additional workers are added to the work force.

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DESIGN STUDY DS-30

CONCRETE CASK RADIATION ANALYSIS

1.0 INTRODUCTION

This design study summarizes the results of the radiation analysis performed for the conceptual design of the concrete casks for the Monitored Retrievable Storage (MRS) Facility. Six concrete cask designs have been identified:

(1) Spent fuel concrete cask
(2) High-level waste (HLW) concrete cask
(3) Nonfuel-bearing components concrete cask
(4) 50-R/hr RHTRU concrete cask
(5) 1,000-R/hr RHTRU concrete cask
(6) West Valley high-level waste (WV HLW) concrete cask

The following areas are addressed herein:

(1) Radiation level limits established for the concrete casks.

(2) Analytical methods and models used.

(3) Development of the material description and radiation source terms used.

(4) Results of the analysis.

(5) Additional studies performed in support of this analysis.

(6) Worker radiation exposure assessment.

This analysis was performed for a conceptual design of the concrete casks. The methods used in this analysis are considered adequate for the detail of the design.

2.0 RADIATION LEVEL LIMITS

The conceptual concrete cask designs were based on limiting radiation levels in all areas accessible to whole body exposure, as follows:

(1) Side surface limit: <20 mrem/hr
(2) Top surface limit: <10 mrem/hr
(3) Bottom surface limit: <200 mrem/hr

These levels were established based on the following:

(1) The surface dose rate for transportable metal storage casks is 20 mrem/hr on the exterior cylindrical surfaces; therefore, concrete cask cylindrical surfaces should be 20 mrem/hr or less.

(2) Since seal welding, inspection, and weld area coating manual activities must be performed on the top of the cask, the top surface dose rates should be reduced to reduce operator and inspector doses.

(3) Access to the cask bottom surface is limited by cask storage and transport configurations. The cask bottom is accessible only during the lifting, translating over the storage pad, and lowering operations. The radiation exposure from the cask bottom surface at the cask outside diameter should be limited to 20 mrem/hr during these noted operations. This results in 200 mrem/hr dose allowable at the center of the cask bottom surface.

3.0 MATERIAL DESCRIPTION

Table 3-1 presents a description of the materials by element weight percent used in this analysis. The fuel assembly and skeleton description was obtained from Reference 1. The HLW description was obtained from Reference 2. The RHTRU waste was assumed to be steel at 3.14 g/cc (see Section 6.1). The WV HLW was assumed to be of the same composition as HLW.

4.0 CALCULATION METHOD AND MODELS

The gamma radiation analysis was performed by using the SCAP point kernel computer code (Ref. 3), supplemented by hand calculations where noted. Two modes of calculation of the SCAP code were used: (1) direct dose - line-of-sight calculations for the majority of the evaluation and (2) single scatter dose calculations for those configurations in which the scattered dose rate was significant.

The various cask designs were modeled in cylindrical (R-Z-θ) geometry, using the SCAP code. The GAMLEG-W cross-section library (Ref. 4) was used to provide the cross-sectional information needed for the calculations. The SCAP code includes a library of bivariant polynomial data for gamma ray buildup coefficient evaluation. Water dose buildup factors were used for all materials. This was done because SCAP allows only one buildup factor for all materials or zones. Water was chosen because it adds a slight margin of conservatism to the calculations. Also included in the SCAP code is a library of flux-to-dose-rate conversion factors.

Estimates of the neutron dose rates were made by using hand-calculation techniques obtained from Reference 5. It is pointed out that these techniques are fairly crude, but historically have produced conservative results, which should only be used to indicate approximate results. It is noted that secondary gamma ray production from neutron interactions was ignored for this analysis because it is expected to be only a small

Table 3-1 - Materials by Element Weight Percent

Element	PWR Assembly	BWR Assembly	WV HLW or HLW	Skeletons	RHTRU	RHTRU	Aluminum	Carbon Steel	Concrete
Hydrogen									0.53
Boron			2.8						
Carbon						0.2		0.2	0.12
Oxygen	9.8	9.3	38.1						52.20
Sodium			9.7						1.70
Magnesium						0.43		0.43	3.87
Aluminum			1.1		100.0		100.0		40.10
Silicon			16.8			0.26		0.26	
Phosphorous			0.9						
Calcium			0.7						
Titanium			3.6						
Chromium				12.24		0.0042		0.0042	
Manganese						0.68		0.68	
Iron			0.7	30.13		97.04		97.04	
Nickel				18.835		0.79		0.79	1.48
Copper			2.4						
Molybdenum			4.0			0.60		0.60	
Barium			6.3						
Gadalinium			8.7						
Uranium	73.0	69.0	4.2						
Zirconium	17.2	21.7		38.794					
Density (gm/cm^3)	3.304[a]	2.706[b]	3.10	1.63[c]	1.08[d]	3.14[e]	2.70	7.80	2.32

[a]Homogenized density within fuel assembly dimensions of 9 in. x 9 in. x 12 ft-6 in.
[b]Homogenized density within fuel assembly dimensions of 6 in. x 6 in. x 14 ft-1 in.
[c]Ten skeletons each weighing 34 kg compacted into a 55-gal drum.
[d]RHTRU waste assumed equivalent to 40 vol% aluminum.
[e]RHTRU waste assumed equivalent to 40 vol% steel.

PARSONS

contribution to the total dose rate at the cask surface. The increase in the spent fuel neutron source caused by the subcritical neutron multiplication factor was also ignored in this analysis.

5.0 CONCRETE CASK SHIELDING ANALYSIS

5.1 SPENT FUEL CONCRETE CASK

The spent fuel radiation sources are obtained from Reference 1, and are presented in Tables 5-1 and 5-2 for PWR and BWR fuel, respectively. The PWR fuel represents the limiting case for shielding analysis. The following cases were analyzed:

(1) (33-10)[1] Consolidated PWR fuel (3:1)[2]: base case
(2) (33-5) Intact PWR fuel
(3) (55-10) Intact PWR fuel

The design for the spent fuel concrete cask shows the cask loaded with consolidated and intact fuel in Figures 5-1 and 5-2, respectively. Figures 5-3 and 5-4 present the SCAP geometry models used to analyze the spent fuel concrete cask loaded with consolidated and intact PWR fuel, respectively.

Figures 5-1, 5-2, and 5-5 present the dose rate results for (33-10) consolidated and (33-5) and (55-10) intact PWR fuel, respectively.

5.2 HLW CONCRETE CASK

The HLW radiation sources were obtained from Reference 2, and are presented in Table 5-3.

The design for the HLW concrete cask is shown in Figure 5-6, which also presents the dose rate results for the HLW concrete cask. Figure 5-7 presents the SCAP geometry model used to analyze the HLW concrete cask.

5.3 NONFUEL-BEARING COMPONENTS CONCRETE CASK

The fuel assembly skeleton sources provide the worst-case analysis for the nonfuel-bearing components. These sources are from Parsons, and are presented in Table 5-4.

The design for the nonfuel-bearing components concrete cask is shown in Figure 5-8, which also presents the dose rate results. Figure 5-9 presents the SCAP geometry model used to analyze the nonfuel-bearing components concrete cask.

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[1](33-10) is used herein as an abbreviation for burnup and time out of reactor for spent fuel; i.e., (33-10) means a 33,000 MWD/MTU burnup and 10 yr out of reactor.

[2](3:1) means that the fuel rods from three PWR assemblies are placed in one canister.

Table 5-1 - PWR Spent Fuel Assembly[a] Source Strength

Gamma Source Strength (gamma/sec)

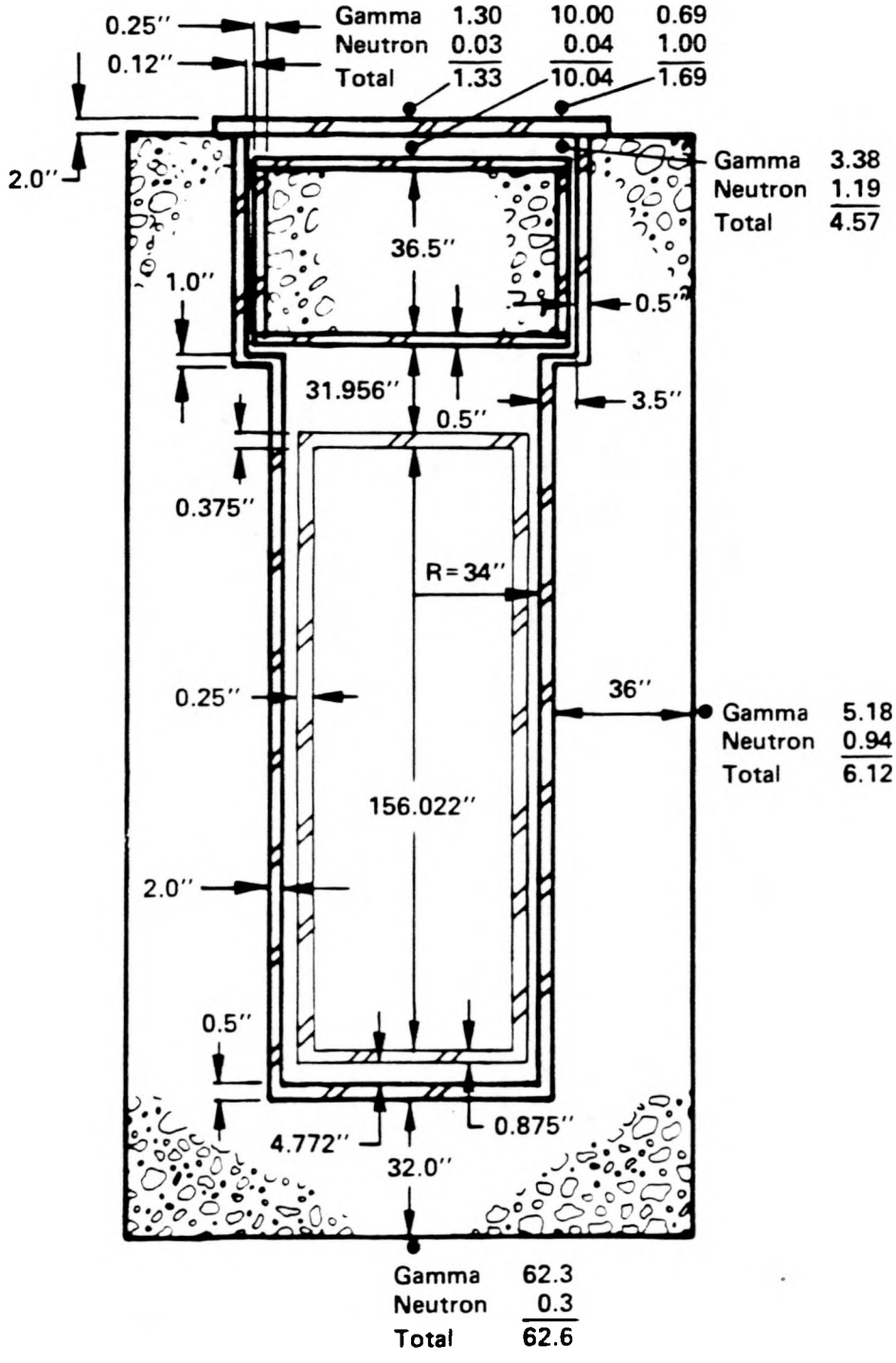
MeV	33,000 MWD/MTU 5 yr Cool	33,000 MWD/MTU 10 yr Cool	55,000 MWD/MTU 5 yr Cool	55,000 MWD/MTU 10 yr Cool
0.05	2.152E+15	1.301E+15	3.234E+15	2.085E+15
0.0575	2.875E+14	1.765E+14	4.278E+14	2.798E+14
0.085	1.857E+14	1.035E+14	2.813E+14	1.680E+14
0.125	1.877E+14	9.725E+13	2.971E+14	1.706E+14
0.225	1.571E+14	8.570E+13	2.315E+14	1.373E+14
0.375	9.439E+13	4.195E+13	1.332E+14	6.445E+13
0.575	2.308E+15	1.518E+15	4.023E+15	2.526E+15
0.850	4.883E+14	1.206E+14	1.028E+15	2.514E+14
1.250	3.169E+14	1.606E+14	4.712E+14	2.392E+14
1.750	3.627E+12	1.425E+12	6.158E+12	2.820E+12
2.250	2.017E+12	3.264E+10	2.175E+12	3.745E+10
2.750	6.260E+10	2.124E+09	8.265E+10	3.071E+09
3.500	7.993E+09	2.652E+08	1.063E+10	3.834E+08
5.000	4.560E+06	3.783E+06	2.265E+07	1.875E+07
7.000	5.258E+05	4.360E+05	2.612E+06	2.162E+06
10.00	7.165E+04	5.941E+04	3.560E+05	2.947E+05
Total neutron source (n/sec)	2.297E+08	1.915E+08	1.134E+09	9.409E+08

[a]Initial uranium loading is 0.462 MT.

Table 5-2 - BWR Spent Fuel Assembly[a] Source Strength

	Gamma Source Strength (gamma/sec)			
	28,000 MWD/MTU		48,000 MWD/MTU	
MeV	5 yr Cool	10 yr Cool	5 yr Cool	10 yr Cool
0.05	6.807E+14	4.254E+14	1.040E+15	7.022E+14
0.0575	9.094E+13	5.820E+13	1.373E+14	9.440E+13
0.085	5.842E+13	3.376E+13	8.952E+13	5.623E+13
0.125	5.902E+13	3.212E+13	9.525E+13	5.757E+13
0.225	4.927E+13	2.788E+13	7.369E+13	4.611E+13
0.375	2.978E+13	1.361E+13	4.165E+13	2.132E+13
0.575	7.548E+14	5.091E+14	1.301E+15	8.549E+14
0.850	1.495E+14	3.796E+13	3.015E+14	7.674E+13
1.250	6.716E+13	3.411E+13	1.094E+14	5.634E+13
1.750	1.173E+12	4.810E+11	1.983E+12	9.588E+11
2.250	5.461E+11	9.108E+09	5.666E+11	1.002E+10
2.750	1.931E+10	6.477E+08	2.377E+10	8.694E+08
3.500	2.476E+09	8.275E+07	3.065E+09	1.135E+08
5.000	1.726E+06	1.432E+06	8.095E+06	6.702E+06
7.000	1.990E+05	1.650E+05	9.335E+05	7.728E+05
10.00	2.712E+04	2.249E+04	1.273E+05	1.053E+05
Total neutron source (n/sec)	2.158E+08	1.800E+08	1.007E+09	8.354E+08

[a]Initial uranium loading is 0.186 MT.



Note: Dose Rates are in Units of mRem/hr

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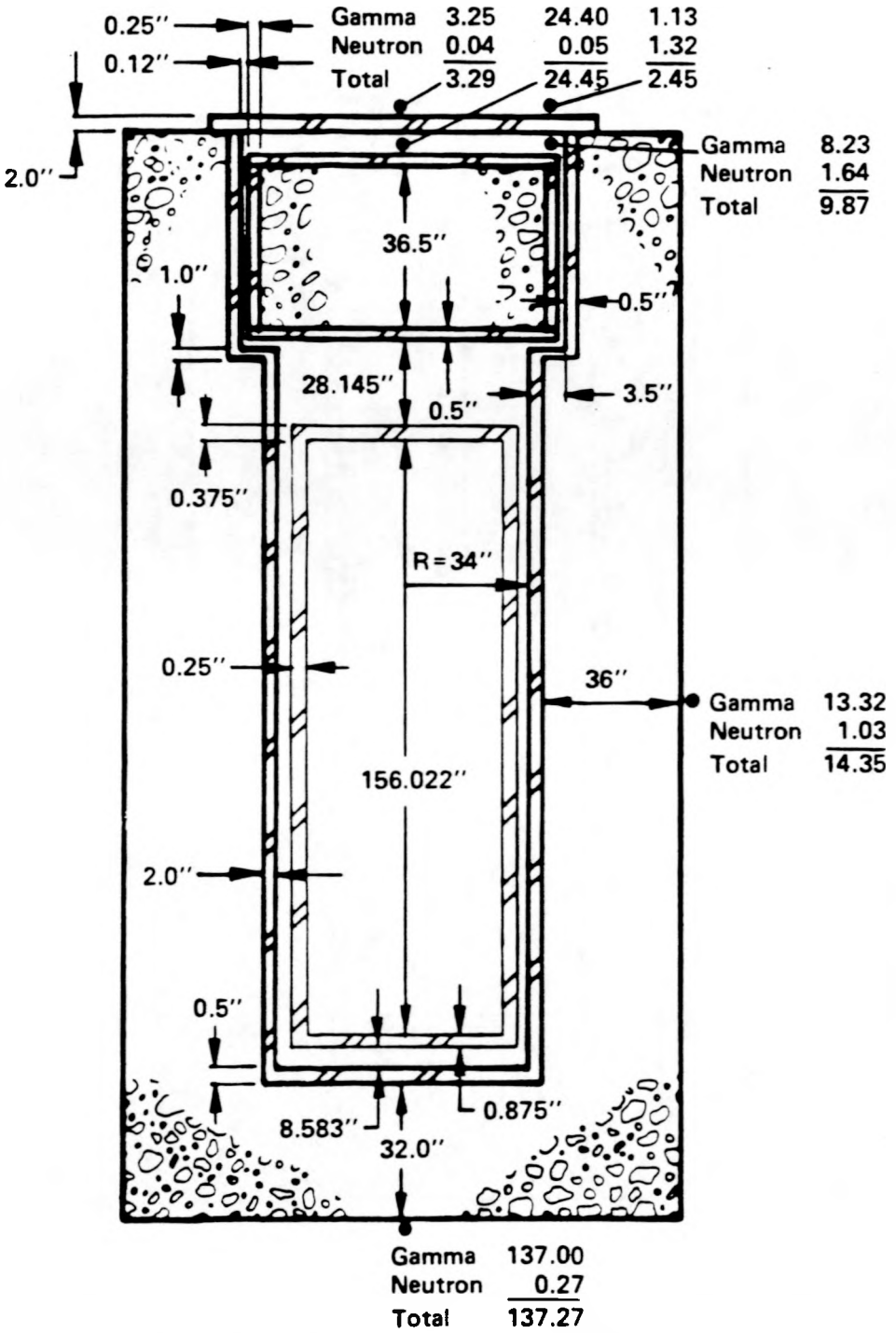
Figure 5-1 - Consolidated (33-10) Spent Fuel Concrete Cask Design



Note: Dose Rates are in Units of mRem/hr

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Figure 5-2 - Intact (33-5) Spent Fuel Concrete Cask Design

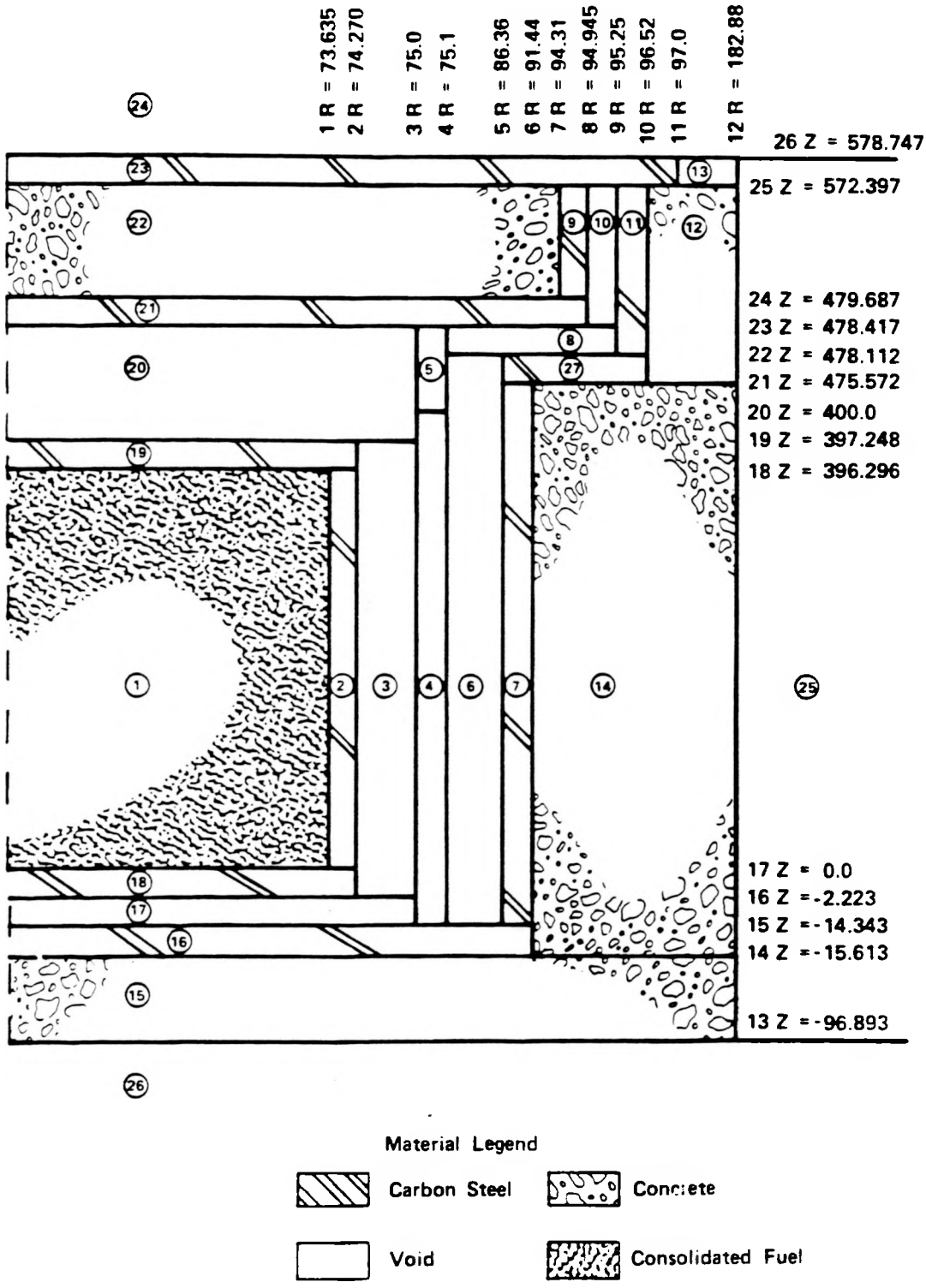


Figure 5-3 - SCAP Model for Consolidated Fuel Concrete Cask

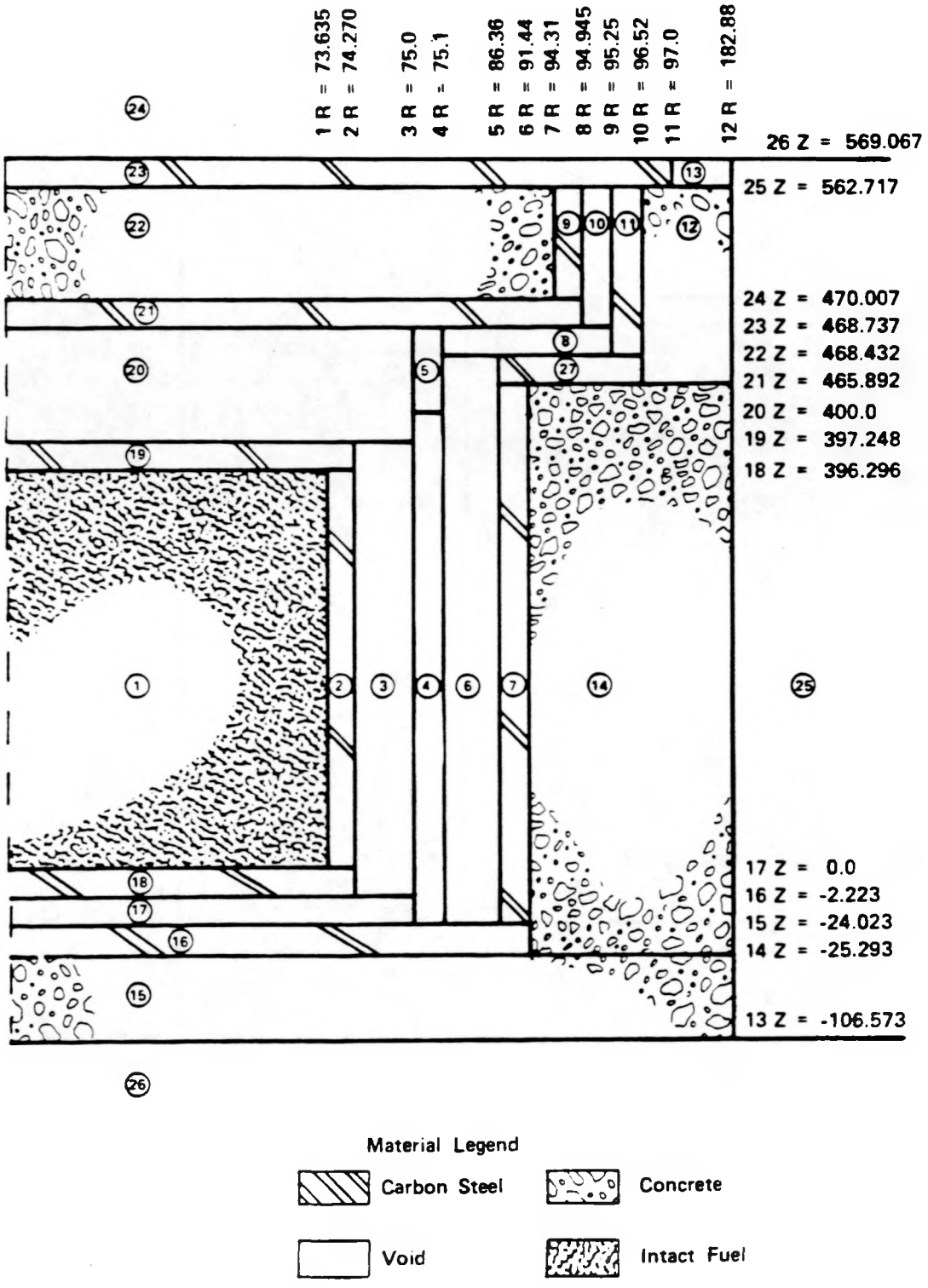
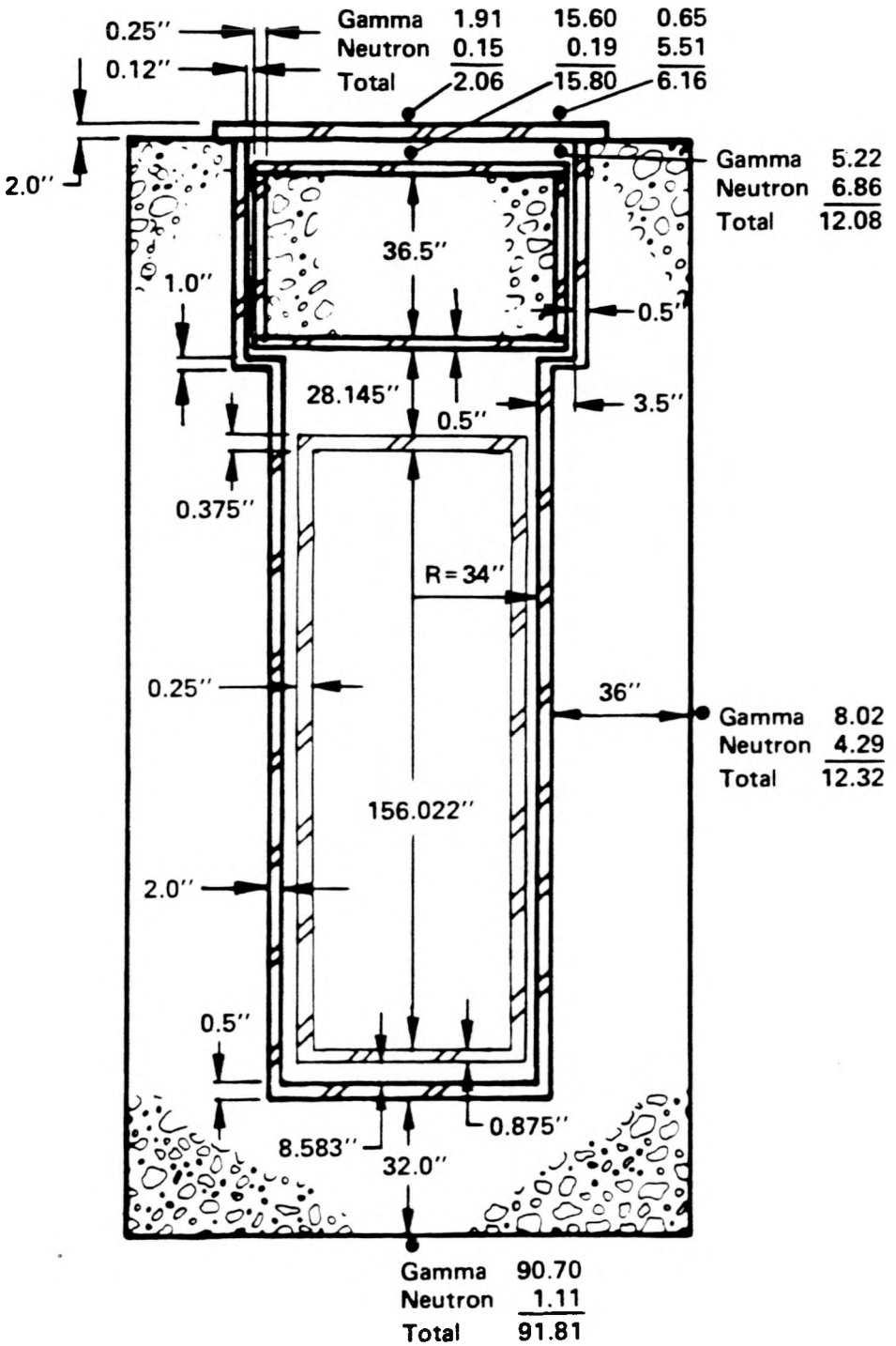


Figure 5-4 - SCAP Model for Intact Fuel Concrete Cask



Note: Dose Rates are in Units of mRem/hr

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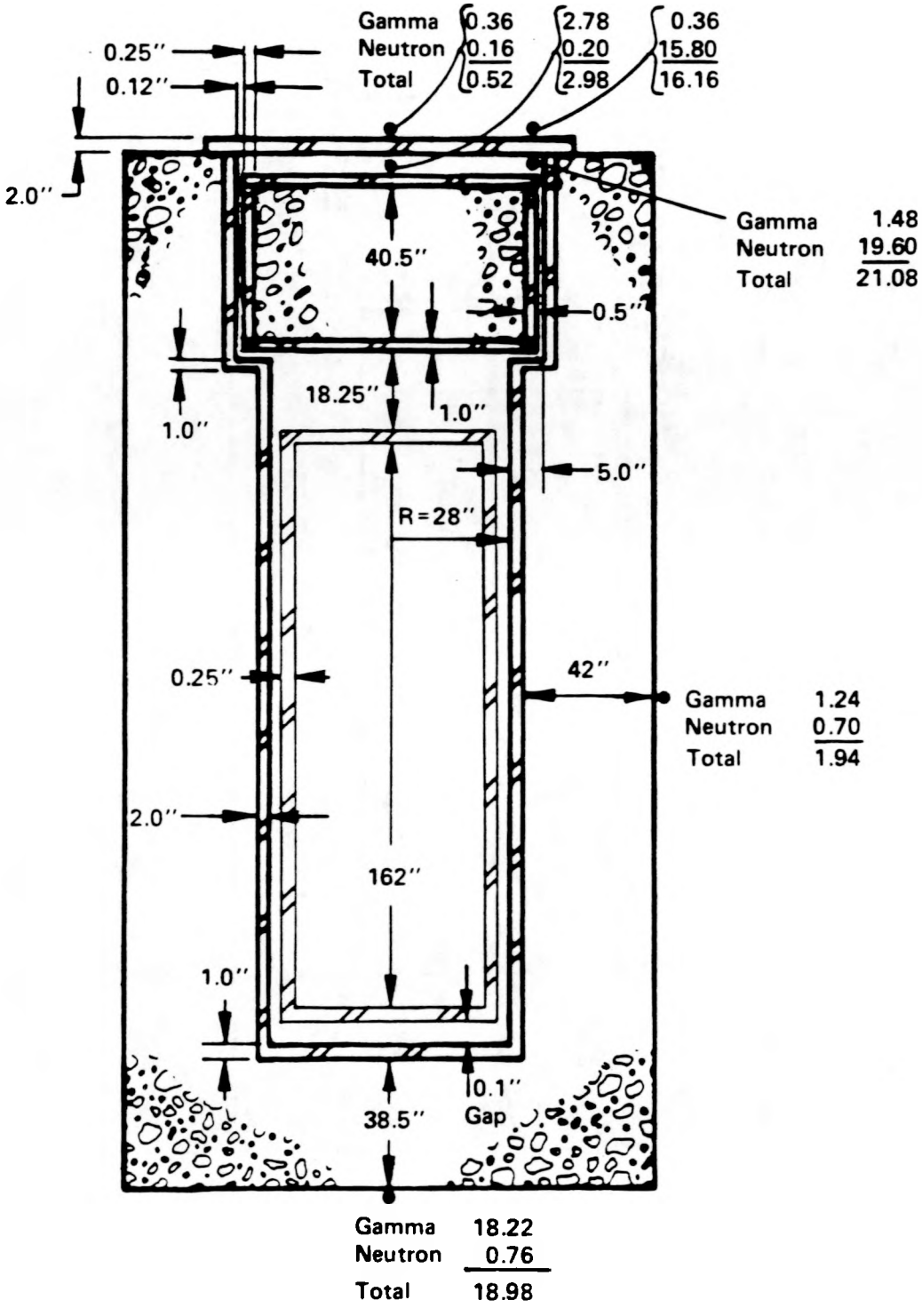
Figure 5-5 - Intact (55-10) Spent Fuel Concrete Cask Design



Note: Dose Rates are in Units of mRem/hr

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Figure 5-6 - HLW Concrete Cask Design

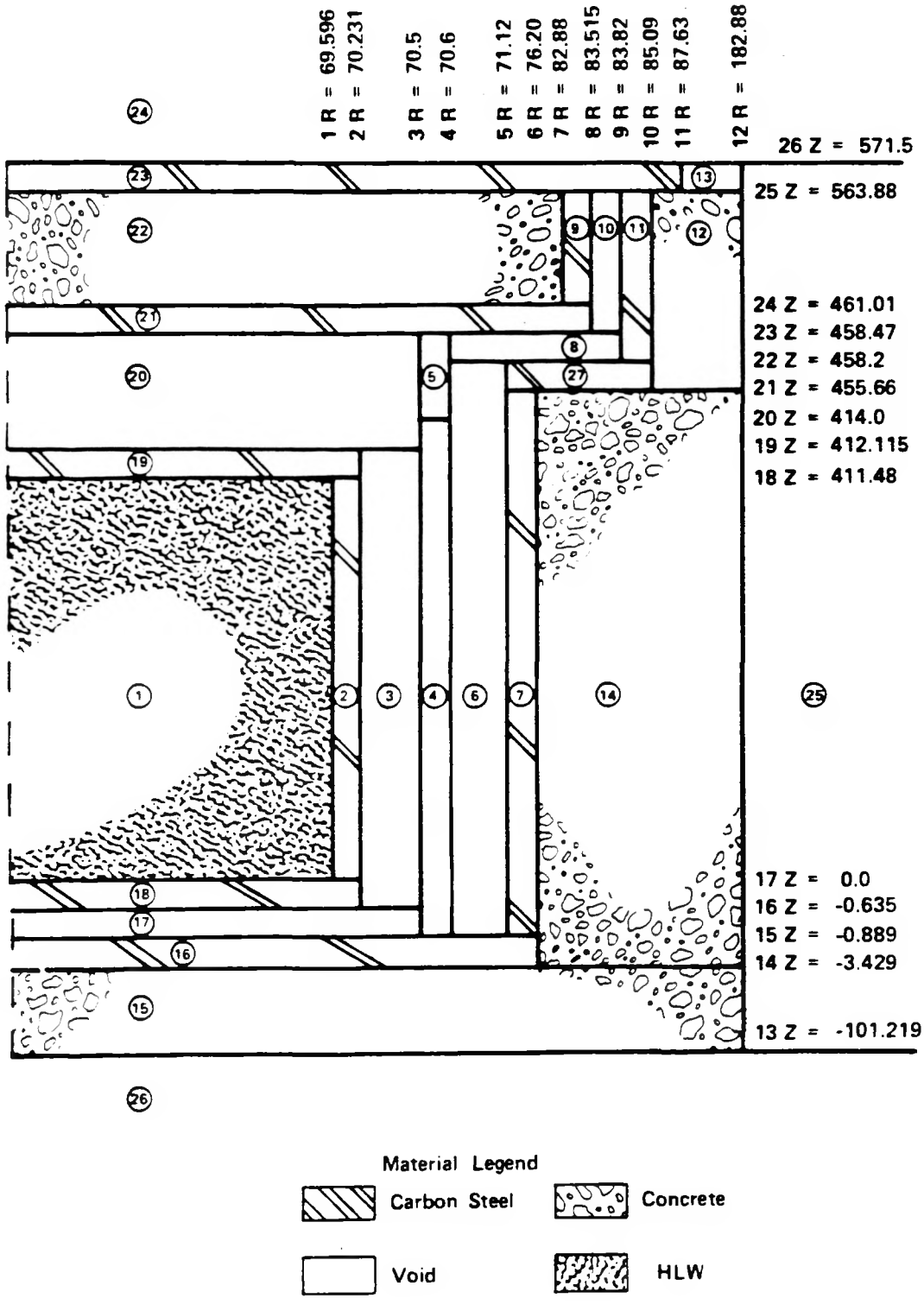


Figure 5-7 - SCAP Model For HLW Concrete Cask

Table 5-3 - HLW Source Strength

Group	E (MeV)	Gamma Source Terms 10-yr Decay Time (MeV/w-s/MTU)
1	0.085	8.6 + 5
2	0.125	1.0 + 6
3	0.225	1.9 + 6
4	0.375	1.5 + 6
5	0.575	4.9 + 7
6	0.85	6.1 + 6
7	1.25	3.6 + 6
8	1.75	1.6 + 5
9	2.25	4.3 + 3
10	2.75	3.3 + 2
11	3.5	5.4 + 1

Power = 38.4×10^6 W

2.28 MTU per canister

Note: From Reference 6, the HLW design level neutron source is 1×10^9 neutrons/sec per HLW canister.

Table 5-4 - Gamma Source Terms for 33-10 PWR Skeletons

Group	E (MeV)	Source (gamma/sec/Skeleton)
1	0.05	2.879E + 12
2	0.0575	2.305E + 11
3	0.085	9.070E + 10
4	0.125	3.565E + 10
5	0.225	2.361E + 10
6	0.375	7.561E + 10
7	0.575	9.326E + 10
8	0.85	5.071E + 10
9	1.25	7.765E + 13
10	1.75	2.519E + 2
11	2.25	4.115E + 8
12	2.75	1.273E + 6

Note: (33-10) refers to the skeleton associated with a fuel assembly with 33,000-MWD/MTU burnup with 10 yr out of reactor.

5.4 WV HLW CONCRETE CASK

From Reference 6, page 1.9, the WV HLW surface dose rates are 3 x 10^6 mrem/hr gamma and 1.3 mrem/hr neutron. The neutron levels are so low, they will not be considered. The WV HLW gamma source was assumed to have the same energy spectrum as HLW with 10-yr decay, but normalized to a surface dose rate of 3 x 10^6 mrem/hr.

The design for the WV HLW concrete cask is shown in Figure 5-10, which also presents the dose rate results for the WV HLW concrete cask. Figure 5-11 presents the SCAP geometry model used to analyze the WV HLW concrete cask.

5.5 RHTRU CONCRETE CASKS

There is a high degree of uncertainty in the composition and source makeup for RHTRU. With this in mind, the following was assumed:

(1) RHTRU waste consists of 40 vol% steel.

(2) The source is 100% Co-60, normalized to a specified waste surface dose rate.

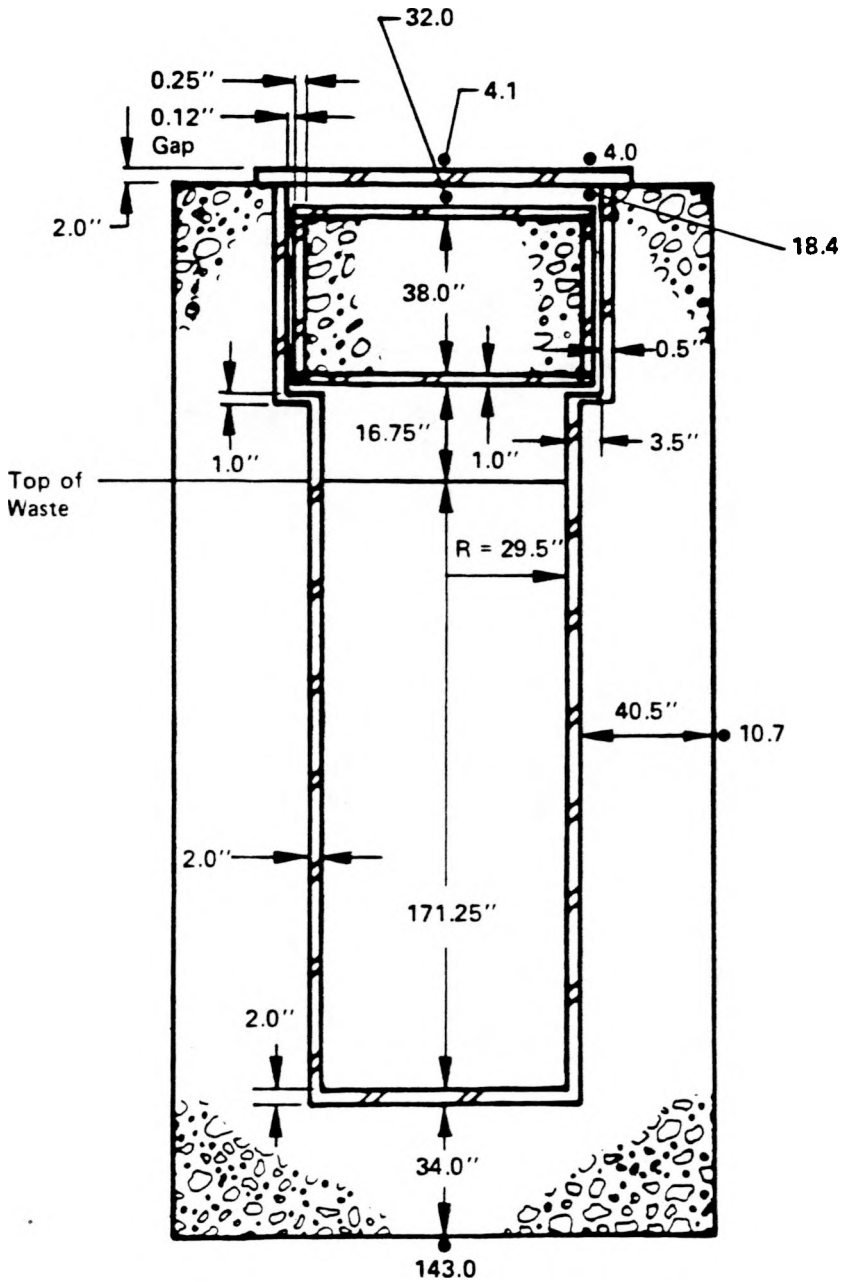
Individual concrete casks for 50- and 1,000-R/hr RHTRU waste have been designed. In addition, placing 2,500-R/hr RHTRU into the WV HLW concrete cask design has been examined. Figures 5-12, 5-13, and 5-14 present the 50- and 1,000-R/hr RHTRU cask designs, and the 2,500-R/hr RHTRU waste loaded in the WV HLW cask design, respectively. Figures 5-15, 5-16, and 5-17 present the SCAP geometry models used to analyze the above designs. Figures 5-12, 5-13, and 5-14 present the dose rate results for the 50-, 1,000-, and 2,500-R/hr RHTRU cases, respectively.

6.0 SUPPORTING STUDIES

This section presents some additional supporting studies performed for this analysis.

6.1 COMPOSITION OF RHTRU WASTE

No explicit information was provided as to the composition or density of the material to be contained in the RHTRU canisters. It seems likely that a majority of the canisters could contain miscellaneous metallic waste, including significant void regions. The waste was, therefore, modeled as 40% dense steel (3.14 g/cc). Calculations were performed comparing 40% dense aluminum with 40% dense steel (3.14 g/cc) RHTRU; the resulting dose rates were different by only a few percent. This is because, in each case, the source was normalized to yield the same dose rate at the waste surface. In addition, the assumption of an essentially monoenergetic source (Co^{60} ~ 1.25 MeV) eliminates any distortions in source spectra, which could have resulted if a multigroup energy spectrum had been used with source materials of significantly differing self-attenuation properties. The results of this evaluation are, therefore, concluded to be conservative and independent of the actual waste composition.



Note: Dose Rates are in Units of mRem/hr

Figure 5-8 - Skeleton (Nonfuel-Bearing Components) Concrete Cask Design

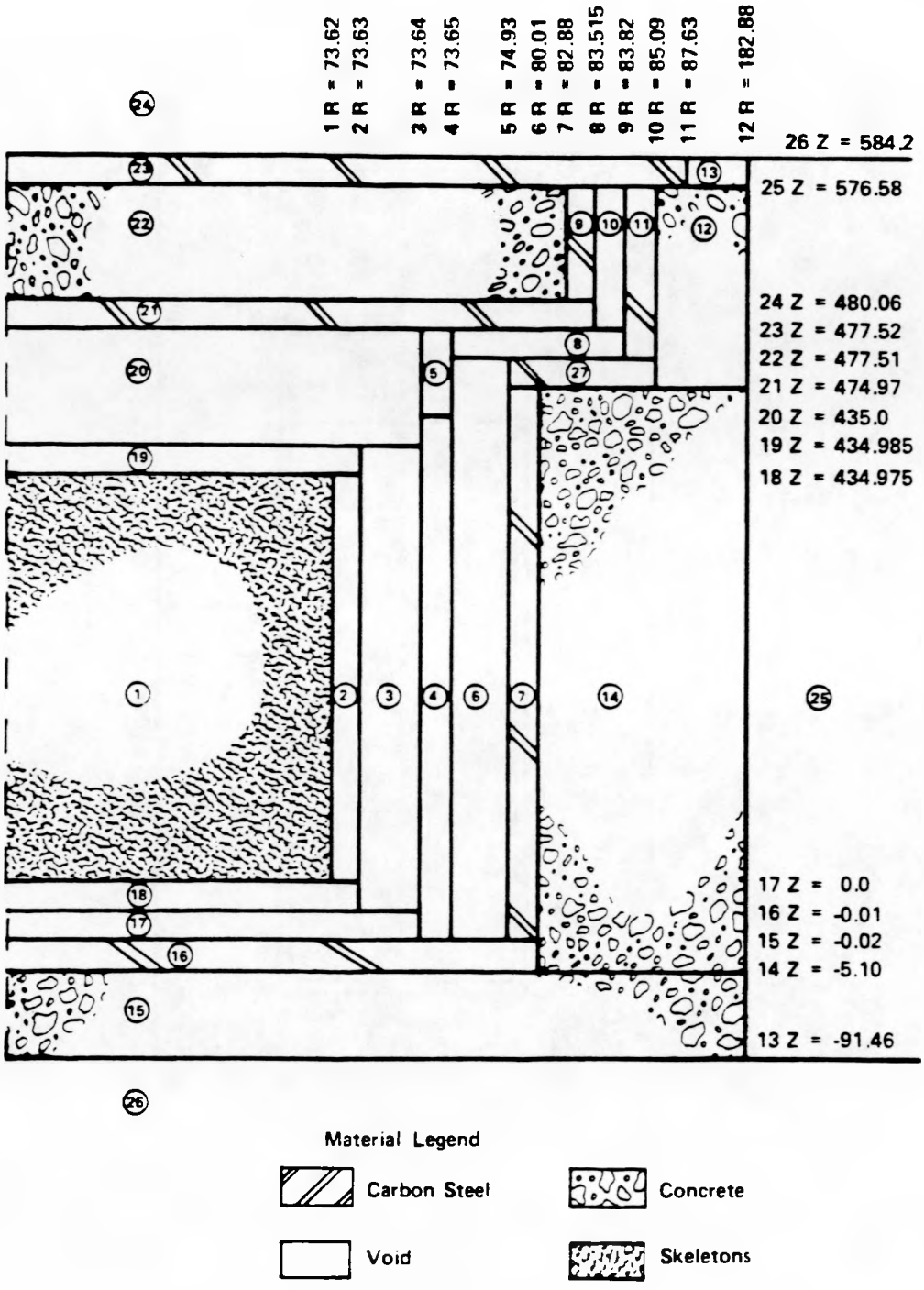


Figure 5-9 - SCAP Model for Skeleton Cask

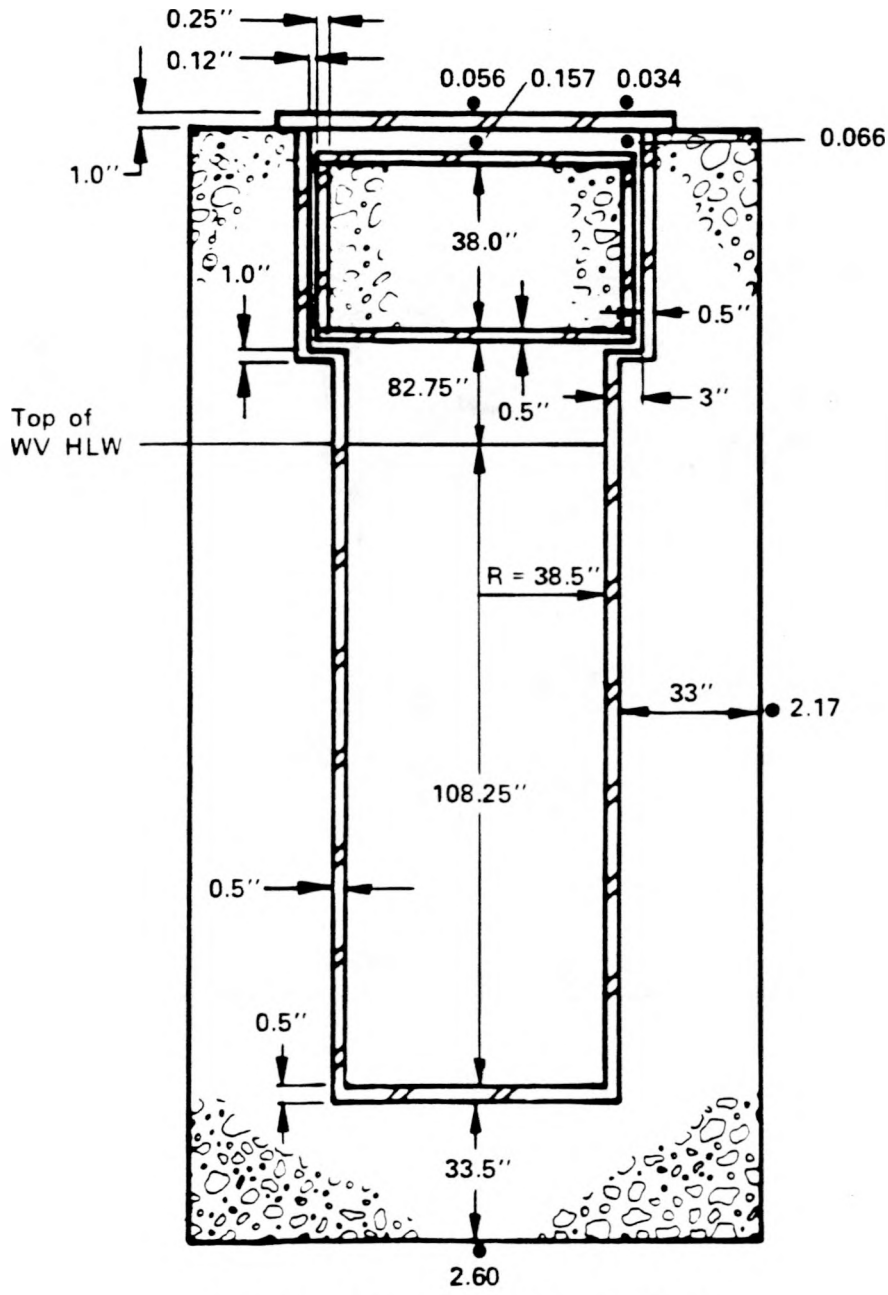


Figure 5-10 - West Valley High-Level Waste (WV HLW) Concrete Cask Design

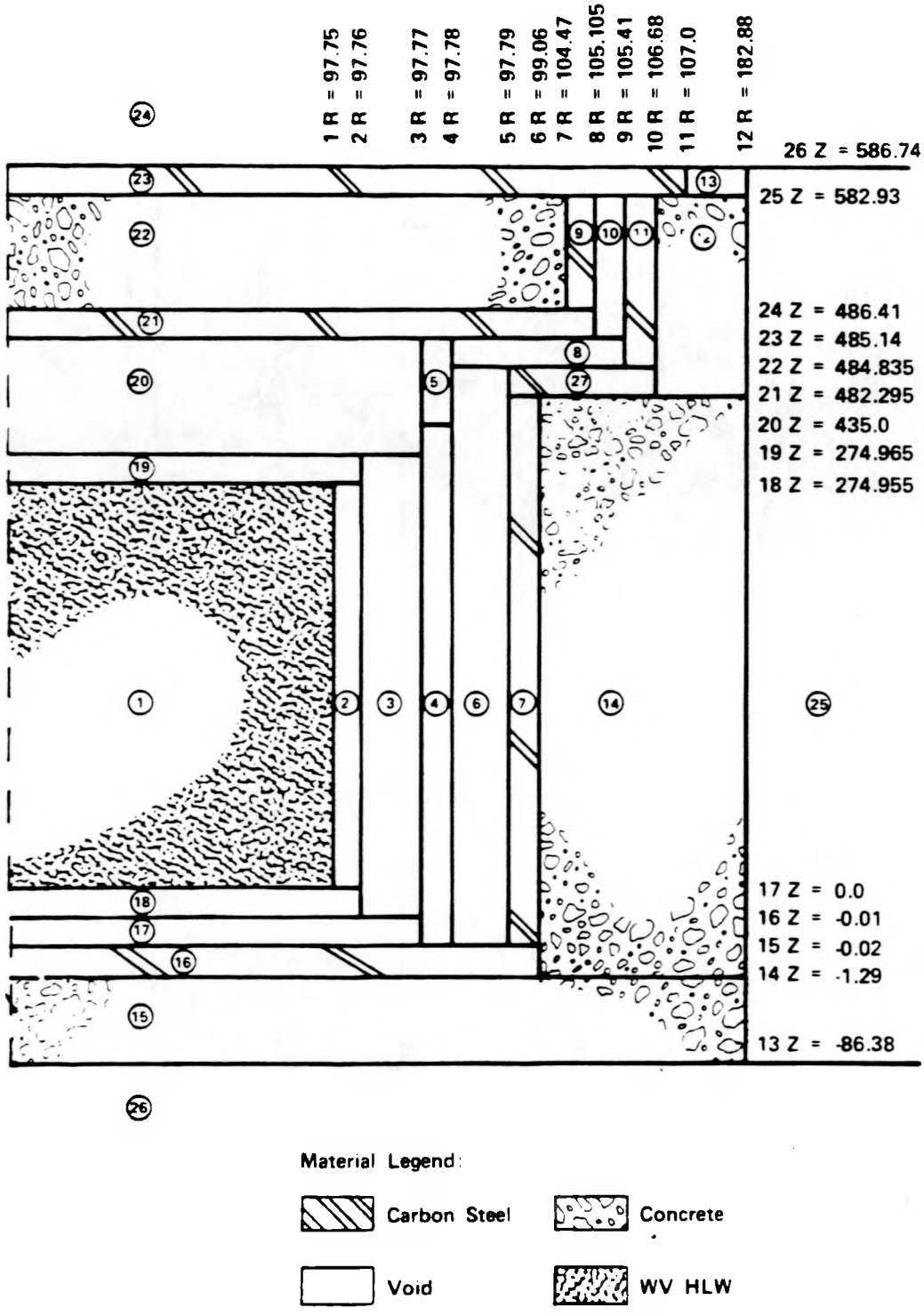


Figure 5-11 - SCAP Model for WV HLW Concrete Cask

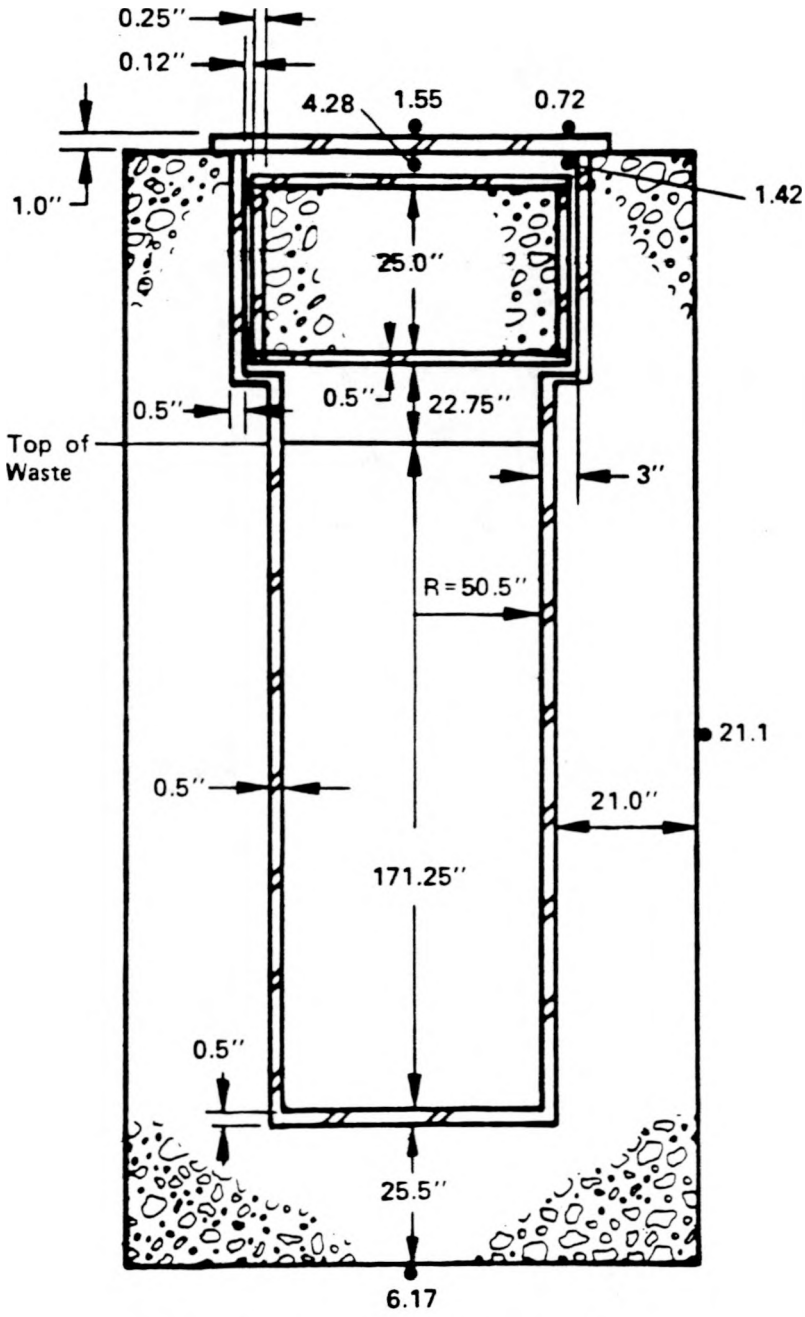


Figure 5-12 - 50-R/hr RHTRU Concrete Cask Design

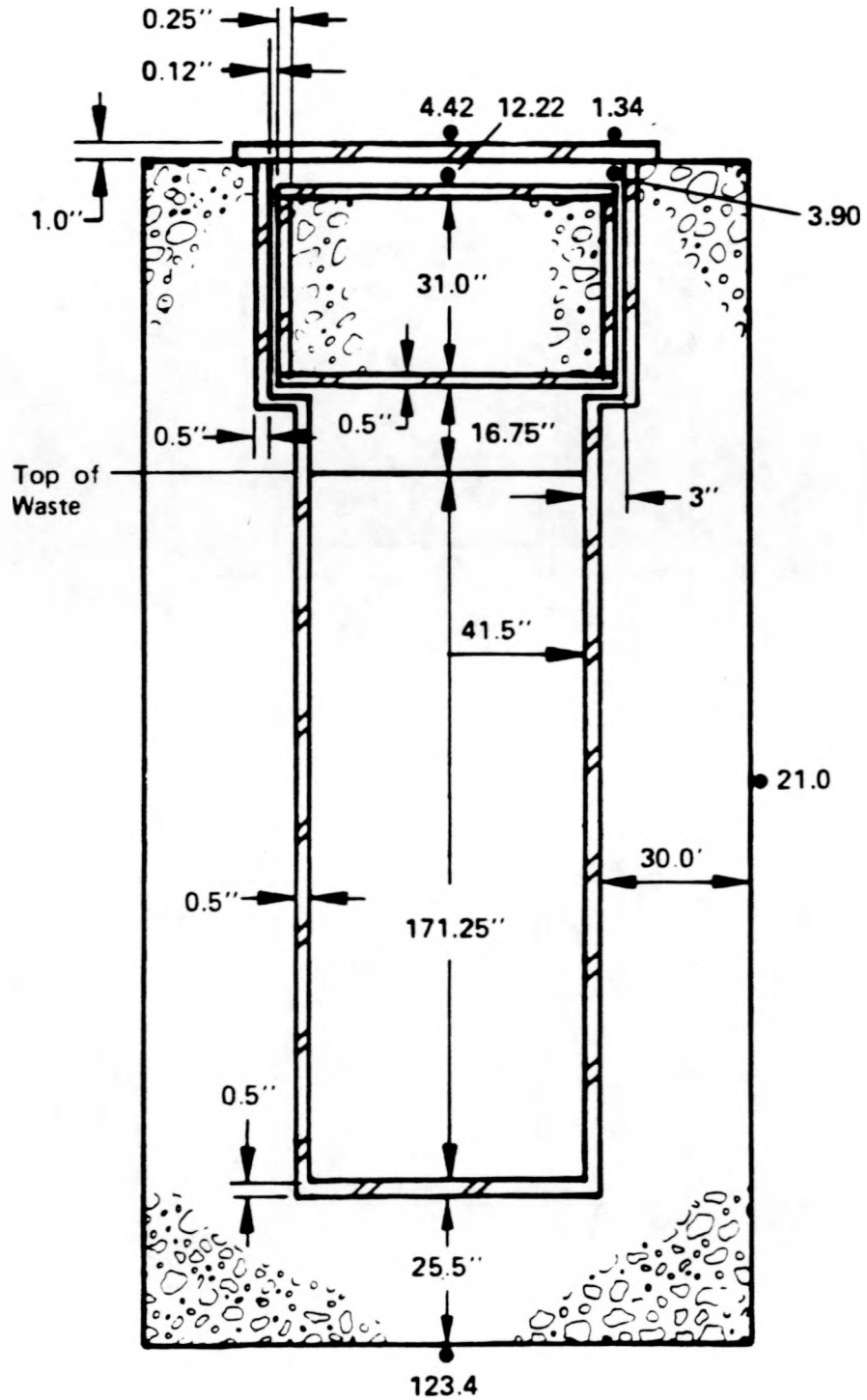


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Figure 5-13 - 1,000-R/hr RHTRU Concrete Cask Design

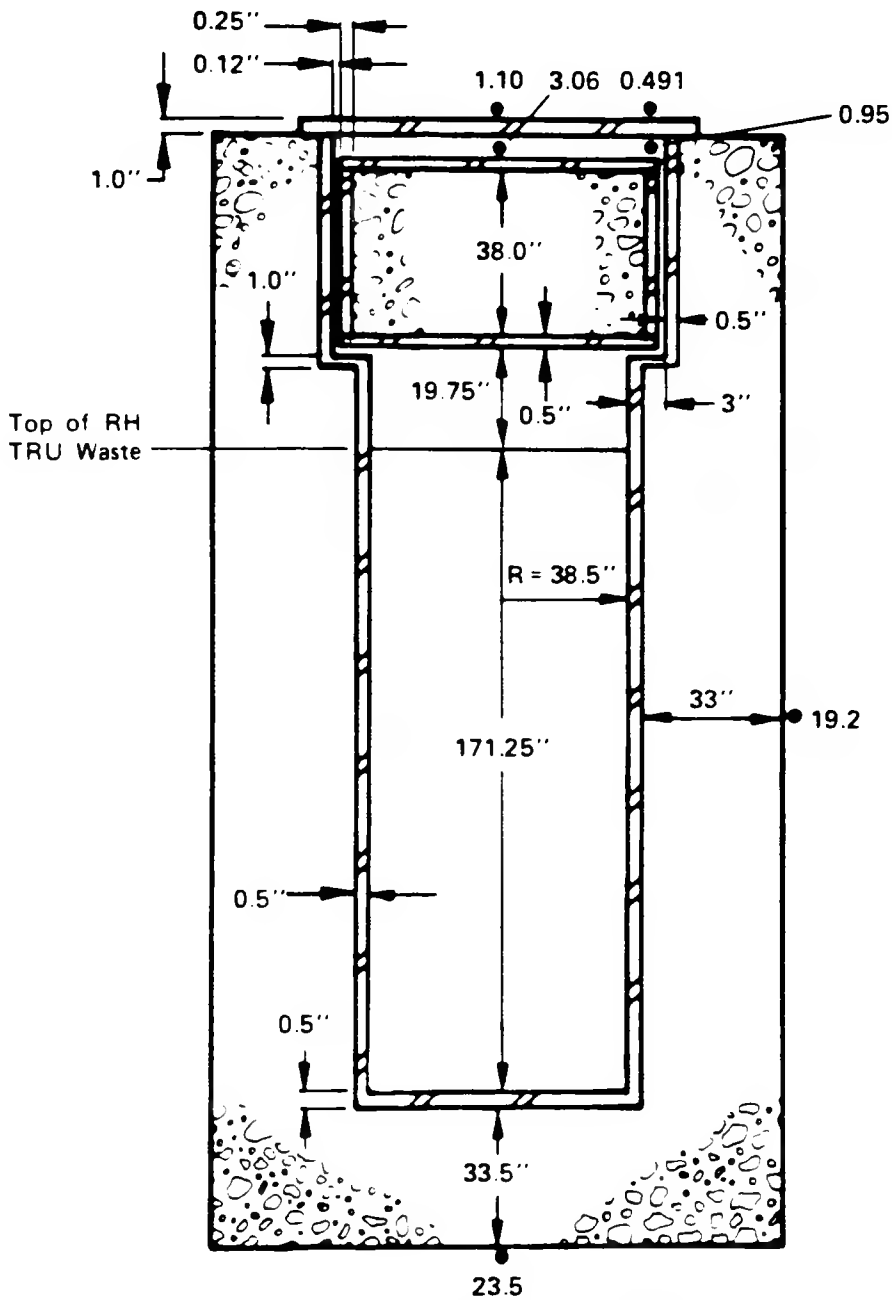

Figure 5-14 - 2,500-R/hr RHTRU in WV HLW Concrete Cask

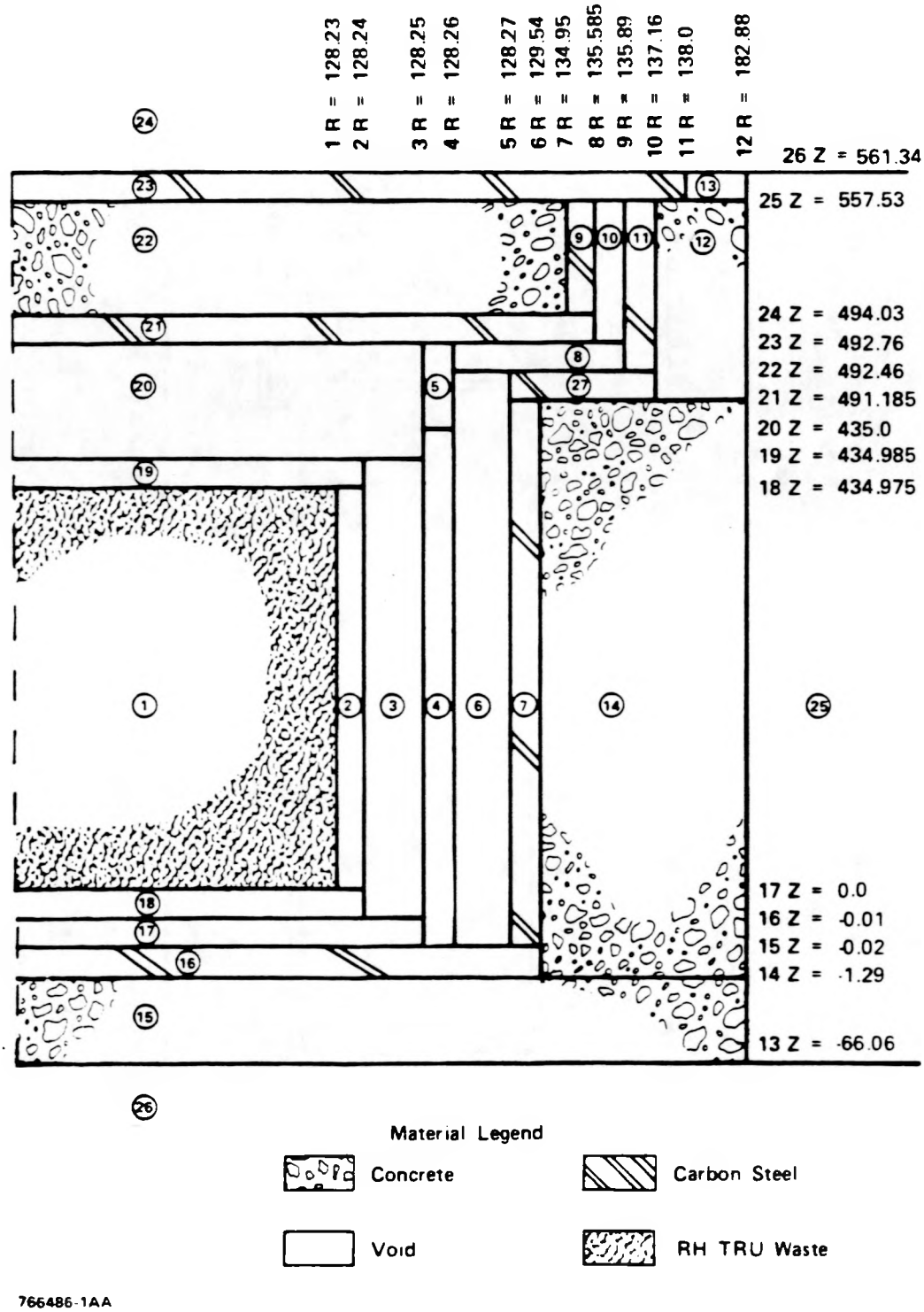

Figure 5-15 - SCAP Model for 50-R/hr RHTRU Concrete Cask

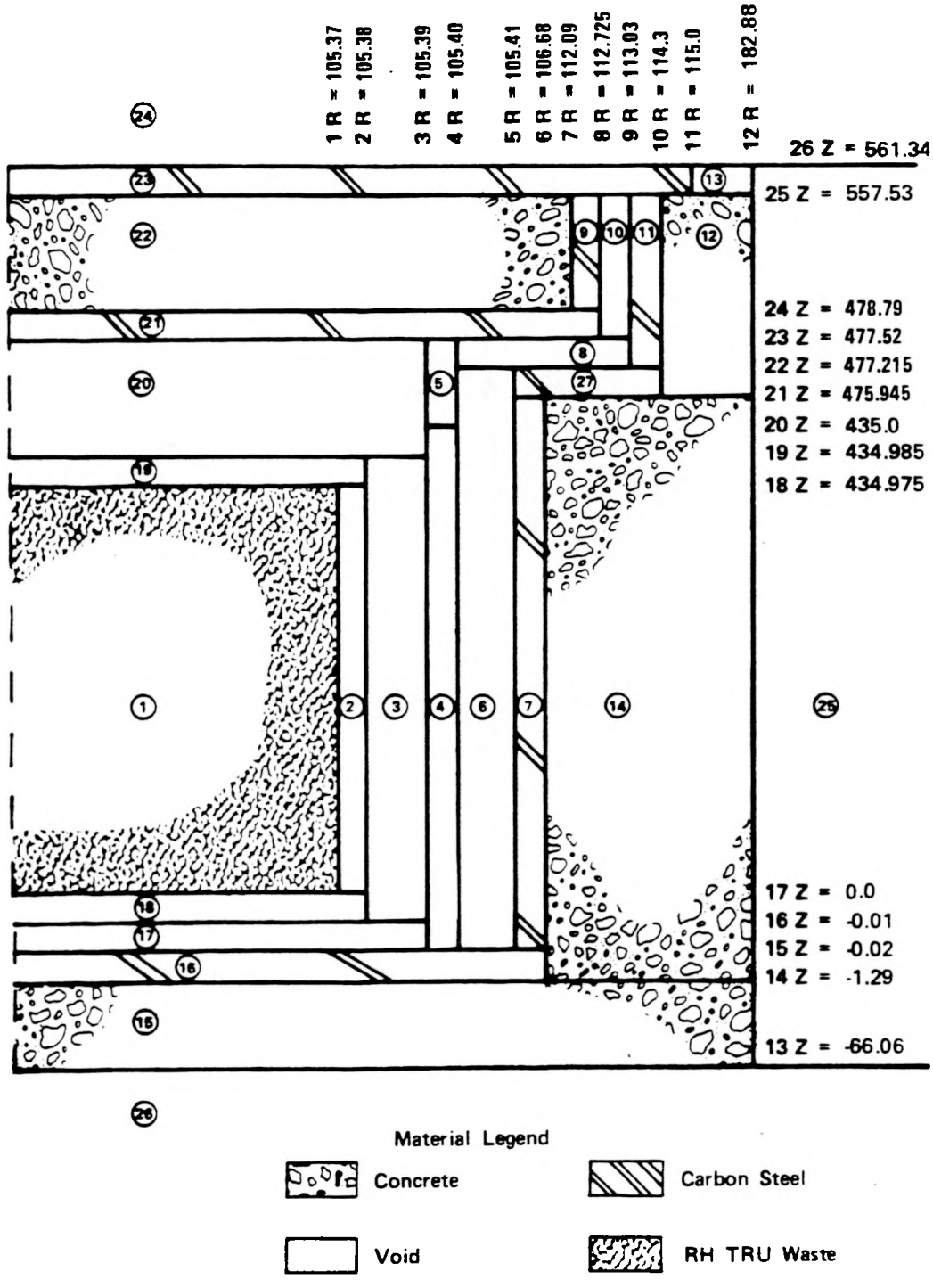

Figure 5-16 - SCAP Model for 1,000-R/hr RHTRU Cask

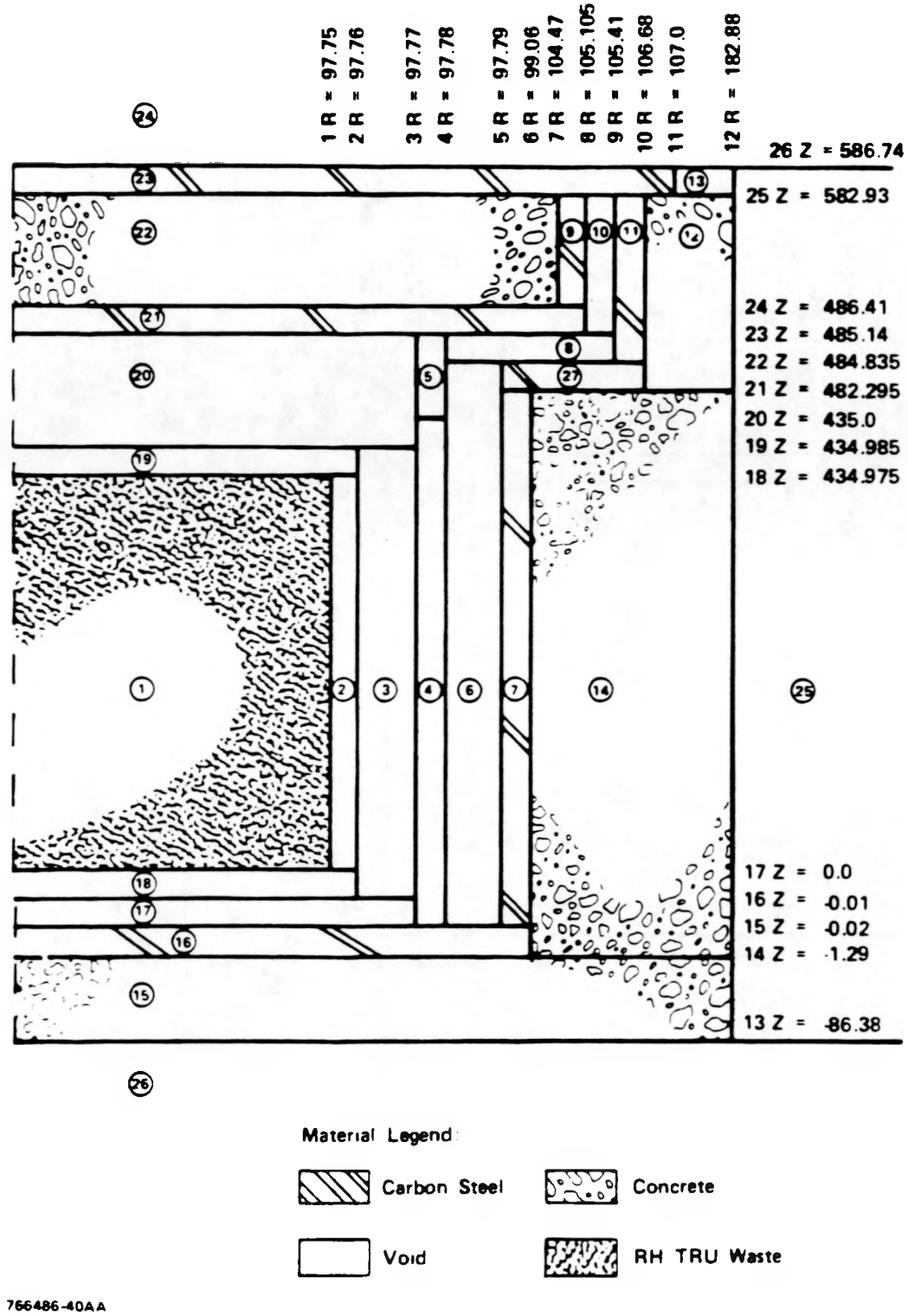

Figure 5-17 - SCAP Model for 2,500-R/hr RHTRU in WV HLW Concrete Cask

6.2 SKELETON COMPACTION

It was desirable to know the effect on surface dose rates of the degree to which the skeletons were compressed.

It is the contention here that, to within reasonable limits, the cask surface dose rate is independent of the number of skeletons compressed into the drums. This is because the dose rate is directly proportional to source density and inversely proportional to physical density of source material. If twice the number of skeletons are packed into the same volume, the specific source doubles, but the physical density also doubles. To investigate this, the skeleton calculations in Section 5.3 were rerun with the density and the source strength increased by a factor of 10. The results at the cask side surface from the two runs differed by less than 1%.

6.3 GAP-SIZE/STEP-SIZE VARIATION

When the analysis of the concrete cask design was performed, the gap size between the cask shield plug and the cask cylindrical wall was 0.12 in. Following this analysis, a design change was made that increased the gap size to 0.5 in. To partially compensate for the increase in the dose rate streaming through this larger gap, the shield plug step size was increased.

Estimates of the impact of these shield plug gap-size and step-size variations on the scatter component of the dose rate were made. The gamma scatter portion of the dose rate, for all cask designs, is very small (less than 10% of the total dose rate). The neutron scatter portion, however, is a much larger portion of the total dose rate (based on conservative hand-calculational methods). Step sizes for all cask designs were increased so that the overall impact of increasing the gap size from 0.12 to 0.50 in. would limit the increase in the scatter component to a factor of less than 3. The calculational methods used to determine the neutron scatter component are considered to be very conservative. Therefore, the overall impact of the design change from 0.12 to 0.5 in. is expected to be small.

7.0 RADIATION EXPOSURE ASSESSMENT

This section presents an estimate of the worker radiation exposure assessment for the concrete casks (estimate based on 1,800-MTU/yr throughput rate, excluding onsite-generated HAW).

7.1 BASIS FOR CASK STORAGE AND RETRIEVAL OPERATIONS

(1) Locations (described in Table 7-1) and times (defined in Table 7-2) were estimated for a single cask handling operation.

(2) A crew chief was included to oversee all cask handling operations.

(3) The entire storage area crew (crew chief, crane operator, and handling technicians 3 and 4) is assumed to spend 40 min in storage cask radiation field per cask, even if their assigned activities take less than 40 min.

Table 7-1 - Concrete Cask Radiation Exposure Points Description

Location	Operation
Point A	Eyebolt removal - hands on eyebolt without cask cover
Point B_1	Operator kneeling on cask top for eyebolt removal (without cask cover)
Point B_2	Operator or inspector kneeling on cask top (with cask cover on) for welder setup, weld inspection, cleaning, coating, etc.
Point C	Operator standing on work platform, aligning cover
Point D	Operator on work platform welding machine console
Point E	Gas sample port - hands on bolts, cover, port connections
Point F	Operator standing next to cask for gas sample or pressure check
Point G	Transporter operator sitting in cab for cask transfer
Point H	Operator standing in transfer corridor
Point I	Gas sample port - hands on bolts, cover, port connections
Point J	Thermocouple junction box - manual operations in box
Point K	Operator standing next to cask
Point L	Operator sitting in cab of transporter or crane
Point M	Operators traveling to and from cask handling location
Point N	Inspector examining seal weld from cherry picker
Point O	Operator moving along cask row for weld examination

Table 7-2 - Exposure Estimates

Storage and Retrieval Operations

Worker	Location	Time (min/cask)	Rate (cask/yr)	Exposure (mrem/hr)	Exposure (mrem/yr)
Storage Cask Handling, Crew Chief	D	90	204	0.154	47.1
	H	105	204	0.646	230.6
	M	45	204	10.2	1,560.6
	L	10	204	11.2	381.5
	C	5	204	0.02	0.34
	F	5	204	1.459	24.80
	K	5	204	13.55	230.4
Total[a]					2,475.34
Transporter Operator	G	40	204	1.152	156.7
	L	10	204	11.22	381.5
	M	10	204	10.2	346.8
Total					885.0
Crane Operator	M	10	204	10.2	346.8
	L	40	204	11.22	1,525.9
Total					1,872.7
Handling Technician 1 (cask lid welding)	B1	10	204	2.09	71.06
	A (hands only)	6	204	1.07	21.83
	C	10	204	0.02	0.68
	B2	20	204	0.565	38.42
	D	60	204	0.154	31.42
Total					141.58
Inspector 1 (weld integrity)	B2	40	204	0.565	76.84
	F	10	204	1.459	49.61
Total					126.54
Handling Technician 2 (cask pressure check)	F	20	204	1.459	99.21
	E (hands only)	5	204	1.838	31.25
	H	20	204	0.646	43.93
Total					143.14

[a]Does not include dose to hands.

Table 7-2 (Contd)

Worker	Location	Time (min/cask)	Rate (cask/yr)	Exposure (mrem/hr)	Exposure (mrem/yr)
Handling Technician 3 (cask handling)	M	20	204	10.2	693.6
	F	5	204	1.459	24.80
	K	5	204	13.55	230.35
	L	20	204	11.22	762.96
Total					1,711.71
Handling Technician 4 (instrumentation hookup)	M	10	138[b]	9.88	227.24
	K	30	138[b]	13.12	905.28
	J (hands only)	20	138[b]	13.87	638.02
Total					1,132.52

Monitoring Operations

Worker	Location	Time (min/day)	Time (days/yr)	Exposure (mrem/hr)	Exposure (mrem/yr)
Technician 1 (monitoring)	L	180	250	11.22	8,415.0
	K	180	250	13.55	10,162.0
	J (hands only)	135	250	14.33	8,060.6
	M	30	250	10.2	1,275.0
Total					19,852.0
Inspector 2 (accountability)	N	180	10	14.03	420.9
	O	180	10	11.22	336.6
	M	30	10	10.2	51.0
Total					808.5
Technician 2 (accountability)	L	360	10	11.22	673.2
	M	30	10	10.2	51.0
Total					724.2

[b]Only performed for spent fuel casks.

(4) Instrumentation hookup (thermocouples) is assumed for only spent fuel casks (138 of 204).

(5) The onsite-generated RHTRU casks (estimated at about 17 per year) were neglected in the assessment of the storage, monitoring, and inspection operations.

7.2 BASIS FOR CASK MONITORING OPERATIONS

The basis for cask monitoring operations was established as follows:

(1) Monitoring technician(s) take gas samples from all 204 casks once each month at the rate of about 10/day.

(2) Inspector 2 and Technician 2 perform accountability inspection of all 204 casks once each year.

(3) Accountability inspection is estimated to take 10 days/yr for 204 casks (approximately 20/day).

7.3 ASSESSMENT RESULTS

The assessment was done by using dose rates determined for a composite cask, which assumed that 50% of the casks are consolidated (33-10) PWR spent fuel casks, 18% are intact (33-5) PWR spent fuel casks, 26% are PWR nonfuel-bearing component casks, and 6% are WV HLW casks. Figures 7-1 and 7-2 show the locations of interest for exposure estimates from a single cask and multiple casks, respectively. Table 7-1 describes their locations.

Results are shown in Table 7-2 for the individuals involved in storage and/or retrieval operations and for monitoring operations.

The total yearly exposures were estimated to be:

(1) 0.7 mrem/yr for cask sealing operations in the R&H Building (204 casks/yr).

(2) 7.8 mrem/yr for cask emplacement operations in the storage area (204 casks/yr).

(3) 19.8 mrem/yr for cask monitoring operations (gas sampling each cask once per month).

(4) 1.5 mrem/yr for cask accountability inspection (204 casks/yr).

These values are considered to be very conservative estimates of the total exposures. The conservatisms included in the dose rates and exposure estimates are noted below.

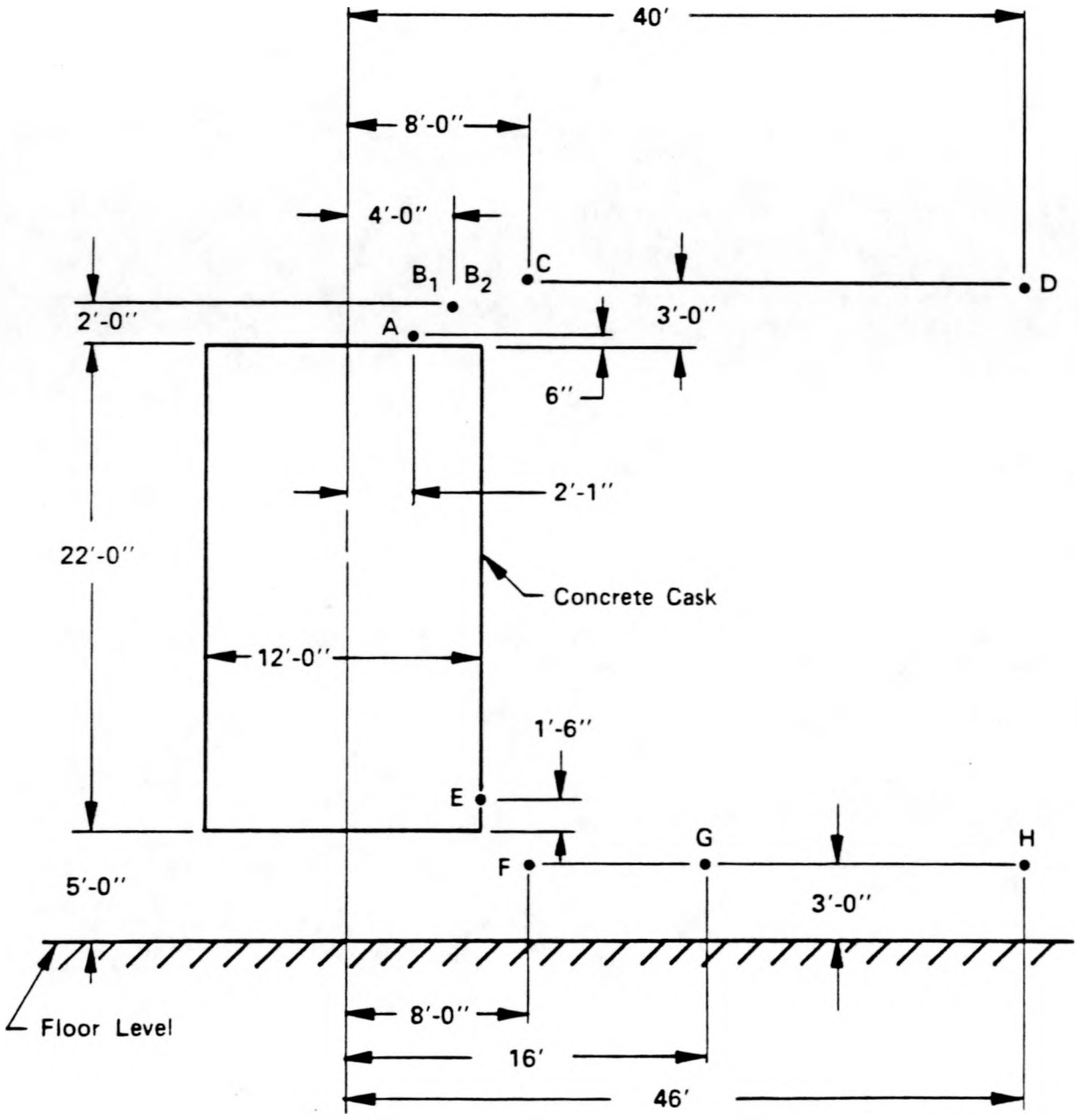

Figure 7-1 - Concrete Cask Radiation Exposure Locations for Cask Operations in R&H Building

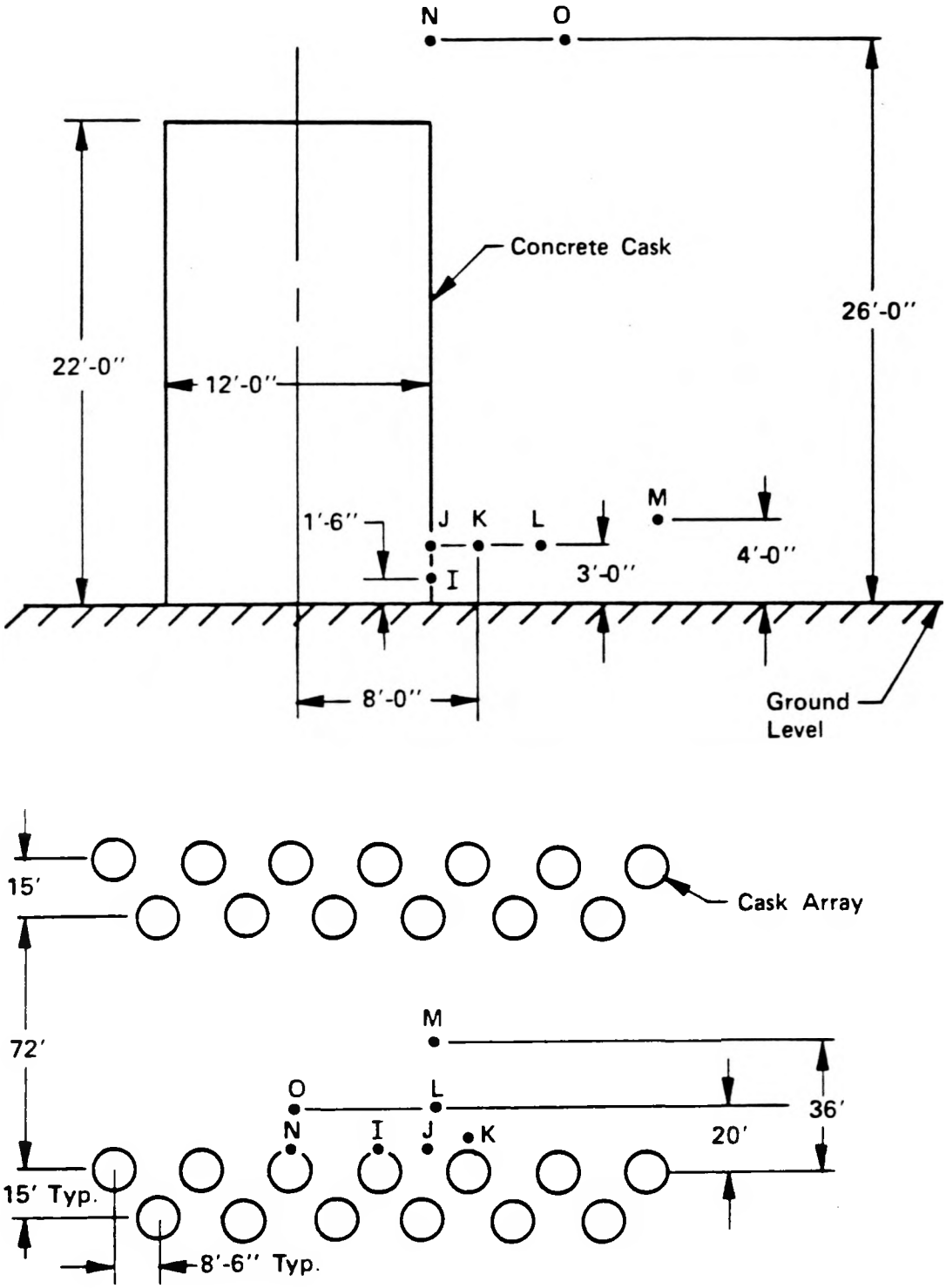

Figure 7-2 - Concrete Cask Radiation Exposure Locations for Cask Operations in Storage Area

7.4 CONSERVATISMS IN ANALYSIS

Dose rates for spent fuel casks were assumed to be from all PWR spent fuel. By Reference 6 requirements, the casks will contain 60% PWR spent fuel and 40% BWR spent fuel. The lower doses from the BWR spent fuel were not calculated for this design phase.

Dose rate calculations for the consolidated spent fuel casks (101 of the 204) were performed by using radiation sources for intact spent fuel. These sources include the radiation dose from the nonfuel-bearing components removed from the fuel assemblies during consolidation.

The spent fuel radiation sources provided by PNL and Parsons were generated by using very conservative material quantities as input data for ORIGEN II. Specifically, the quantity of Cobalt 59 input to ORIGEN as being present in the spent fuel hardware was 112 grams. This exceeds the values recognized by Oak Ridge and the NRC (approximately 72 grams) in References 7 and 8. For 10-yr-old spent fuel, the source from 40 extra grams of Cobalt 60 is significant.

Dose rate calculations for the nonfuel-bearing components (NFBC) were based on only PWR NFBC. The NFBC casks will consist of 28% PWR and 72% BWR, using the fuel assembly ratios defined in Reference 6.

Radiation sources for the NFBC were generated by using conservative material quantities. The Cobalt 59 content in all NFBC (the major radiation source) was assumed to be the maximum (that from a 17 x 17 PWR spent fuel assembly). The quantity used neglected the reduction in Cobalt 59 quantity defined by both Oak Ridge and NRC, which accounts for reduced in-core material activation from the flux and energy falloff at the ends of the fuel assembly compared to the constant value flux used in the ORIGEN II method of material activation calculation.

A handling technician was included in the storage area crew to align the cask and cask handling fixture. This function could be performed by the transporter operator or crew chief. The inclusion of this extra man increased the total exposure by 1.71 mrem/yr.

Monitoring activities for the casks (assumed as gas sampling for all 204 casks) will more realistically consist of gas sampling and pressure checks for the spent fuel casks (68% of the casks) and only pressure checks for the NFBC, West Valley HLW, and onsite-generated RHTRU casks. This would reduce the time for monitoring activities by about 15%. In addition, statistical sampling methods will probably be used after several years of MRS Facility operation, which could further reduce monitoring activity time.

7.5 FURTHER EXPOSURE CONSIDERATIONS

Considerations of how the total exposures can be reduced (other than cask redesign) are as follows:

- Provide shielded cabs for the cask transporter and mobile storage area crane.

- Provide shielded vehicles(s) for storage area crew movement throughout the storage area and for crew radiation protection during operations not requiring their direct participation (instrumentation hookup, monitoring, etc.).

- Provide shielded vehicle for accountability inspection (shield for driver and for inspector).

- Reduce size of crew for cask operations.

- Reduce number of monitoring operations by determining reasonable frequencies and type of cask integrity checks (gas sampling and/or pressure check), making use of statistical sampling techniques, etc.

- Design a WALDO (remotely operated, motion and vision duplicating manipulator) for performing the inspection and monitoring operations.

In addition to these considerations, Title II concrete cask design optimization activities could include increasing size of cask (shielding wall thickness) or use of specific concrete aggregates or additives that enhance both shielding effectiveness and cask wall thermal conductivity.

8.0 SUMMARY

Six concrete cask designs, loaded with various waste forms, have been evaluated for radiation shielding; the results for these designs are summarized in Table 8-1.

Table 8-1 - Summary of Total Dose Rate Results for Concrete Casks (mrem/hr)

	Side	Bottom	Top-Center of Cask		Top-Over Gap	
			Below Cover	Above Cover	Below Cover	Above Cover
Spent Fuel Cask						
Consolidated (33-10)	6.12	62.6	10.04	1.33	4.57	1.69
Intact (33-5)	14.35	137.27	24.45	3.29	9.87	2.45
Intact (55-10)	12.32	91.81	15.80	2.06	12.08	6.16
HLW Cask						
HLW	1.94	18.98	2.98	0.52	21.1	16.2
Nonfuel-Bearing Components Cask						
Skeletons (33-10)	10.7	143.0	32.0	4.1	18.4	4.0
50 R/hr RHTRU Cask						
50 R/hr RHTRU	21.1	6.17	4.28	1.55	1.42	0.72
1,000 R/hr RHTRU Cask						
1,000 R/hr RHTRU	21.5	123.4	12.22	4.42	3.90	1.34
WV HLW Cask						
WV HLW	2.17	2.60	0.15	0.056	0.066	0.034
2,500 R/hr RHTRU	19.2	23.5	3.06	1.10	0.95	0.491

PARSONS

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DESIGN STUDY 31

CONCRETE STABILITY AND REBAR CORROSION IN A CONCRETE CASK

1.0 INTRODUCTION

This design study discusses the constitution and properties of concrete structures in order (1) to assess the problem of rebar corrosion as it applies to the steel reinforcement network currently being designed for the Monitored Retrievable Storage (MRS) cask, and (2) to define data and observations on concrete formulations and properties related peripherally to the corrosion problem.

2.0 BACKGROUND

Structural concrete has a relatively high compressional strength, but is poor at resisting tensile or flexural loads. To provide some degree of tensile strength, a network of metal rods, or rebars (reinforcing bars), is frequently emplaced within the concrete molding system before pouring. These rebars are usually of mild steel, and are, accordingly, subject to corrosion if aggressive corrodents come into contact with them. The main problem caused by rebar corrosion lies, not in any loss of strength of the rebars themselves, but in the stresses exerted within hardened concrete by the corrosion products (Ref. 1). Because the density of the corrosion products (hydrous FeO, Fe_3O_4, and Fe_2O_3) is about half that of metallic iron, the subsequent expansion within the rebar volume (fixed after curing) tends to crack the concrete structure, permitting further entry of corrodents and progressive loss of structural integrity. Therefore, it is important to assess the possibility of rebar corrosion, and to protect the structure by all available means.

3.0 REBAR CORROSION

3.1 MECHANISM

In an acid solution, the anodic reaction responsible for the corrosion of iron is a simple oxidation:

$$Fe \rightarrow Fe^{++} + 2e^{-} \qquad (1)$$

whereas the cathodic reaction is the reduction of the hydrogen ion:

$$2H^{+} + 2e^{-} \rightarrow H_2 \qquad (2)$$

In the cement environment, however, the pH is controlled by the hydrolysis of $Ca(OH)_2$, leading to a value of about 12, which is moderately basic (Ref. 1). In this range of pH, the ferrous ion, Fe^{++}, is thermodynamically unstable (Ref. 2), so the anodic reaction consists in the oxidation of iron directly to insoluble magnetite:

$$3\ Fe + 8\ OH- \rightarrow Fe_3O_4 + 4\ H_2O + 8e^- \quad (3)$$

or to hematite:

$$2\ Fe_3O_4 + 2\ OH- \rightarrow 3\ Fe_2O_3 + H_2O + 2e^- \quad (4)$$

These materials adhere to the metal substrate, interfering with the further oxidation of the metal and slowing the corrosion process to a near-vanishing rate. This condition of effective noncorrosion is called passivation. The corresponding cathodic reaction is the reduction of oxygen:

$$H_2O + \frac{1}{2}\ O_2 + 2e^- \rightarrow 2\ OH- \quad (5)$$

or of water:

$$2\ H_2O + e^- \rightarrow 2\ OH- + H_2 \quad (6)$$

Passivation is normally a stable condition, during which active corrosion occurs at the slow rate controlled by diffusion of oxygen through the oxide film. However, certain substances, notably the chloride ion, Cl^-, are capable of penetrating the corrosion film, thereby destabilizing the state of passivation and allowing active iron corrosion to proceed rapidly (Ref. 3). Some threshold level of chloride ion concentration is necessary before the rate of film repair is overtaken by the rate of film rupture. Once this level is available, however, the rate-controlling process for the further corrosion of iron is the supplying of oxygen to Reaction (5) or water to Reactions (5) and (6). That is, there must be present sufficient chloride ions at the metal surface to destabilize the film, but these ions are not consumed, and their supply rate is, therefore, not controlling. If the rate of supply of oxygen is sufficiently diminished, however, regardless of the presence of water, the oxygen potential will decrease to the point where metallic iron is immune from corrosion attack, and corrosion activity must cease (Ref. 2). To forestall corrosion of rebars encapsulated in concrete, therefore, it is imperative (1) to eliminate the entry of the chloride ion, either from the environment of the concrete structure or as a constituent of the concrete ingredients, and (2) to minimize the influx of oxygen.

3.2 MEASURES TO MINIMIZE REBAR CORROSION

In conventional concrete structures, rebar corrosion is of significance only in saline environments: seawater or seawater-splash zones, highways and bridges where salt is applied as a deicer, parking garages in such geographic areas, etc. In other, nonsaline applications, rebar corrosion is not considered a problem (Ref. 1). Thus, if the present application were conventional, the corrosion problem could be dismissed. The present application is not conventional, however, for three reasons:

(1) The long structure lifetime requirement (100 yr) compared with conventional structures.

(2) The high steady-state temperatures and temperature gradients that will be obtained.

(3) The presence of an intense radiation field.

Accordingly, all measures normally taken to prevent corrosion in a saline environment are recommended for the present application, and should be regarded as safety factors to compensate for whatever uncertainties are generated by the three nonconventional factors listed above. Assuming that the chosen material will be a normal portland cement, possibly Type II or Type V, these measures include a number of concrete modifications:

(1) Ensure that the specified water/cement ratio is as low as possible, consistent with good practice in other respects, to limit the amount of free water in the as-cured cement and thereby minimize its permeability (Ref. 1).

(2) Ensure good cement mixing and consolidation to prevent inhomogeneities, segregation of constituents, and voids. Use vibratory techniques where possible.

(3) Maintain adequate cover (depth of concrete) over the rebars to ensure that the diffusion distance through which the chloride ion or oxygen must migrate is large. Recommended minimum cover: 6 cm (Ref. 1).

(4) Include pozzolans (siliceous materials that can combine with free lime) such as fine silica in the mix to increase resistance to saline environmental effects (Ref. 4).

(5) Use a low-alkali cement: limit Na_2O and K_2O to less than some maximum (about 0.6%); this will help to limit intrinsic chloride content.

(6) Use a dense, nonpermeable aggregate. Although the cement is the usual source of permeability, it is still advisable to limit the permeability of all constituents; in the present case, such dense

aggregates as magnetite or baryte will add a bonus by boosting the radioactive shielding capability of the concrete.

The above practices are recommended and ought to be used to the extent that they are consistent with other aspects of design, are practicable, and are cost-effective.

Several practices are sometimes suggested for improving the corrosion resistance of concrete rebars that are not recommended here for reasons related to the specific problems of cask design. These include the following:

(1) Impregnation of the concrete mixture with a monomer, which is subsequently polymerized in situ. The polymer is expected to fill the porous voids in the concrete, drastically reducing its permeability and increasing its strength and durability (Ref. 5). In the present case, however, polymer impregnation is not recommended because, after curing of the concrete, the gamma field generated by the waste will cause radiolytic decomposition of the evaporable water (that contained in pores, capillaries, and on surfaces) introduced into the concrete when it was mixed, forming free oxygen and hydrogen gases. The resulting gas pressure, if unrelieved by escape through the now-filled connected porosity, might cause cracking of the concrete. The organic polymer would itself be subject to radiolytic decomposition, and its radiolytic gaseous products would augment the pressure generated by the water decomposition.

(2) Use of steel shot as aggregate material to cut down permeability. Just as the corrosion of rebars and the resulting corrosion product expansion can cause cracking of the concrete, the introduction of steel shot can lead to the same phenomenon, except that the resulting corrosion damage will be much more uniformly distributed than in the rebar case. This is obviously an undesirable result. Because, unlike rebars, the shot is not essential, it ought not to be used.

(3) Modification of rebars: use of an alternative material other than mild steel or of a corrosion-resistant coating. Neither alternative is justified in the present case where the risk of corrosion is not great. In some respects, the use of coatings might be deleterious. For example, experience has shown that the mill scale, which is usually allowed to remain intact on rebars, makes possible an excellent bond with the concrete. It is unlikely that as good a bond could be formed between a coating and the concrete without considerable experimentation with various coating materials. Moreover, rebar coatings must be limited to inorganic materials because organic coatings are subject to radiolytic degradation with undesirable gaseous products.

(4) Cathodic protection of the rebars is possible, but is not regarded as cost-effective because of the small corrosion risk. In addition,

authorities are not in agreement about the general applicability of cathodic protection to rebar systems for a number of reasons, including the poor and variable conductivity of concrete, the reduction of concrete strength by generation of hydrogen at the cathode (the protected rebar), and the almost random variability of possible corrosion attack, both spatially and temporally (Ref. 1).

4.0 CONCRETE PROPERTIES BEARING ON CORROSION BEHAVIOR

This section includes a number of observations relevant, in one way or another, to the corrosion stability of rebars as it is affected by the properties or behavior of concrete, where the relevance is more indirect or distant than in the preceding sections.

4.1 CONCRETE TYPE

It has been assumed above that the concrete to be specified for cask construction would be one of the conventional portland-cement types. A number of alternatives exist, with considerable structural and thermal advantages, but all are more expensive and harder to fabricate. Detailed rebar corrosion information does not exist for them, and would have to be secured experimentally, should one be selected. These concretes include (but are not limited to) the following:

(1) Calcium aluminate cement - a rapid-hardening cement made by fusing limestone and bauxite. It sets in about 24 hr and, if subsequently heated to 800°C, will form a stable ceramic bond, rendering it stronger and less heat-affected than other cements (Ref. 6).

(2) Phosphate-bonded castables - formed by reaction of orthophosphoric acid or acidic phosphates with oxides or siliceous materials. Subsequent heating forms stable Al - PO_4 bonds, and the cement is stronger, has more abrasion resistance, and has better dimensional stability than many other cement types (Ref. 7).

(3) Fireclay-type cements, formed from hydrated aluminum silicates. These materials form mullite-type phases when heated to about 1,100°C, and are subsequently strong and dimensionally stable at high temperature (Ref. 8).

All of the above cements require some form of heat treatment after hydraulic curing before they can assert their desirable properties; this may be difficult for a form as massive as an MRS cask.

4.2 COMPRESSIVE STRENGTH OF CONCRETE

Recent studies of the influence of moisture on changes in the compressional strength, flexural strength, and modulus of elasticity of portland cement containing gravel or limestone aggregates, when heated to temperatures as high as 500°F, have shown distinct differences, depending on whether the sample billets were heated at atmospheric pressure or in a saturated-steam

environment (Ref. 9). In the former case, changes observed were evidently related to the loss of free water and, in the latter case, to its retention. The loss of free water leads to little or no change in compressive strength, and slight losses (10 to 20%) in flexural strength and modulus of elasticity upon heating to 500°F. However, when free water is retained, substantial deterioration occurs in the same properties with increasing degrees of severity as temperature increases over the same range. It is thought that this deterioration occurs as a result of hydrothermal reactions between the concrete constituents and the trapped water. The significance of these findings to the present application lies in the appreciation that the 3-ft-thick cask wall, with its inside bonded to a metal cylinder, represents a configuration embracing both moisture cases: At the exterior, where water can more easily escape during heating, little mechanical change in concrete properties is expected; at the inside, however, where the concrete is effectively sealed and water is trapped, the properties will deteriorate, losing compressive strength, flexural strength, and elasticity. Intermediate positions will have properties between these extremes.

It is true that, over the long period of the cask lifetime, the amount of trapped water will be diminished by outward diffusion. However, it is not at all certain that the hydrothermal changes mentioned above are reversible, and the prospect of a return to the earlier properties is not to be counted on. This situation of variable properties induced by a variation in water content is further complicated by the radial thermal gradient. It is not clear, at the present stage of design, whether the variable-strength situation described could lead to excessive cracking of the concrete; however, if such a condition occurs, one of the results may well be an influx of air-saturated water, permitting corrosion attack on rebars with consequences that have been discussed. Another result might be loss of structural integrity. When the design is assessed for these possibilities, therefore, it is important that concrete properties be assigned appropriately to the various concrete regions, not only as a function of temperature, but as a function of waste content and its impact on overall cask temperature distribution.

4.3 THERMAL CONDUCTIVITY

The thermal conductivity of concrete is of importance to rebar corrosion for several reasons. For a fixed rate of heat dissipation through a solid body, the thermal conductivity controls the temperature level and the magnitude of the temperature gradient. The temperature level sets the aqueous environment, whether steam or liquid, and thus governs the type of oxidative activity, steam-phase oxidation, or liquid-phase ionic corrosion. The temperature also governs the rate of activity; generally, the higher the temperature, the higher the rate. The gradient, if it is large enough, can contribute to cracking of the concrete, thereby weakening defenses against rebar corrosion. In general, it is desirable to have the lowest possible temperatures and gradients to limit corrosion (an exception can occur for the shift from steam oxidation to water corrosion, the former being

generally more benign). In considering the formulation of concrete in relation to its thermal conductivity, the following considerations apply (Ref. 10):

(1) The thermal conductivities of various types of as-hardened portland cements can vary from 0.9 to 1.3 W/m-K. These values are decreased as the water content increases, and are also decreased with a rise in temperature (up to 30% for temperature above 400°C).

(2) The various types of rock that can, in crushed form, be added to the concrete mix as aggregate have thermal conductivities ranging from less than 1 to more than 5 W/m-K; moreover, their thermal conductivities decrease with an increase in temperature (in some cases, more sharply than the cement mixtures discussed above). Because the aggregate generally represents the bulk of the concrete volume, its properties are usually the determining factor in setting the thermal characteristics of a given design.

(3) The thermal conductivity of a hardened concrete can be substantially increased by the introduction of copper (or other metal) fibers into the mix before curing. Vibratory compaction of the slurry can sometimes be used to align the fibers in the direction of future thermal flow, boosting the effect obtained by their random orientation. At 5 vol% fiber loading, the increase in thermal conductivity can be as much as a factor of five. Metal-fiber additions also tend to improve strength, toughness, and other mechanical properties, as well as increasing the concrete density, thus providing improved shielding. Copper is more noble than iron, and would, therefore, be cathodic in an iron/copper couple; such couples would not form, however, except where individual fibers are in contact with rebars and, even then, only in the presence of a liquid electrolyte.

Because the composition of the concrete mix will be based on many design considerations other than thermal properties, temperature calculations should be reworked after the final mix is chosen. The various factors listed above will obviously have a strong influence on the final temperature outcome.

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DESIGN STUDY DS-32

DRYWELL THERMAL ANALYSIS

1.0 INTRODUCTION

Conceptual drywell designs have been developed for the Monitored Retrievable Storage (MRS) Facility for use in storing of spent fuel (SF) and high-level nuclear waste (HLW). In support of that work, analyses have been performed, considering both waste forms, to evaluate drywell thermal performance. The analyses parametrically varied certain key variables (drywell spacing, soil thermal conductivity, and waste-form heat generation) for the purpose of identifying values of those parameters that would result in satisfactory drywell performance. Thermally, drywell performance is measured in terms of its ability to maintain key waste package temperatures at values below specified limits. The purpose of this design study is to describe and document the thermal analysis performed in support of the conceptual drywell designs, and to discuss the results that were obtained.

The analyses performed for this design phase were based on the analysis approach and methods developed from spent-fuel drywell testing and analyses at the E-MAD Facility (Ref. 9) and from repository waste package analyses (Ref. 13 and 14). Brief justifications for assumptions made in the models and in parameters used in the analyses are presented herein, with further details available in the noted references.

2.0 WASTE FORMS

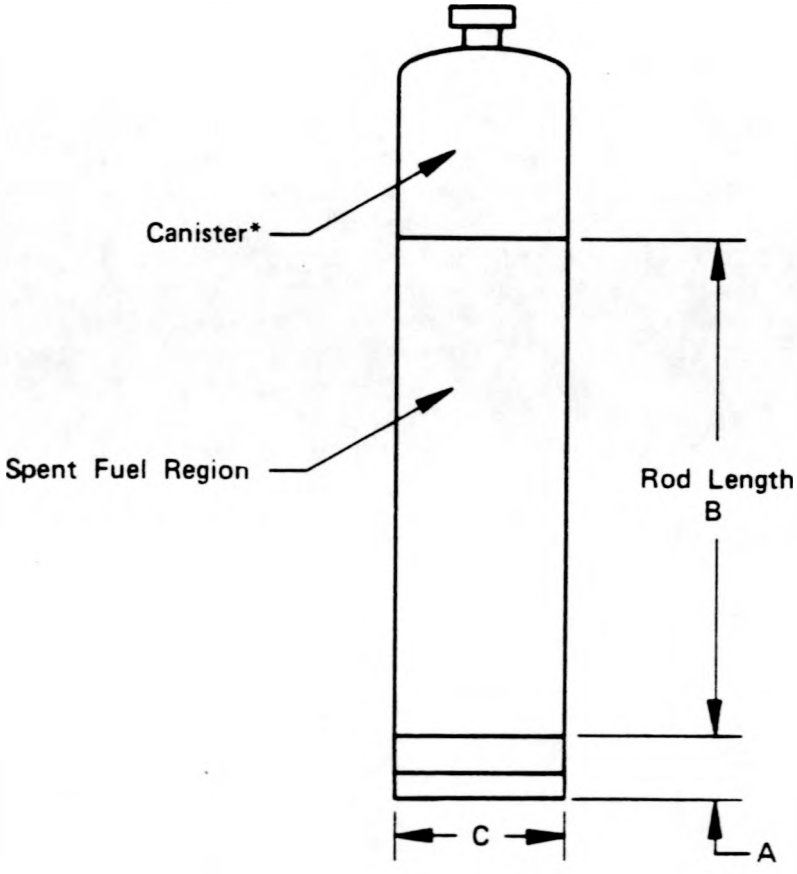
2.1 INTRODUCTION

As indicated above, two basic waste forms have been considered during the MRS study: spent fuel and high-level waste. Within these two categories, waste-form variations were also considered; these and the reference waste forms are described below.

2.2 SPENT FUEL

2.2.1 Reference Waste Form - Consolidated Spent-Fuel Rods

The reference spent-fuel waste form consists of a bundle of spent-fuel rods in a sealed, stainless steel canister. Pertinent data relative to the fuel rods and canister configuration are identified in Figure 2-1. The bundle was assumed to contain 792 fuel rods from three Westinghouse 17 x 17 PWR spent-fuel assemblies. Only the PWR case was analyzed as a result of higher heat load per canister. It is generally accepted, in waste package design, that an acceptable design for PWR spent-fuel rods will also be acceptable with



	Dimensions (cm)		
Case	A	B	C
Reference – Consolidated	12.1	385.0	32.4
Alternate – Intact	21.8	385.0	32.4

* Canister Wall Thickness – 0.635 cm
Canister Material – Stainless Steel

766583-8AB

Figure 2-1 - Spent-Fuel Waste Form Physical Data

BWR rods. The spent-fuel canister was assumed to have no internal partitions, which could enhance heat transfer from the bundle interior to the canister, and the rods were assumed to be in loose bundle form and arranged on a triangular pitch. Although the bundle is not banded, the packing would still be fairly tight; the minimum average spacing between adjacent rods is estimated at approximately 0.05 cm. All calculations for this reference case assumed the fuel had been discharged from reactor with 33,000 MWD/MTU burnup, and that it cooled 10 yr before being placed in dry storage. The heat-generation rate corresponding to these conditions is 1,650 W per canister. Thermal performance calculations for the reference waste form were also made for burnup/cooling-period combinations of 33,000/5 and 55,000/10, corresponding to heat-generation rates at dry storage emplacement time of 2,520 and 3,150 W per canister, respectively.

2.2.2 Alternate Waste Form - Intact Spent Fuel

The alternate spent-fuel waste form was an intact PWR spent-fuel assembly encapsulated in the reference waste-form canister. Waste-form positioning within the canister is identified in Figure 2-1. As in the reference waste-form case, only calculations with PWR fuel were performed, and with the same three burnup/cooling-period combinations: 33,000/10, 33,500/5, and 55,000/10. The heat-generation rates at dry storage emplacement time for these cases were assumed to be 550, 840, and 1,050 W per canister, respectively.

2.3 HIGH-LEVEL WASTE

2.3.1 Reference High-Level Waste Form

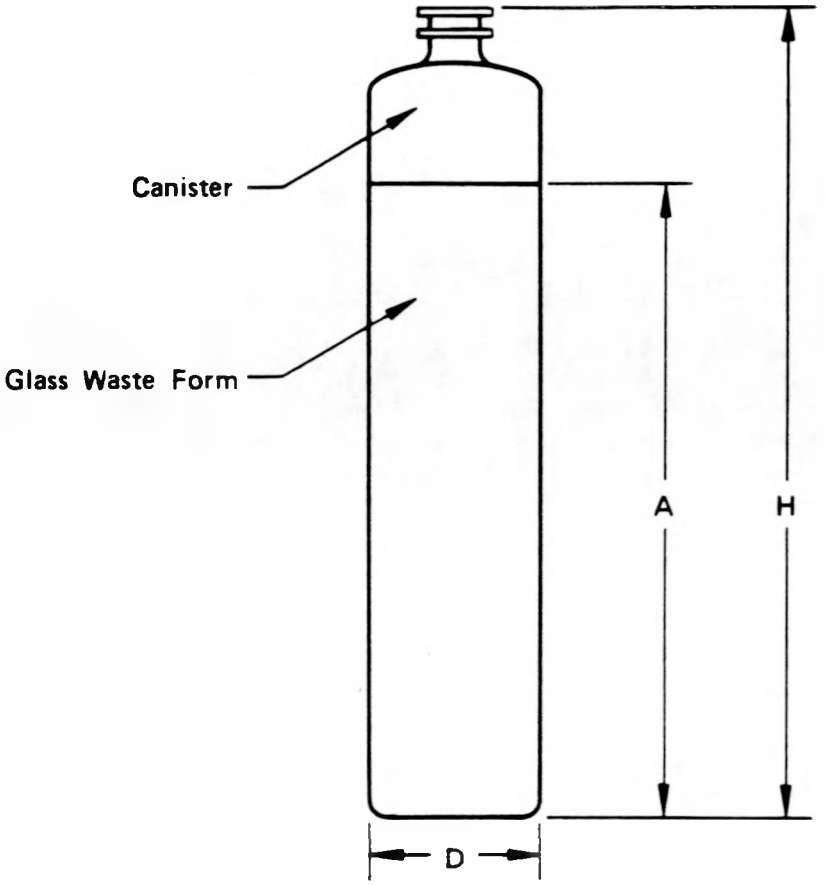
The HLW forms considered during the study were assumed to consist of a borosilicate glass matrix containing the nuclear waste material, which has been installed in a stainless steel canister. Pertinent data relative to the glass and canister are identified in Figure 2-2. In the reference case, the waste-form heat-generation rate at dry storage emplacement time was assumed to be 2,200 W, as specified in Reference 1 for commercial HLW 10 yr out of reactor. This corresponds to a volumetric heat-generation rate of 0.01055 W/cm^3.

2.3.2 Alternative High-Level Waste Forms

Alternative HLW forms 1 and 2 were assumed to employ the same glass/waste composition and volumetric heat-generation rate as the reference case. Thus, the heat-generation rates at emplacement time for these alternatives were 3,300 and 19,100 W, respectively.

2.3.3 West Valley High-Level Waste Form

The West Valley (WV) waste form was also assumed to be based on borosilicate glass. The total waste-form heat load specified by Reference 2 is only 220 W, however, corresponding to a volumetric heat-generation rate of 0.00029 W/cm^3.



Dimensions (cm)*

Case	D	A	H
Reference	32.4	274.3	304.8
Alternate 1	32.4	411.5	457.2
Alternate 2	76.2	411.5	457.2
West Valley	61.0	274.3	304.8

*Canister Wall Thickness — 0.635 cm
Canister Material — Stainless Steel

Figure 2-2 - High-Level Waste Form Physical Data

2.4 DECAY HEAT CHARACTERISTICS

Decay heat data in normalized form are presented in Table 2-1 for spent fuel and HLW. Data are not provided for WV HLW because a transient analysis was not required to demonstrate acceptable thermal performance.

3.0 DRYWELL PHYSICAL DESCRIPTION

A drywell elevation view, identifying major components and dimensions, is provided in Figure 3-1. The drywell consists of a carbon-steel liner centered in a vertical borehole. For stability and heat-transfer reasons, the annular space surrounding the liner is filled with grout. Inside the liner, a single canister, containing the waste material, is emplaced. There is a loose fit between the liner and canister, and the canister simply rests on the liner bottom. For shielding, a carbon-steel plug is positioned at the top of the liner, and a carbon-steel cover plate is welded in place at the very top of the drywell for security and to prevent water from leaking in.

4.0 ANALYSIS APPROACH

For conceptual design purposes, the objective of the MRS drywell thermal analysis was to estimate the peak values of key waste-package temperatures as functions of independent variables, such as soil thermal conductivity, drywell spacing, and waste-form heat load. These peak values would then be compared with established temperature limits to aid in defining ranges and combinations of the independent variables that would lead to satisfactory drywell performance. Acceptable spent-fuel drywell thermal performance was based on limiting the peak fuel cladding temperature to 375°C, whereas acceptable HLW thermal performance was based on two limits: 375°C on the peak canister temperature and 500°C on the waste-form temperature. These limits are specified in Reference 1.

To predict these key waste-package temperatures, two computer models were prepared: a three-dimensional drywell field model and a one-dimensional package model. The models interface at the drywell liner, and the trace of peak liner temperature versus time produced by the field model is used to drive the separate package model. The field model accurately represents the drywell field and all drywell features, except details associated with the waste form itself. Of course, the overall size, heat capacity, and heat generation of the waste form were accurately represented, but physical detail could be omitted, as the purpose of the field model was only to predict liner temperature. The field model applies the finite-element calculational method, and it can be used to predict transient temperatures throughout the drywell field. Temperature-dependent thermal properties can be handled. The model was designed to readily accommodate changes in the drywell spacing, thereby enabling parametric studies of that variable.

Using the transient peak liner temperature from the field model as a boundary condition, the package model applies a steady-state, one-dimensional analysis that is interpreted as representing peak temperature conditions in the package midplane region. Application of the steady-state

Table 2-1 - Waste Form Normalized Decay Heat Data

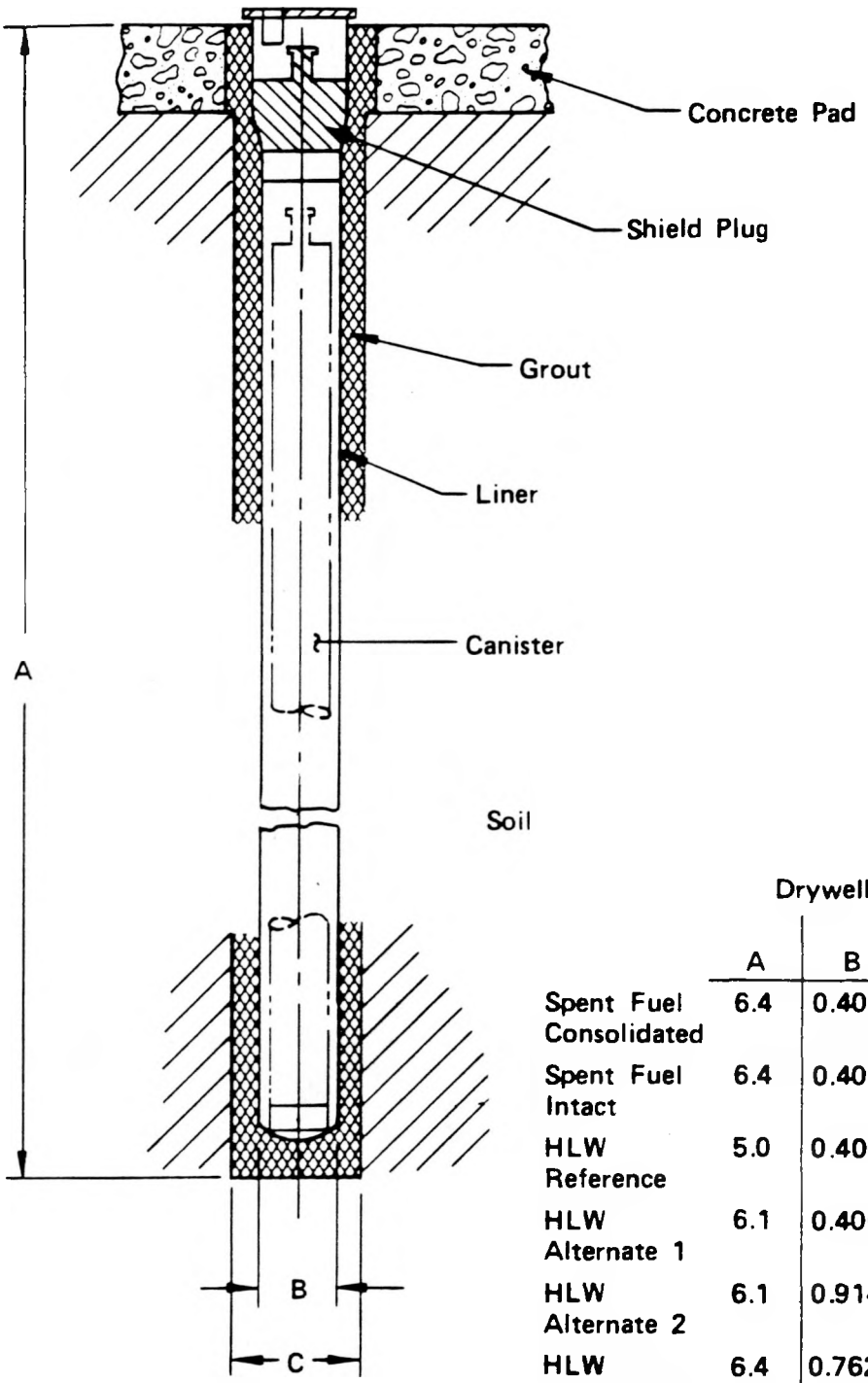
Time After Emplacement (yr)	HLW	SF(1)	SF(2)	SF(3)
0	1.0	1.0	1.0	1.0
5	0.83	0.84	0.85	0.65
10	0.72	0.75	0.76	0.56
15	0.66	0.68	0.69	0.50
20	0.60	0.63	0.63	0.46
30	0.48	0.52	0.53	0.39

Specifications

HLW: 10 yr out of reactor
SF(1): 33,000 MWD/MTU, 10 yr out of reactor
SF(2): 55,000 MWD/MTU, 10 yr out of reactor
SF(3): 33,000 MWD/MTU, 5 yr out of reactor

Data Sources

HLW: Reference 2
SF(1): Reference 3
SF(2): Reference 4
SF(3): Reference 4



Drywell Dimensions (m)

	A	B	C	Liner Wall (cm)
Spent Fuel Consolidated	6.4	0.406	0.660	1.27
Spent Fuel Intact	6.4	0.406	0.660	1.27
HLW Reference	5.0	0.406	0.660	2.62
HLW Alternate 1	6.1	0.406	0.660	2.62
HLW Alternate 2	6.1	0.914	1.220	1.27
HLW West Valley	6.4	0.762	1.067	1.27

Figure 3-1 - Drywell Features and Dimensions

package model is permitted, of course, because the package heat capacity is very small compared with that of the heat-affected zone around the drywell. Thus, at any instant, temperatures within the package will be essentially at their equilibrium values relative to the drywell liner temperature. In the package model, all heat generated within the waste form is conservatively assumed to flow radially outward, and no benefit is taken from heat transfer at the package end surfaces. Separating the drywell field and package analyses in this manner represents a conservative approach, which is suitable for conceptual design purposes.

5.0 ANALYSIS MODELS

The models discussed in the following section were created for solution by using the ANSYS finite-element transient thermal analysis computer program (Ref. 12). Included in this section are descriptions of the models as they were used with the ANSYS program, and a brief summary of the verification done in the analysis.

5.1 DRYWELL FIELD MODEL DESCRIPTION

The drywell field thermal model is depicted in Figure 5-1. It consists of a one-quarter section of the region between four adjacent drywells, arranged in either a square or rectangular pitch configuration. As indicated in Figure 5-1, the lateral lengths of the model side surfaces were set at one-half of the drywell pitch in each direction. All drywells were assumed to be loaded simultaneously, and with packages of equal heat loads, so planes of symmetry would exist at the one-half pitch locations, which were treated as adiabatic. In the depth direction, the model extends from ground level to an arbitrary depth that would not be affected thermally during the time of interest. The selected model depth of 78 m was found to meet this requirement, and an adiabatic surface was established at that location. This approach takes no thermal credit for the presence of a water table.

Typically, the drywell depth is approximately 6 m, and the borehole diameter in the reference spent-fuel and HLW cases is approximately 0.7 m. The drywell liner was assumed to be fabricated of carbon steel, with a thickness of 1.27 cm in the spent-fuel cases. With the hotter HLW waste form, a 2.54-cm liner was required to better distribute heat in the axial direction.

The drywell liner was assumed to be centered in the borehole, with grout filling the annular space between the liner and the hole. At the sidewalls, the grout thickness would typically be 13 cm, and it would be 15 cm at the bottom of the drywell. Grout properties were taken from Reference 9, and were based on E-MAD experience.

The drywell shield plug was assumed to be fabricated from solid carbon steel, and was positioned at the very top of the drywell. Its thickness in the thermal calculations was 36 cm. A 1.5- by 1.5-m concrete pad was assumed to surround each drywell to an approximate depth of 0.5 m.

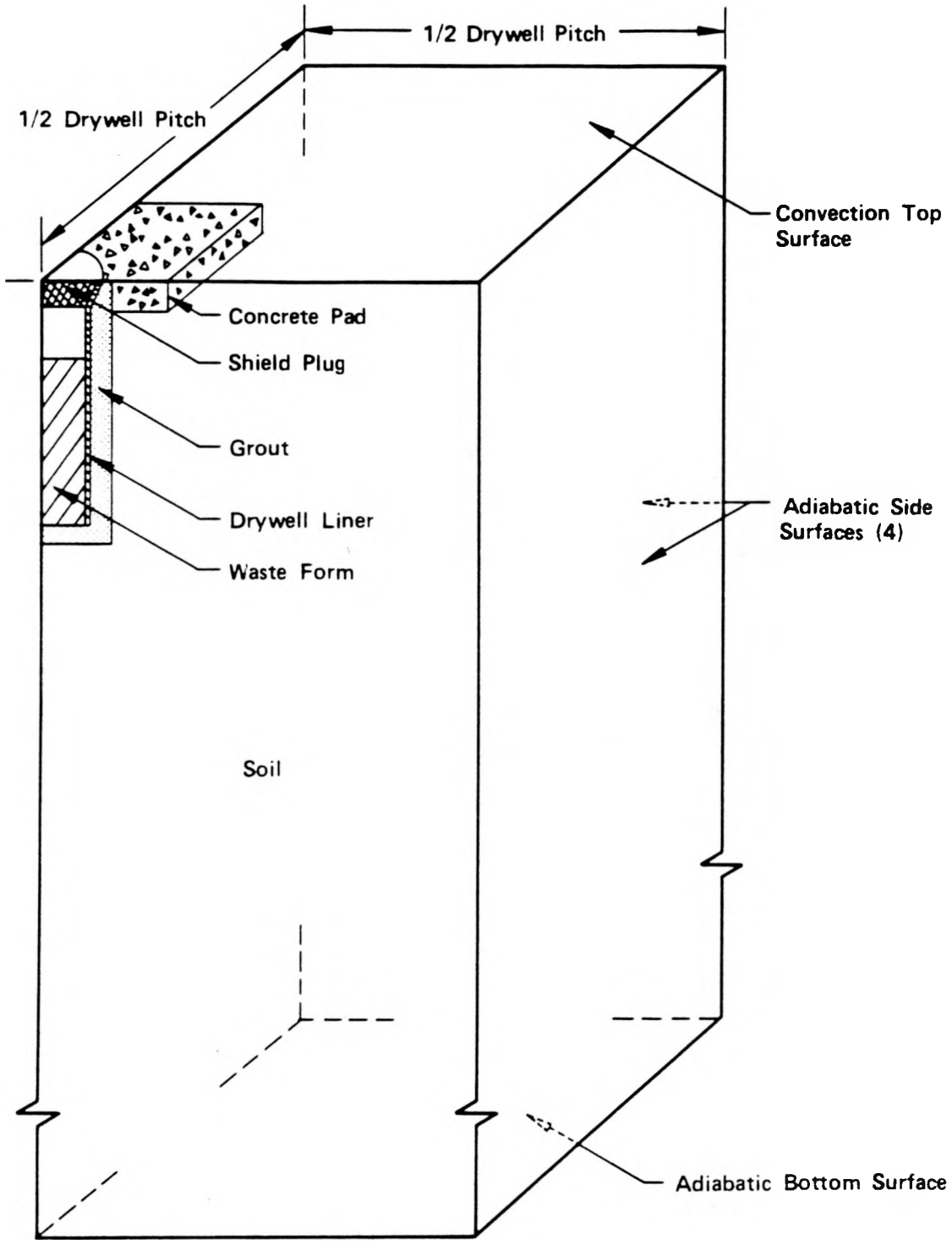


Figure 5-1 - Drywell Thermal Model

At ground level, the exchange of heat between the ground and ambient was assumed to occur by a combination of radiation and convection. This was modeled by an effective convection heat-transfer coefficient of 11.4 W/m^2-°C (2.0 $Btu/hr-ft^2$-°F) (Ref. 5 [pp. 22-26] and 6 [p. 64]). Solar heating was judged not to represent a significant factor, and was neglected. However, the ambient air temperature was set at 38°C (100°F), and held constant with time. This was viewed as a conservative modeling assumption that compensates for the omission of a solar-insolation model. In support of the model, it is noted that Electrically Heated Drywell Test data, recorded at the E-MAD Facility (Ref. 9), indicate that soil temperatures near ground level in a warm, arid climate will be well below 38°C during much of the year. Temperatures at the 15-cm soil depth were found never to exceed 38°C, and fell to 10°C during the winter months.

The waste-form region in the drywell field thermal model was viewed as a homogeneous solid occupying the space within the drywell liner. Internal detail was not assigned to the waste-form model because, as noted above, the primary purpose of the drywell field calculation was to predict peak temperatures at the drywell liner, not within the waste form itself. Thus, correctly representing the radial direction heat flux in the waste-form midplane region was important, and this involved establishing a heated length for the waste form. In the HLW case, this length was set at the waste-form length plus an additional 10 cm to allow for axial heat conduction in the canister wall above the waste.

In the consolidated spent-fuel analysis, the heated length was set at 407 cm. This value included 385 cm for the rod length plus allowances at each end for conduction in the canister wall. In simulating intact fuel, the heated length was increased to 413 cm to include the additional axial heat-conduction effect offered by the lower nozzle.

Because the selection of the effective heated length was based in part on judgment, calculations for the spent-fuel case were made to estimate peak liner temperature sensitivity to variations in heated length. They indicate that a 20-cm length change would alter the peak liner temperature by approximately 10°C. Uncertainty in the heated length is expected to be less than 20 cm; the resulting error in the peak liner temperature is viewed as being acceptable, considering the conceptual design purpose of the analysis. For detailed design studies, however, it may be required to treat the waste-form region more rigorously, and in a way that would avoid the need to establish an effective length of the heat-generating zone.

Waste-form thermal property input does not strongly affect peak liner temperature predictions. Representative values for spent-fuel thermal conductivity, density, and heat capacity were obtained from Reference 3. For HLW, thermal properties for use in the drywell field temperature calculations were drawn from References 2 and 3.

The region between the shield plug and the waste form was modeled with an effective thermal conductivity in the vertical direction that represented the combined effects of conduction and radiation; convection was neglected. Peak liner temperatures at waste-form midplane depend primarily on grout, soil, and liner conditions, and relatively little on the system of resistances above the waste form. Treating the region beneath the shield plug with an approximate model was found to be satisfactory, therefore, because large modeling inaccuracies in this region could be tolerated without having a significant impact on the predicted peak liner temperature, as noted in Reference 9.

5.2 DRYWELL FIELD FINITE-ELEMENT REPRESENTATION

The drywell field thermal model is depicted in finite-element form in Figures 5-2 and 5-3. Figure 5-2 provides a model plan view; Figure 5-3 is an elevation, showing the section identified in Figure 5-2. Of major concern in models of this type are mesh and time-step size. To verify the field model in these respects, a one-dimensional, semi-infinite solid, with constant heat input at one boundary, and for which an exact solution exists, was simulated. The radial mesh spacing from the drywell field model was applied, starting at the drywell liner, as well as the time-step program that was used to simulate transient drywell performance. The ability of the model to predict temperature at the heat-input point was checked. The comparison of model predictions with the exact solution indicated that the mesh and time-step selections were appropriate.

5.3 DRYWELL INTERNAL MODEL DESCRIPTION

Temperatures within the drywell were predicted by using a computer-based, one-dimensional package model, which is depicted in its most general form in Figure 5-4. All heat generated within the waste-form zone is assumed to flow radially outward, and no benefit is taken from package end surfaces. As many as four package barriers can be modeled, each of a different material. The gaps between barriers can be filled with a solid material (with a user-supplied value of thermal conductivity) or a gas (either air or helium), or they can be evacuated. In gas-filled cases, heat transfer across a gap will occur by a combination of conduction, convection, and radiation. For radiation calculations, the view factor assumes a concentric cylinder configuration, and the emissivity of each radiating surface is specified by the user. The convection/conduction heat transfer is calculated by using the equivalent thermal conductivity approach, which is described in many references (e.g., Ref. 7, pp. 330-331). This approach considers two parallel surfaces separated by a gas and operating at different temperatures. Heat transfer from one surface to the other occurs by conduction through the gas and by local convection cells. The gap is assumed to be sealed at the ends so that there is no net gas throughput.

When the waste material is present in glass-log form, the glass is assumed to be in perfect thermal contact with the inner surface of package barrier 1, and the thermal conductivity of the waste material is represented as a

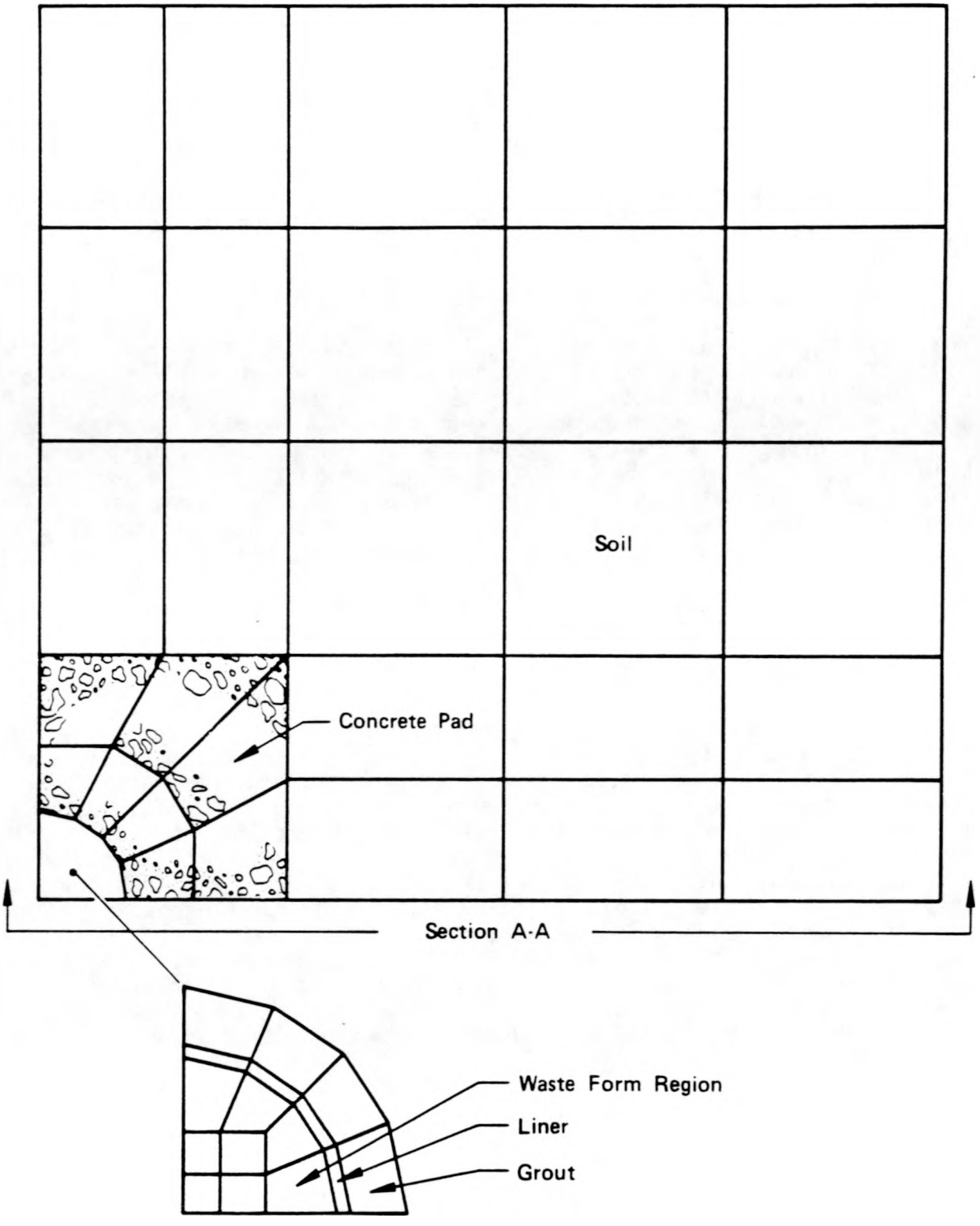


Figure 5-2 - Drywell Field Finite-Element Thermal Model - Plan View

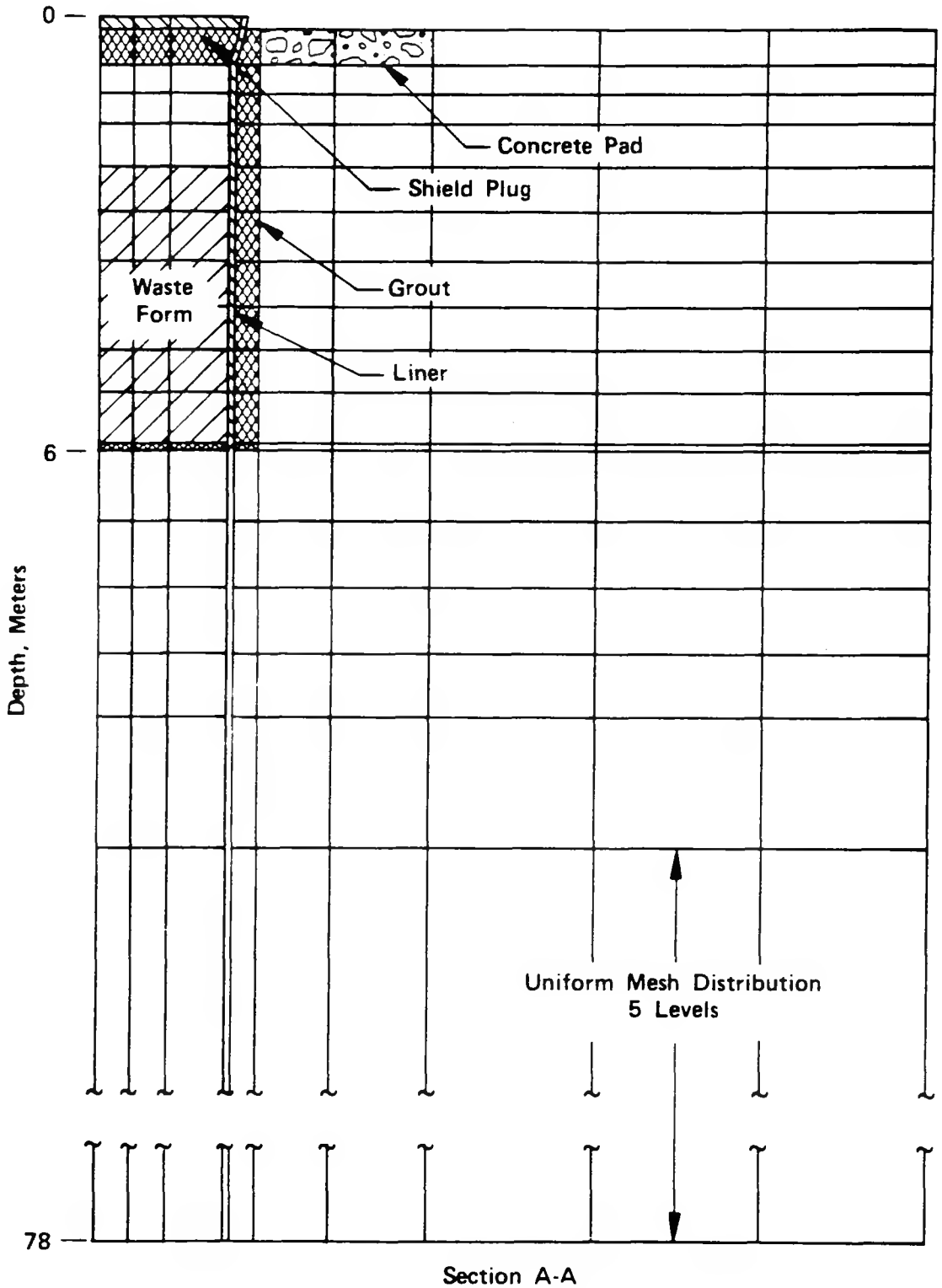
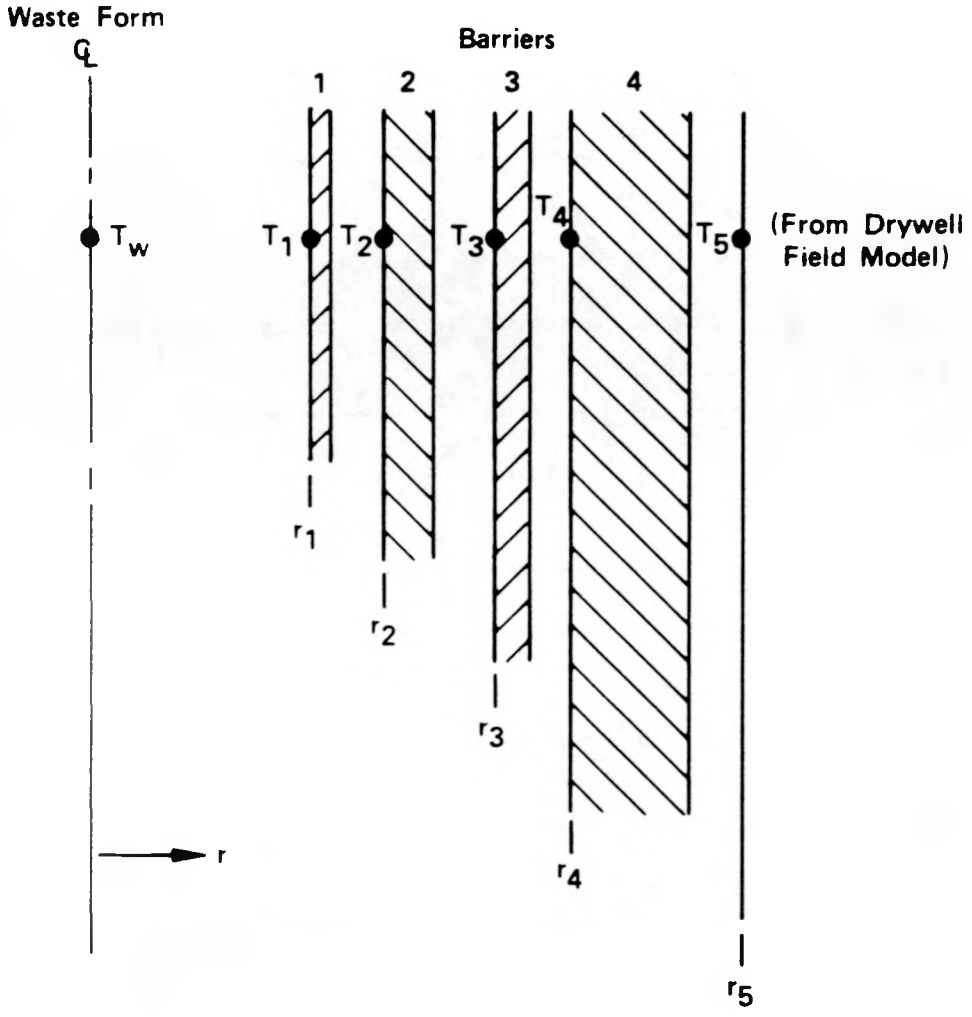


Figure 5-3 - Drywell Field Finite-Element Thermal Model - Elevation View



Variables

- Heat Load Per Unit Length
- Barrier Radii – r_1, r_2, r_3, r_4, r_5, and Thicknesses
- Barrier Thermal Conductivities
- Emissivities (If Gaps Between Barriers are Gas Filled or Evacuated)
- Filler Thermal Conductivities (If Gaps are Solid-Filled)

Figure 5-4 - One-Dimensional Waste Package Thermal Model

linear function of temperature. The user must supply slope and intercept values. The program evaluates the conductivity iteratively, using the arithmetic average of the waste centerline and outer surface temperatures.

To model a spent-fuel waste form, the theoretical method developed in Reference 8 is applied. It considers thermal radiation between adjacent rods, but conservatively neglects any effect of conduction and convection within the bundle region. In Reference 8, relationships are developed between a parameter Z and rod bundle physical parameters: pitch-to-diameter ratio, number of rods in the bundle, and bundle configuration (triangular or square pitch). An example of the Z correlation is provided in Figure 5-5, where Z is graphed versus the pitch-to-diameter ratio for several bundle sizes (number of rods). In Reference 8, the Z function is also related to other parameters according to the following expression:

$$Z = \frac{\sigma \left(T_W^4 - T_1^4\right)}{Q_R/A_R} - \left(\frac{1-\varepsilon}{\varepsilon}\right)\left(1 + \frac{nA_R}{A_1}\right)$$

where

T_W = peak cladding temperature, ^oK
T_1 = bundle outer row temperature, ^oK
= Stefan-Boltzmann constant, W/cm^2K^4
Q_R = heat-generation rate for a single rod, W
A_R = single rod heat-transfer area, cm^2
= rod surface emissivity
A_1 = bundle peripheral heat-transfer area, cm^2
n = Number of rods in bundle

Generally, many of the parameters in the Z equation will be known. The value of Z, as noted above, depends only on physical characteristics, as do A_R and A_1. Further, ε can be assigned, based on analytical simulation comparison with actual test data; Q_R will be available from decay-heat predictions; and T_1 will be determined during the drywell field calculation. Thus, T_W is the remaining unknown, and is determined iteratively.

When analyzing a loose bundle of consolidated fuel rods, it has been customary to assume rod contact with the canister. In that case, the model evaluates A_1 based on the the inside diameter of barrier 1. For the banded bundle case, in which a definite annular space would exist between the bundle and the canisters, that annulus would be modeled as the region between barriers 1 and 2, with barrier 1 assigned a negligibly small thickness and a large thermal conductivity to effectively remove it from the calculation. A similar approach is applied to the square, intact bundle case. The radius of cylindrical barrier 1 is selected to produce a circumference equal to the bundle perimeter; the thickness of barrier 1 is again set at a small value; and the radius of barrier 2 is selected to match that of the spent-fuel canister.

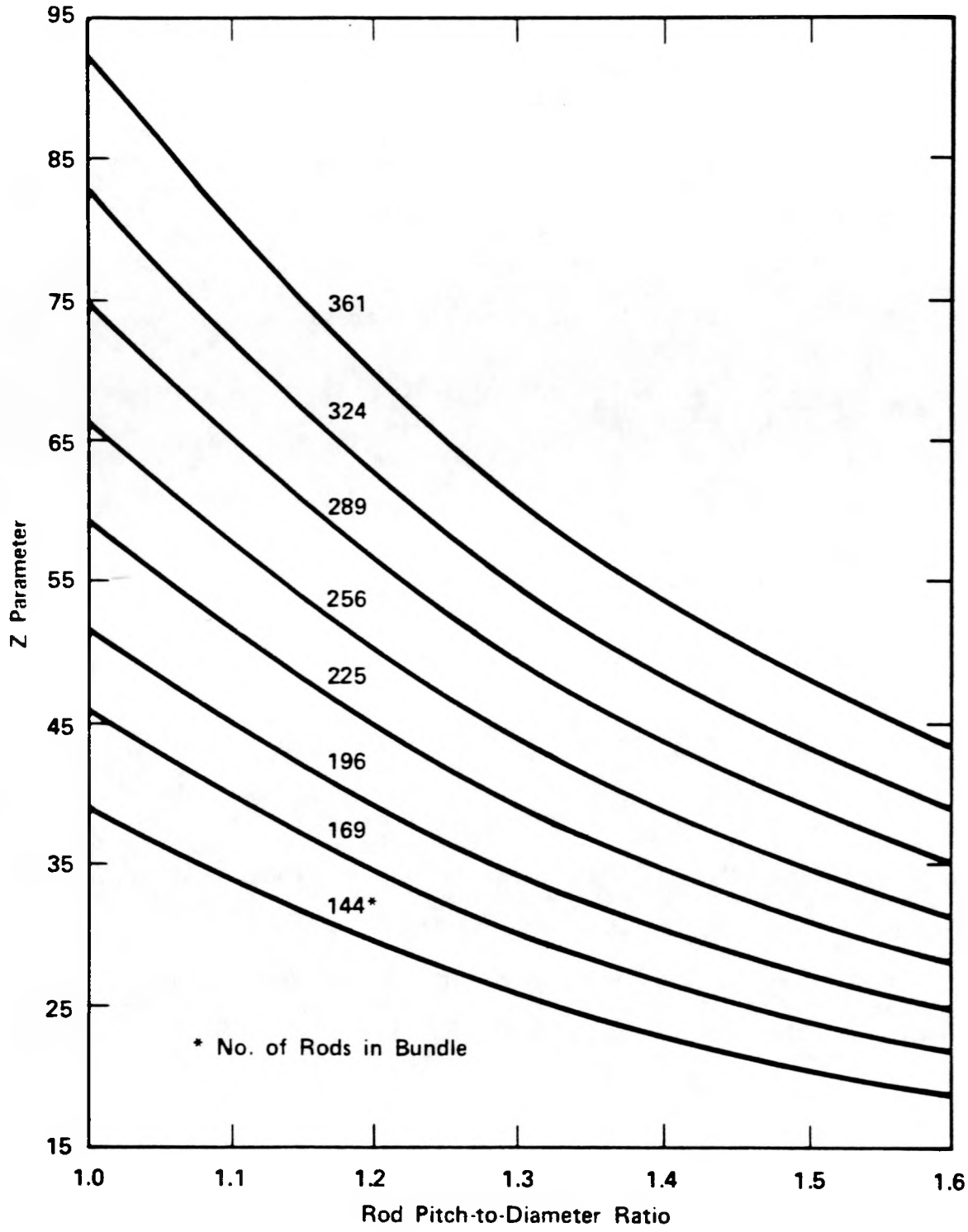


Figure 5-5 - Z Parameter for Square-Pitch Rod Bundles
(Source: Ref. 8)

During development of the waste-package thermal model, hand calculations were performed to validate the model for glass-log simulation. In the spent-fuel case, measured cladding temperatures are available from the Fuel Assembly Internal Temperature Measurement Test program, conducted by Westinghouse at the Nevada Test Site E-MAD Facility (Ref. 9). Peak cladding temperatures from a series of test runs have been compared with package model predictions, and the quality of the agreement is good. It is noted that this test program was performed with intact spent-fuel assemblies - not consolidated fuel, which is the reference MRS spent-fuel waste form. The intact assembly experiments are considered to provide an excellent test for any analysis method, however, because they controlled the relative effects of the three heat-transfer modes (thermal radiation, conduction, and convection) by altering the canister backfill condition (air, helium, or vacuum), and they were performed at two different decay-heat levels.

6.0 MATERIAL THERMAL PROPERTIES

Material properties applied during the drywell thermal analysis are identified in Table 6-1. Because site-specific information was unavailable for this design study, soil density and specific heat capacity were based on measurements of E-MAD soil. As indicated in Table 6-1, the soil thermal conductivity was varied parametrically during the study. The soil thermal conductivity was held constant throughout the region surrounding the drywell, and the effect of temperature on moisture content and thermal conductivity was neglected. Grout properties used in the study were based on E-MAD data. The specific heat capacity of the grout (assumed to be a two-to-one mixture of E-MAD soil and cement) was based on dry soil and cement properties, whereas its density and thermal conductivity were taken from measurements performed at E-MAD on cured grout samples.

7.0 THERMAL ANALYSIS RESULTS

Parametric analyses were conducted to determine peak temperatures for the drywell waste forms, which are identified and described in Section 2. In summary, the waste forms were:

Spent fuel - consolidated rods
Spent fuel - intact assembly
HLW - reference (32.4-cm-dia canister, 274.3-cm log)
HLW - Alternative 1 (32.4-cm-dia canister, 411.5-cm log)
HLW - Alternative 2 (76.2-cm-dia canister, 411.5-cm log)
HLW - West Valley

Results of the parametric thermal analyses with these waste forms are discussed in the sections that follow. Because these analyses were performed to support conceptual drywell designs (verify acceptable thermal performance), only the peak fuel cladding, HLW canister, and HLW waste-form temperatures were considered important; therefore, only these temperatures are presented. Transient analyses were performed to calculate these peak temperatures; however, the specifics of the heatup transient and subsequent

Table 6-1 - Material Properties for Drywell Thermal Analysis

Material	Thermal Conductivity (W/cm-K)	Density (g/cm^3)	Specific Heat Capacity (J/g-K)	Emissivity
Soil	0.012	1.68[a]	1.05[a]	--
Grout	b	1.87[a]	0.84[a]	--
Concrete	0.0182[c]	2.28[c]	0.84[c]	--
Carbon steel (liner)	0.40[c]	7.84[c]	0.46[c]	0.5[d]
Stainless steel (canister)	0.17[c]	7.84[c]	0.46[c]	0.5[e]
Spent fuel (consolidated)	f	9.28[g]	0.26[g]	0.8[h]
Spent fuel (intact)	f	9.28[g]	0.26[g]	0.8[h]
High-level waste	i	3.1[j]	0.75[j]	--
Air	k	1	1	--

[a] E-MAD soil properties (Ref. 9, p. 93).
[b] E-MAD grout property (Ref. 9, p. 92); can be represented by interpolation between following points:

T(°C)	K(W/cm-C)
10	0.0114
205	0.0111
260	0.0069
371	0.0061

[c] Typical handbook value.
[d] Reference 10, p. 4-110.
[e] Reference 11, p. 475.
[f] See Section 5.3 for spent-fuel thermal analysis method description.
[g] Reference 3, p. 35-A.
[h] Using method described in Section 5.3, a fuel cladding emissivity of 0.8 was found to conservatively predict E-MAD Fuel Assembly Internal Temperature Measurement Test peak cladding temperature (see Ref. 9).
[i] $K = 0.0085 + 7.5 \times 10^{-6}$ T(°C) over the range T = 0 to 600°C (Ref. 2).
[j] Reference 3, p. 36-A.
[k] Thermal conductivity of air (for input to conduction/convection method of Ref. 7, p. 330) was approximated according to following expression: $K = 2.4562 \times 10^{-4} + 5.917 \times 10^{-7}$ T(°C).
[l] Neglected.

cooldown (caused by heat level decays) were not considered appropriate to this study. In general, peak temperatures were found to occur within the first 5 yr after package emplacement. For example, in the reference HLW case (2,200-W package), with the drywells spaced at 11 m in 0.008 W/cm-K soil, the peak liner temperature (340°C) was predicted at approximately 1 yr. In the reference consolidated spent-fuel case (1,650-W package), however, with drywells spaced at 6 m in the same soil, the peak liner temperature (275°C) did not occur until 3.5 yr after emplacement. The difference in peak times is related mainly to waste-form heat load and dimensional effects. In the HLW case, the higher heat load and shorter heated length combine to produce an average radial heat flux at the liner nearly twice that in the spent-fuel case.

7.1 SPENT FUEL - CONSOLIDATED RODS

Figure 7-1 provides peak fuel cladding temperature predictions for the consolidated spent-fuel waste-form configuration. The soil thermal conductivity was varied parametrically, and the cladding temperature was demonstrated to be very sensitive to changes in that parameter, particularly when the conductivity is small (0.5 W/m-K or less) because the major thermal resistance offered by the system is caused by the soil. As indicated in Figure 7-1, soil thermal conductivities of approximately 0.6 W/m-K or greater are needed to limit peak fuel cladding temperature in the consolidated spent fuel to 375°C. Figure 7-1 also indicates that isolated drywell spacing for the soil thermal conductivities analyzed is approximately 8 m. Drywell temperatures will be virtually independent of spacing beyond that value.

7.2 SPENT FUEL - INTACT ASSEMBLY

Peak fuel cladding temperature predictions for intact spent fuel (a single fuel assembly per drywell) are presented in Figure 7-2. Two soil thermal conductivities are represented in addition to three combinations of burnup and time out of reactor. It is apparent that, in all cases, a relatively small drywell spacing can be selected that will result in adequate waste package cooling. However, because all intact fuel thermal performance was acceptable for the spacing needed for the reference 33,000/10 consolidated spent fuel, no additional analyses were performed to determine spacing at which the intact fuels reached the 375°C fuel cladding temperature limit.

7.3 HLW - REFERENCE

Results of calculations with the HLW reference waste form are plotted in Figure 7-3. For HLW, two temperature limits are of concern: peak canister (375°C) and peak waste form (500°C). With a small-diameter waste form, the canister limit will be reached first and will, therefore, be controlling. Two soil thermal conductivity values are represented in Figure 7-3. The calculations indicate potentially unacceptable performance with the lower conductivity value, but very acceptable performance in the more conductive soil.

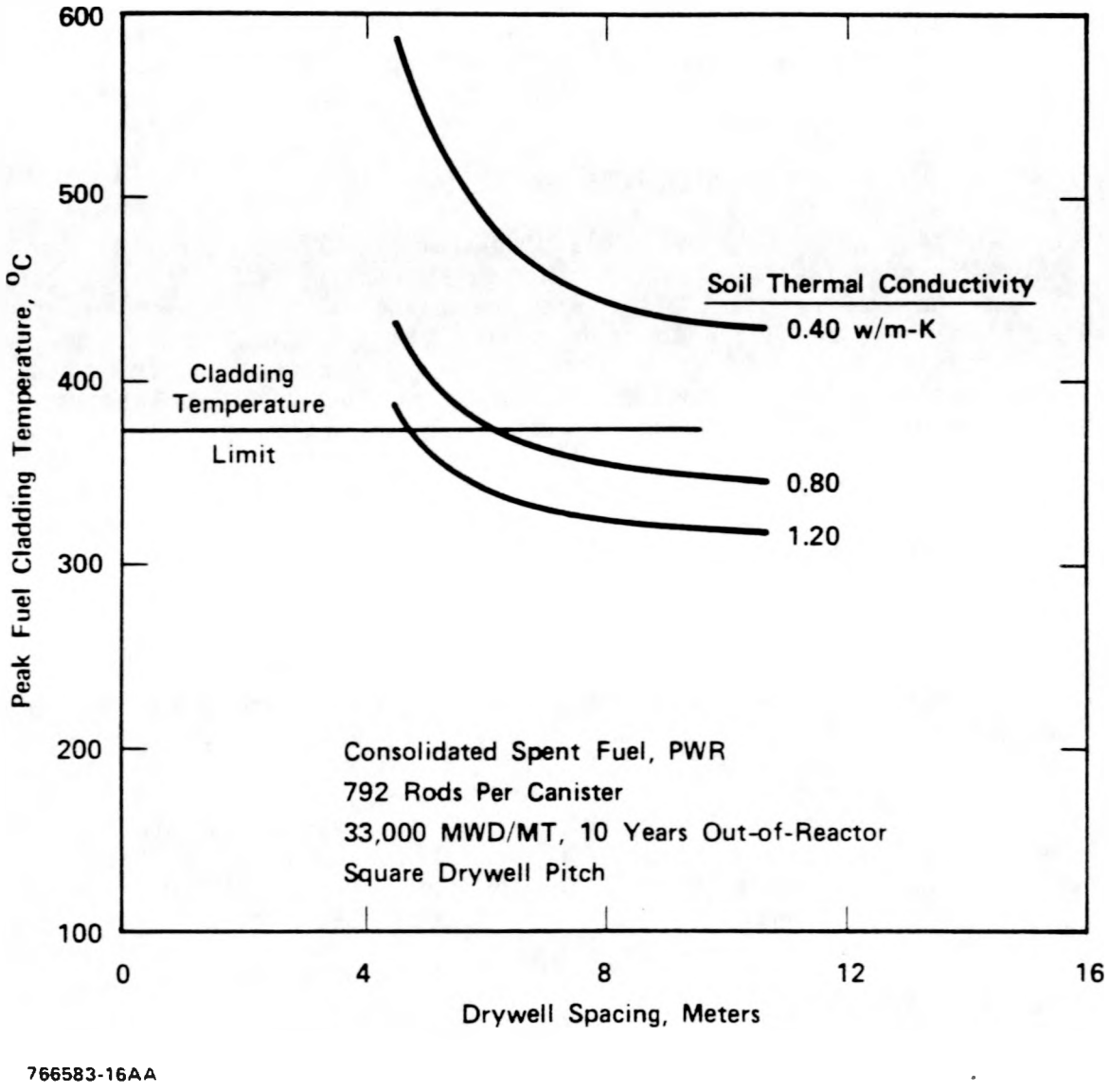


Figure 7-1 - MRS Consolidated Spent-Fuel Drywell Thermal Performance Predictions - Temperature Versus Drywell Spacing and Soil Thermal Conductivity

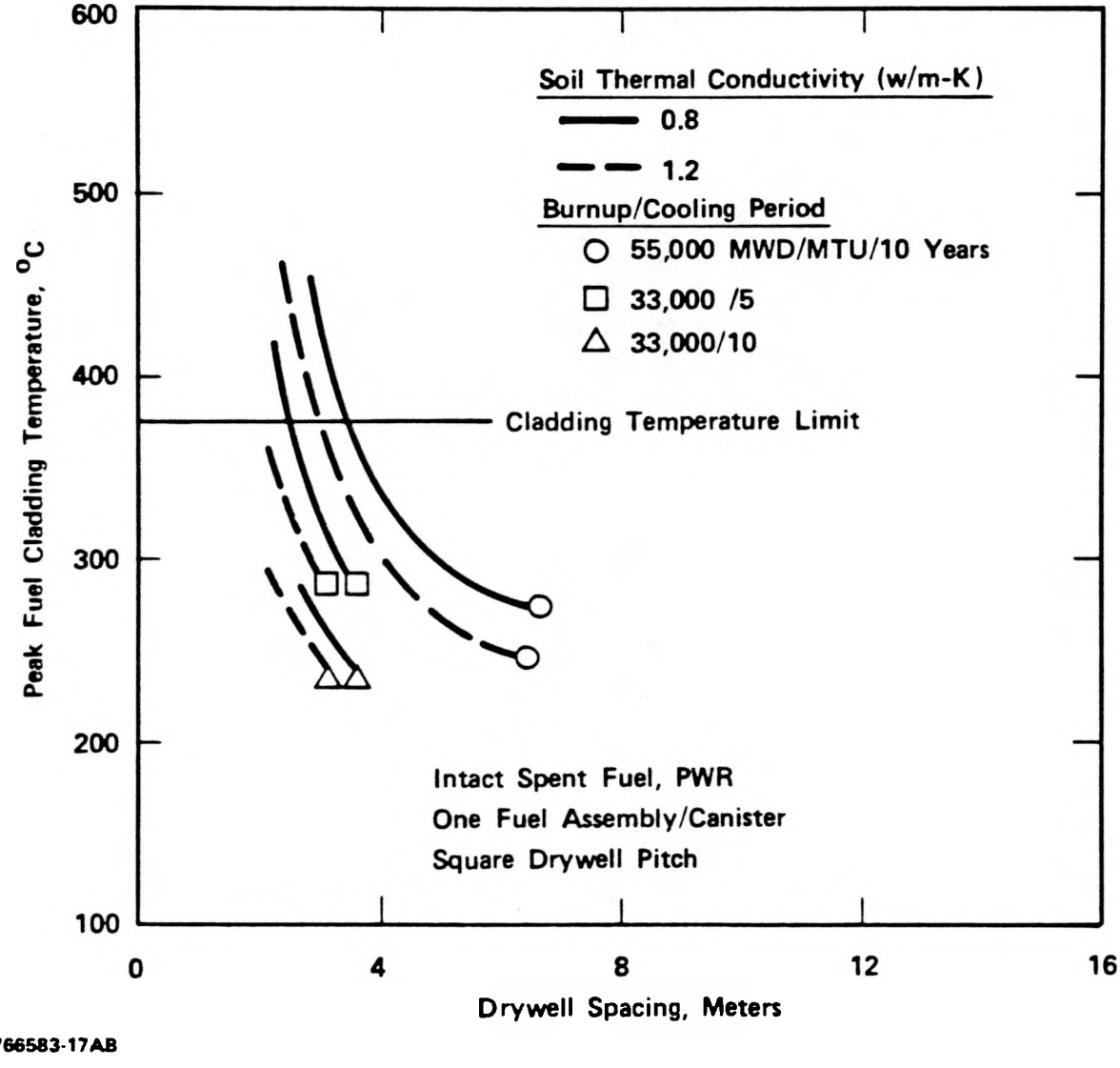


Figure 7-2 - MRS Intact Spent-Fuel Drywell Thermal Performance Predictions - Temperature Versus Drywell Spacing, Soil Thermal Conductivity, and Burnup/Cooling Period

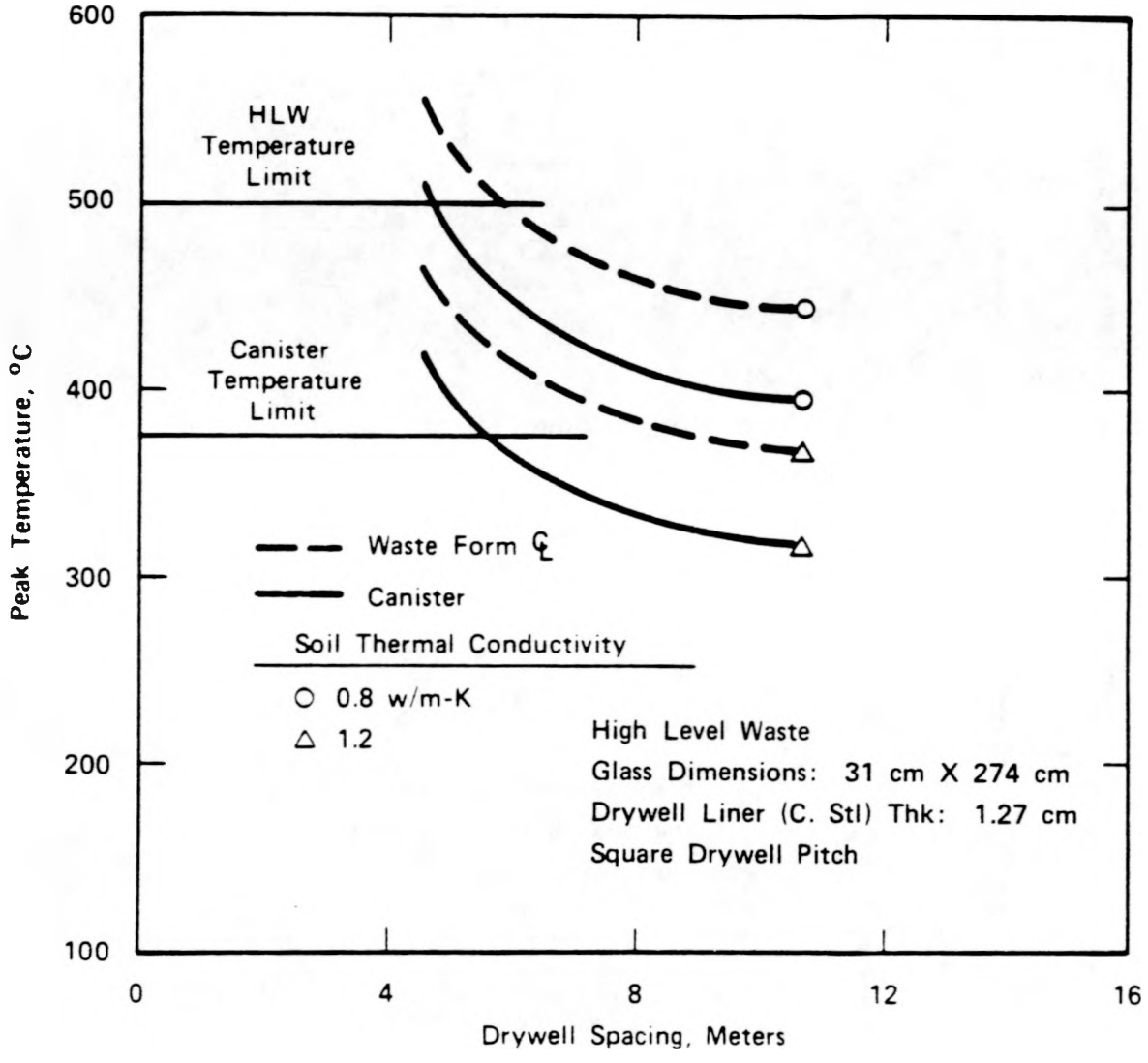


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Figure 7-3 - MRS Reference HLW Drywell Thermal Performance Predictions - Temperature Versus Drywell Spacing and Soil Thermal Conductivity

Figure 7-4 also demonstrates the effect of drywell liner thickness on waste-form temperature. The basic calculations were performed with a 1.27-cm, carbon-steel liner. As the figure indicates, increasing the liner thickness will reduce waste package temperatures. For drywells with a 2.54-cm (1-in.), carbon-steel liner spaced at 10.7 m, the predicted peak canister temperature was 377°C. It is estimated that a 12-m spacing would satisfy the 375°C limit. This is because of the improved ability of the liner axially to distribute heat and, as a result, reduce the heat flux into the grout and soil in the package midplane region.

7.4 HLW - ALTERNATIVE 1

The result of increasing the waste log length can be discerned in Figures 7-4 and 7-5. According to Figure 7-4, a 2.54-cm drywell liner and a 12-m drywell spacing would yield acceptable canister temperatures with the reference-length log. In Figure 7-5, temperatures for the same conditions have been plotted, but the log length has been increased by 50% and the volumetric heat-generation rate is displayed as the independent variable. With the reference heat-generation rate (relative heat generation = 1.0), the longer log would lead to a peak canister temperature that is unacceptable by approximately 50°C. A reduction of the relative heat-generation rate, or the quantity of waste material contained in the log, to approximately 0.85 would be required if the canister temperature limit is to be met. On the positive side, even with a reduction in the relative heat-generation rate, a net increase of nearly 30% in the waste per drywell would be realized by lengthening the log.

A calculation was also performed for the lengthened HLW log in higher-conductivity soil (1.2 W/m-K). With drywells spaced at 12.2 m, the key waste-form temperatures were found to be within limits at the reference heat-generation rate.

7.5 HLW - ALTERNATIVE 2

Predicted temperatures for a long (4.1-m), large-diameter (0.76-m) HLW log are presented in Figure 7-6, again as a function of the relative heat-generation rate. Analysis results for two soil thermal conductivities are shown. With the reference glass/waste composition (relative heat generation = 1.0), this log would generate 19,100 W at package-emplacement time. Thus, it should not be surprising that a reduction in the relative heat generation of 20 to 30% would be required for acceptable waste-form temperatures to occur.

7.6 HLW - WEST VALLEY

West Valley HLW will be placed in drywells arranged in a 1.7- by 3.4-m, rectangular pitch pattern. Each log will be 0.61 m dia by 2.74 m, but it will generate only 220 W at emplacement time. This is one-tenth the heat output of the reference HLW waste form. This low heat-generation rate, combined with a large log surface area, is expected to result in low operating temperatures. The peak canister temperature is predicted to be approximately 220°C, corresponding to a peak waste-form temperature of 230°C.

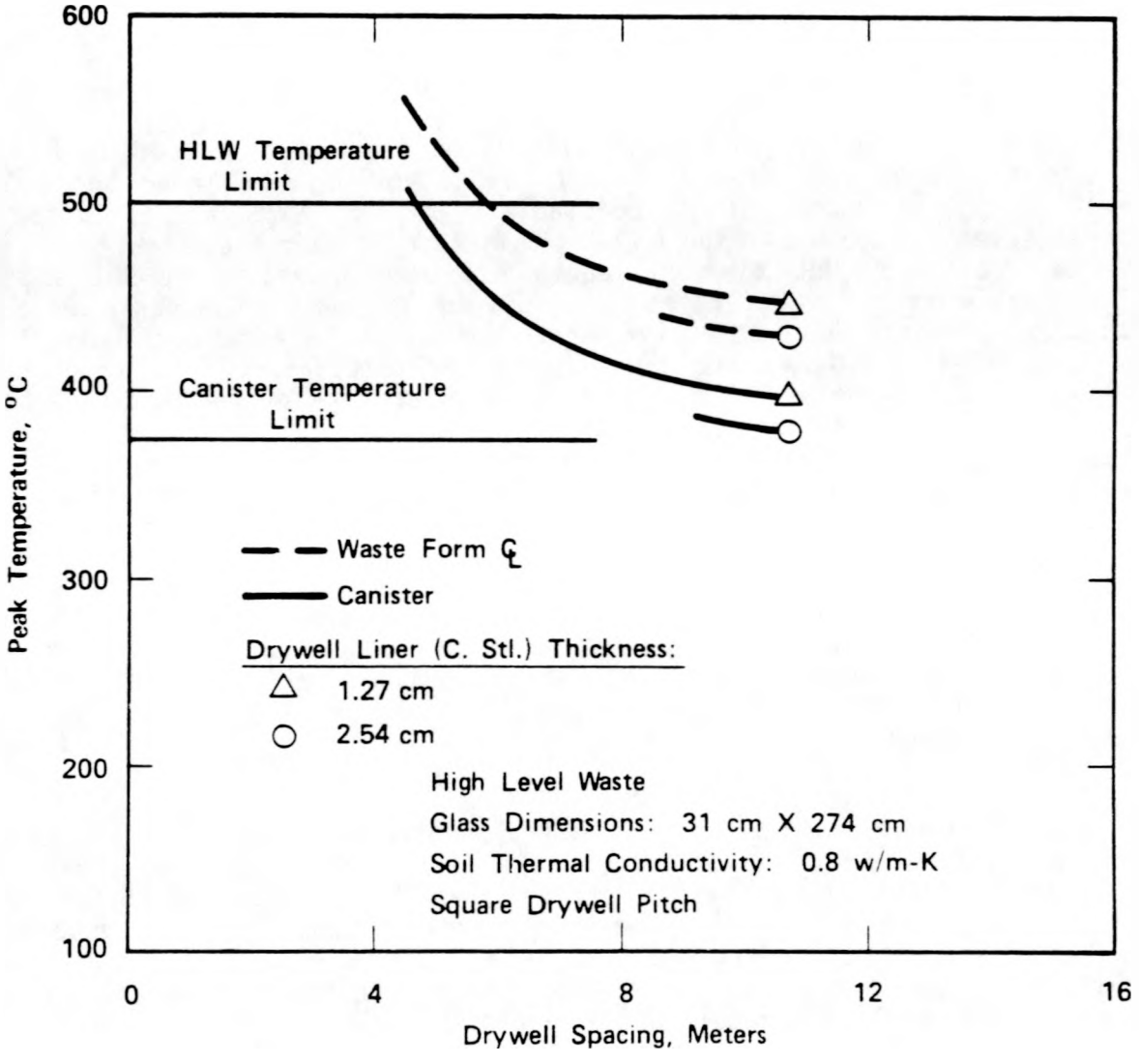
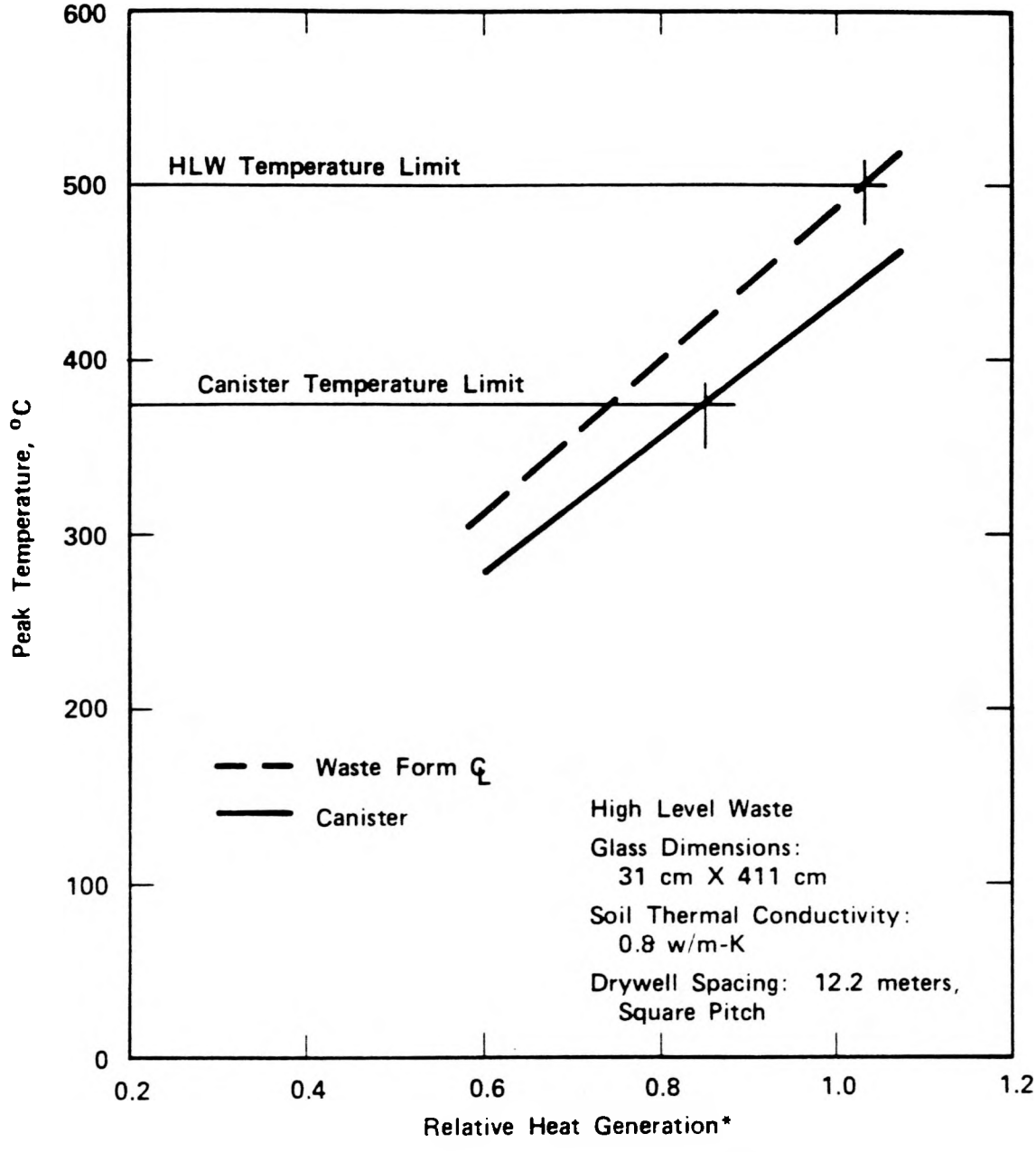


Figure 7-4 - MRS Reference HLW Drywell Thermal Performance Predictions - Temperature Versus Drywell Spacing and Liner Thickness



*Relative to Reference Heat Generation (0.01055 w/cm^3)

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Figure 7-5 - MRS Alternative 1 HLW Drywell Thermal Performance Predictions - Temperature Versus Relative Heat-Generation Rate

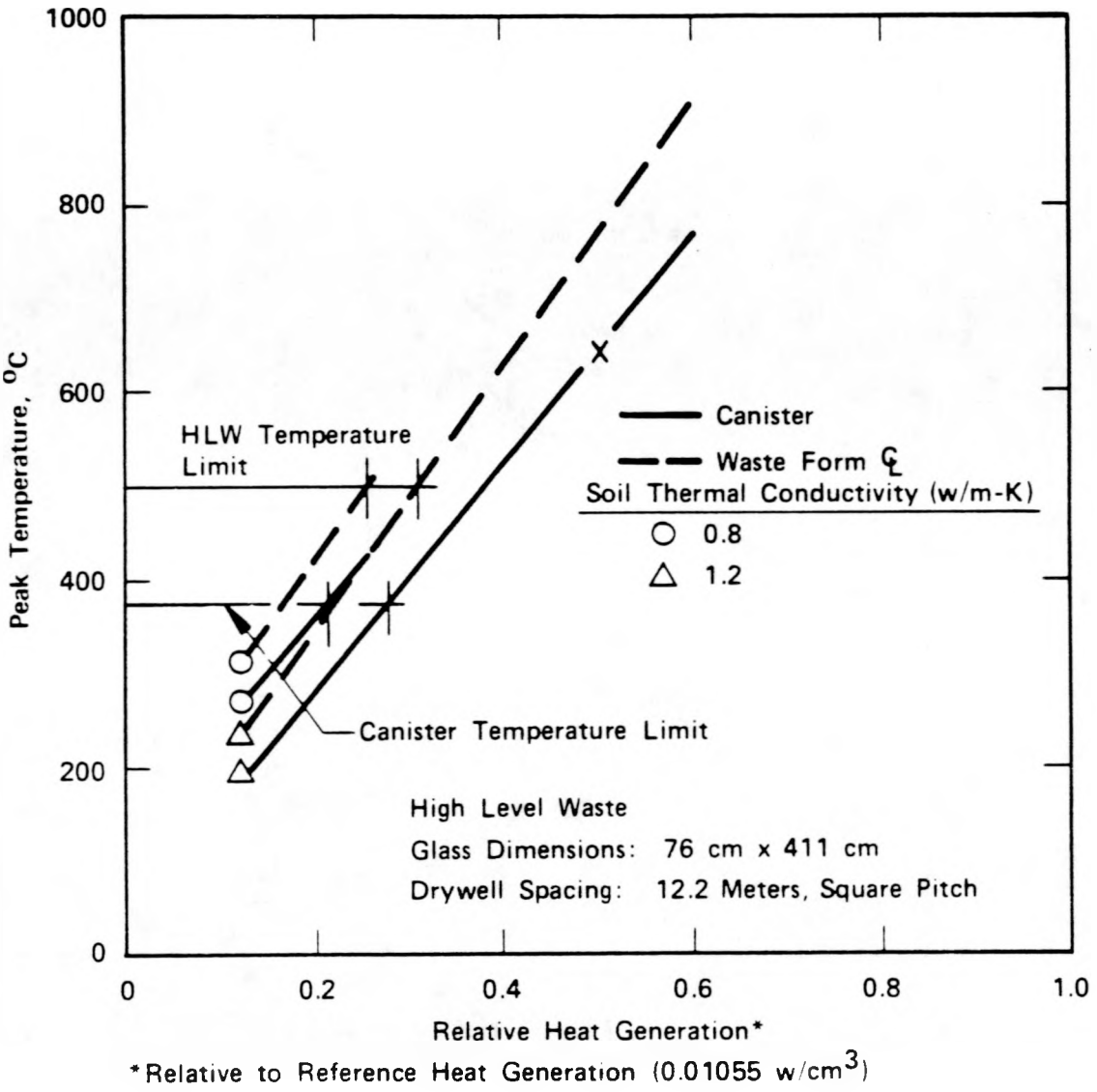

Figure 7-6 - MRS Alternative 2 HLW Drywell Thermal Performance Predictions - Temperature Versus Relative Heat-Generation Rate and Soil Thermal Conductivity

8.0 SUMMARY

Parametric analyses have been performed to predict drywell thermal performance, considering spent fuel and high-level waste (HLW). The analyses varied drywell spacing, soil thermal conductivity, and waste-form heat generation to identify values of those parameters that would result in satisfactory drywell performance; i.e., maintain key waste-package temperatures at values below specified limits. Determinations of the drywell spacings for spent fuel and for HLW were based on maintaining peak fuel cladding temperature below 375°C for spent fuel and maintaining peak HLW canister temperature below 375°C for the reference site with a soil thermal-conductivity value of 1.2 w/mK. The results of the analyses are summarized below.

8.1 SPENT FUEL

Consolidated 33,000-MWD/MTU burnup, 10-yr-old PWR spent fuel can be stored in drywells spaced 16 ft apart at the reference site. For the higher-burnup or shorter-decay-period PWR spent fuel, only intact spent-fuel storage is possible. Calculations were made for consolidated 33,000-MWD/MTU burnup, 5-yr-old fuel and consolidated 55,000-MWD/MTU burnup, 10-yr-old fuel, with drywells in each soil spaced 35 ft apart (thermally isolated from each other) and, in all cases, spent-fuel rod temperature exceeded the 375°C limit.

8.2 HIGH-LEVEL WASTE

Drywell thermal analyses of the three HLW waste forms for the two reference site soil thermal conductivity were used to define the minimum drywell spacings and either the reference or maximum decay-heat loadings that were found to meet the 375°C canister surface temperature limit. The results are provided in Table 8-1.

Table 8-1 - Results of Commercial HLW Drywell Thermal Analyses

Canister (dia x length, ft)	Total Decay Heat (W)	Heat-Generation Rate (W/cm^3)	Minimum Drywell Spacing (ft)
1 x 10	2,200[a]	0.01055[a]	20
1 x 15	3,300[a]	0.01055[a]	40[b]
2.5 x 15	5,348	0.00295	40[b]

[a]Represents reference decay-heat values identified in Reference 1.

[b]A 40-ft spacing represents a field of essentially thermally isolated drywells; i.e., increases in spacing will not result in any increase in total acceptable decay heat.

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FOREWORD

This study was based on the emplacement of 1,800 MTU/yr in drywells located in the storage area. Section 6 of this study addresses an estimate of the total worker radiation exposure for the drywell and transfer shield operations. In increasing the throughput rate from 1,800 to 3,600 MTU/yr, the estimate of the total worker radiation exposure would double. However, the individual worker radiation exposure need not double if addititional workers are added to the work force.

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DESIGN STUDY DS-33

DRYWELL AND TRANSFER SHIELD RADIATION ANALYSIS

1.0 INTRODUCTION

This design study summarizes the results of the radiation analysis performed for the conceptual design of the drywells and transfer shields for the Monitored Retrievable Storage (MRS) Facility.

Three drywell designs have been evaluated. These designs store the following waste:

(1) Consolidated (33-10),[1] intact (33-5), and (55-10) spent fuel
(2) High-level waste (HLW)
(3) Nonfuel-bearing components (skeletons), West Valley (WV) HLW, and RHTRU

Three transfer shield designs have been evaluated that have been designed to transport the following waste:

(1) Consolidated (33-10) spent fuel
(2) HLW, intact (33-5), and (55-10) spent fuel
(3) Skeletons, WV HLW, and RHTRU

The following areas are addressed:

(1) Radiation level limits established for the conceptual design of drywells and transfer shields.

(2) Analytical methods and models used.

(3) Development of the material descriptions and radiation source terms used.

(4) Results of the analysis.

(5) Additional studies performed in support of this analysis.

(6) Worker radiation exposure assessment.

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[1] (33-10) is used herein as an abbreviation for burnup and time out of reactor for spent fuel; i.e., (33-10) means a 33,000-MWD/MTU burnup and 10 yr out of reactor.

2.0 RADIATION LEVEL LIMITS

The radiation level limits established for the drywell and transfer shield are as follows:

(1) Limit the drywell ground surface dose rate to less than 10 mrem/hr for the final emplacement configuration.

(2) Limit the transfer shield surface dose rate to less than 50 mrem/hr.

(3) Limit the dose rate to workers to less than 50 mrem/hr during emplacement of the waste into the drywell.

These values were established arbitrarily for the conceptual design, based on previous drywell and transfer shield design radiation levels.

As a result of the worker radiation exposure assessment presented in Section 6, a dose rate limit of 2.0 mrem/hr was established for the operator cab of the transfer shield transport vehicle.

3.0 MATERIAL DESCRIPTION

Table 3-1 presents the material description by element weight percent used in this analysis. The fuel assembly and skeleton material descriptions were obtained from Reference 1. The HLW description was obtained from Reference 2.

4.0 CALCULATION METHODS AND MODELS

This radiation analysis was performed by using a mixture of hand calculations and SCAP point kernel computer code runs (see Reference 3 for SCAP documentation).

The gamma results for the drywell were obtained by use of the SCAP computer code. Two modes of calculation of the SCAP code were used: (1) direct-dose/line-of-sight calculations and (2) single scatter dose calculations. The various drywell designs were modeled in cylindrical (R-Z-) geometry, using SCAP. The GAMLEG-W cross-section library (Ref. 4) was used to provide the cross-sectional information needed for the calculations. The SCAP code includes a library of bivariant polynomial data for gamma ray buildup coefficient evaluation. Water dose buildup factors were used for all materials. This was done because SCAP allows only one buildup factor for all materials or zones and water adds a slight margin of conservatism to the calculations. Also included in the SCAP code is a library of flux-to-dose-rate conversion factors.

The direct neutron results for the drywell were produced with hand calculations, employing distance and mass attenuation. The hand-calculation methods used to compute the neutron streaming were obtained from Reference 5.

Table 3-1 - Materials by Element Weight Percent

Element	Materials									
	PWR Assembly	WV HLW or CHLW	Skeletons	Carbon Steel	Cast Iron	Concrete	Grout	Soil	BISCO NS-3	Lead
Hydrogen						0.53	0.53	0.53	4.59	
Boron		2.8							1.0	
Carbon				0.2	1.0	0.12	0.12	0.12	9.31	
Oxygen	9.8	38.1				52.20	52.20	52.20	56.84	
Sodium		9.7				1.70	1.70	1.70		
Magnesium				0.43		3.87	3.87	3.87		
Aluminum		1.1				40.10	40.10	40.10	17.89	
Silicon		16.8		0.26					3.36	
Phosphorous		0.9								
Calcium		0.7							5.61	
Titanium		3.6								
Chronium			12.241	0.0042						
Manganese				0.68						
Iron		0.7	30.13	97.04	99.0				0.56	
Nickel			18.835	0.79		1.48	1.48	1.48		
Copper		2.4								
Molybdenum		4.0		0.60						
Barium		6.3								
Gadalinium		8.7								
Uranium	73.0	4.2								
Zirconium	17.2		38.794							
Lead										100.0
Density (gm/cm^3)	3.304[a]	3.10	1.63[b]	7.80	7.21	2.32	2.16	1.85	1.78	11.34

[a]Homogenized density within fuel assembly dimensions of 9 in. x 9 in. x 12 ft-6 in.
[b]Ten skeletons each weighing 34 kg compacted into a 55-gal drum.

PARSONS

The hand calculations used to estimate the direct neutron and gamma dose rates for the transfer shields employed distance falloff and material-attenuation factors derived from transport calculations. These hand calculations are fairly crude, but historically have produced conservative results, which should be used to indicate approximate results. Because this is a conceptual design, however, the hand calculations are considered adequate.

5.0 DISCUSSION AND RESULTS

5.1 DRYWELLS

A drywell design was analyzed for each of the following forms of waste:

(1) Consolidated (33-10), intact (33-5), and (55-10) spent fuel
(2) High-level waste (HLW)
(3) Skeletons, WV HLW, and RHTRU

The requirement was to limit the dose rate at the surface of the drywell to less than 10 mrem/hr for the final emplacement configuration, and to expose no worker to a dose rate greater than 50 mrem/hr during emplacement of the waste into the drywell. Calculations were done at ground level, extending radially from the drywell vertical centerline to ensure that surface dose rates are less than 10 mrem/hr.

5.1.1 Spent Fuel Drywell

The spent fuel considered in this analysis is as follows:

(1) PWR fuel

(a) (33-10) consolidated (3:1)
(b) (33-5) intact
(c) (55-10) intact

(2) BWR fuel

(a) (28-10) consolidated (7:1)
(b) (48-10) intact

The PWR fuel represents the limiting case for shielding analysis. Table 5-1 presents the PWR spent fuel sources as obtained from Reference 1.

Figure 5-1 presents the drywell design for spent fuel. The SCAP model for this drywell design is shown in Figure 5-2. The SCAP code was used to calculate the direct and scattered gamma results at the drywell surface. Hand calculations were used to estimate the direct and scattered neutron results. These results are shown in Figure 5-1.

Additional analysis was performed to determine the dose rate during emplacement of the spent fuel into the drywell. A SCAP model was set up to

Table 5-1 - PWR Spent Fuel Assembly[a] Source Strength

	Gamma Source Strength (gamma/sec)			
	33,000 MWD/MTU		55,000 MWD/MTU	
MeV	5-yr Cool	10-yr Cool	5-yr Cool	10-yr Cool
0.05	2.152E+15	1.301E+15	3.234E+15	2.085E+15
0.0575	2.875E+14	1.765E+14	4.278E+14	2.798E+14
0.085	1.857E+14	1.035E+14	2.813E+14	1.680E+14
0.125	1.877E+14	9.725E+13	2.971E+14	1.706E+14
0.225	1.571E+14	8.570E+13	2.315E+14	1.373E+14
0.375	9.439E+13	4.195E+13	1.332E+14	6.445E+13
0.575	2.308E+15	1.518E+15	4.023E+15	2.526E+15
0.850	4.883E+14	1.206E+14	1.028E+15	2.514E+14
1.250	3.169E+14	1.606E+14	4.712E+14	2.392E+14
1.750	3.627E+12	1.425E+12	6.158E+12	2.820E+12
2.250	2.017E+12	3.264E+10	2.175E+12	3.745E+10
2.750	6.260E+10	2.124E+09	8.265E+10	3.071E+09
3.500	7.993E+09	2.652E+08	1.063E+10	3.834E+08
5.000	4.560E+06	3.783E+06	2.265E+07	1.875E+07
7.000	5.258E+05	4.360E+05	2.612E+06	2.162E+06
10.00	7.165E+04	5.941E+04	3.560E+05	2.947E+05
Total neutron source (n/sec)	2.297E+08	1.915E+08	1.134E+09	9.409E+08

[a]Initial uranium loading is 0.462 MT.

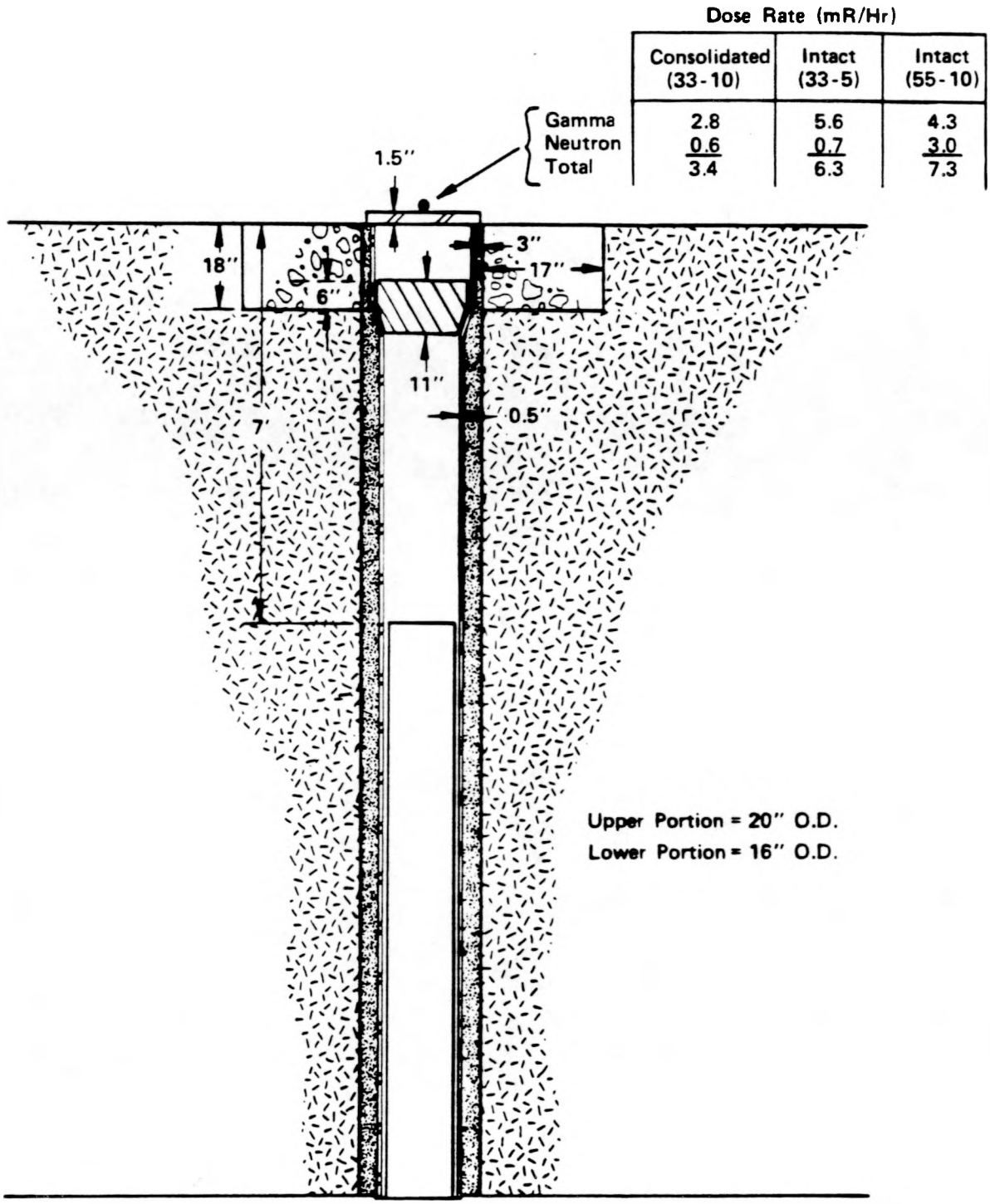


Figure 5-1 - Drywell Design for Spent Fuel

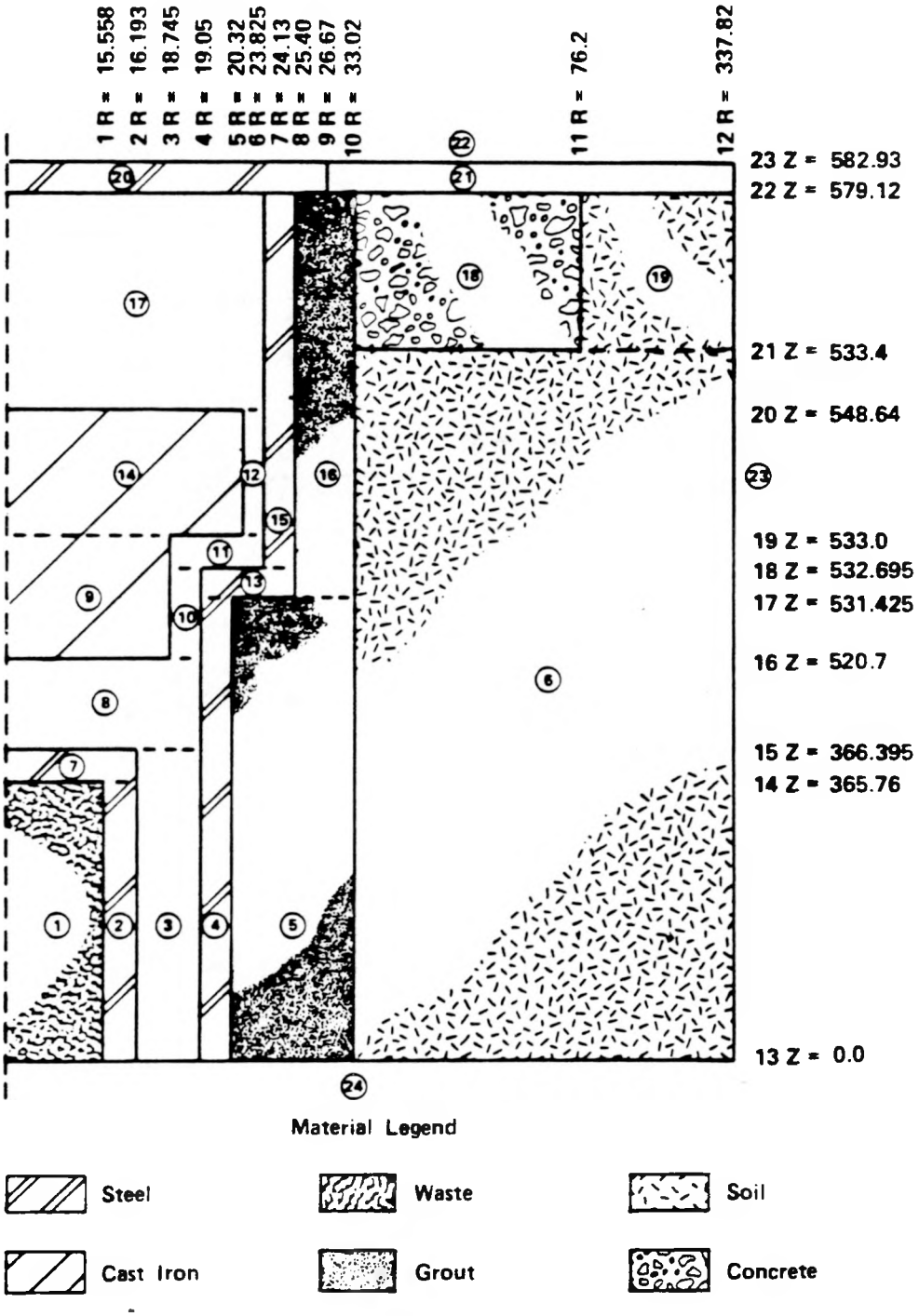


Figure 5-2 - SCAP Model for Drywell With Spent Fuel

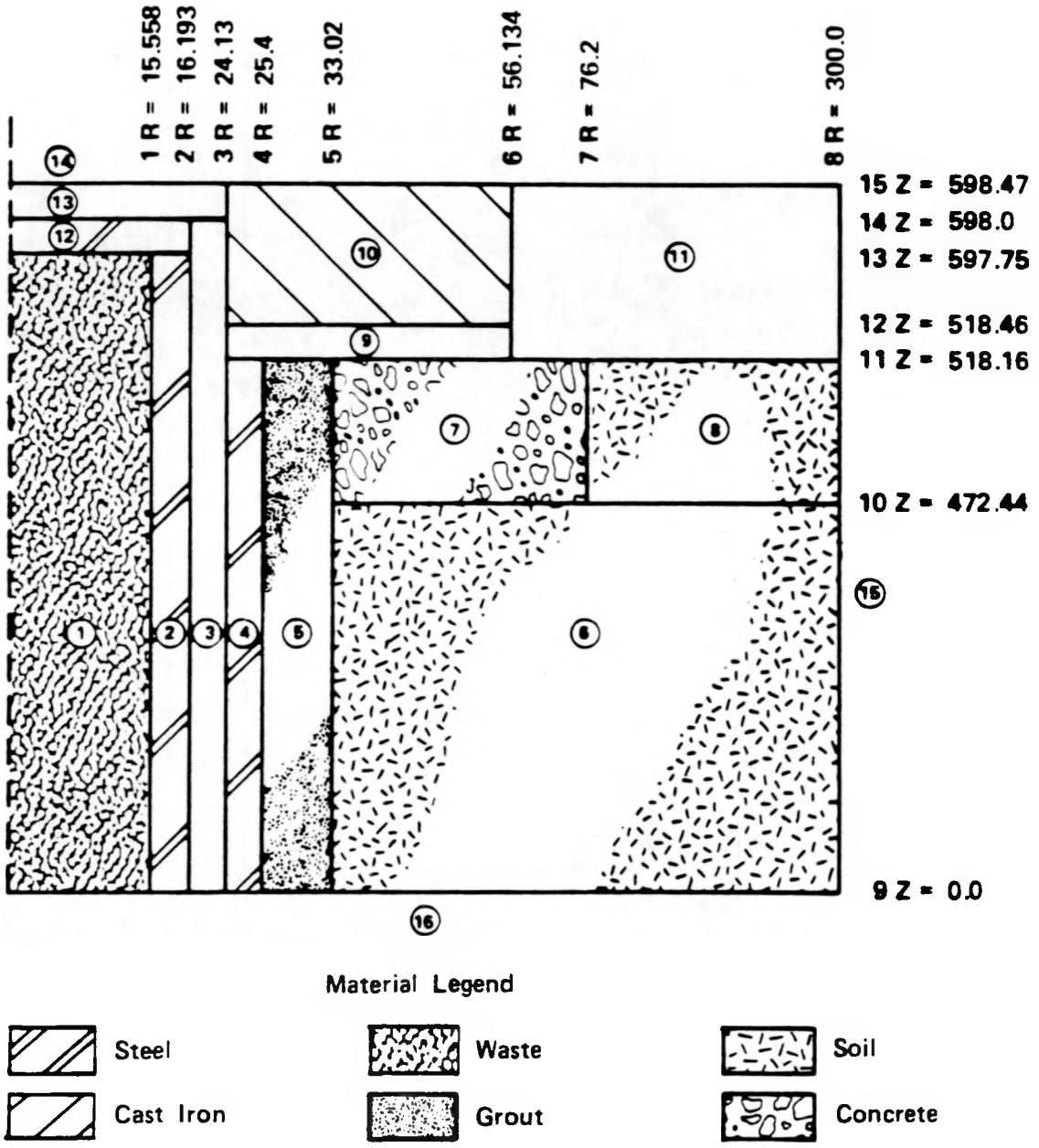


Figure 5-3 - SCAP Model for Direct Gamma Dose Rate Through Concrete Slab During Emplacement of Spent Fuel

model the waste partly in the transfer shield and partly in the drywell. This model is shown in Figure 5-3. This SCAP model was used to calculate the direct gamma dose rate, through the ground, at ground surface. Hand calculations were used to calculate the neutron component from the ground, as well as the gamma and neutron component from the transfer shield. It is noted that this analysis assumes that no gap exists between the bottom of the transfer shield and ground surface. The conclusion is that, during emplacement of spent fuel into the drywell, workers must be kept at least 4.5 ft from the vertical centerline of the drywell to limit the dose rate to less than 50 mrem/hr.

5.1.2 HLW Drywell

Table 5-2 defines the source strength for the high-level waste. Figure 5-4 shows the drywell design for HLW. This geometry was modeled in SCAP and is presented in Figure 5-5. The SCAP computer code was used to calculate the direct and scattered gamma results at the drywell surface. Hand calculations were used to estimate the direct and scattered neutron results. These results are shown in Figure 5-4.

Additional analysis was performed to determine the dose rate during emplacement of the HLW into the drywell. A SCAP model was set up to model the waste partly in the transfer shield and partly in the drywell. This model is shown in Figure 5-6. This SCAP model was used to calculate the direct gamma dose rate, through the ground, at ground surface. Hand calculations were used to calculate the neutron component through the ground, as well as the gamma and neutron component through the transfer shield. It is noted that this analysis assumes that no gap exists between the bottom of the transfer shield and ground surface.

The conclusion from this analysis is that, during emplacement of the HLW into the drywell, workers must be kept at least 4.5 ft from the vertical centerline of the drywell to limit the dose rate to less than 50 mrem/hr.

5.1.3 Skeletons, WV HLW, and RHTRU

Table 5-3 presents the gamma source terms for skeletons. From Reference 6, the dose rate at the surface of WV HLW is 3×10^6 mR/hr gamma and 1.3 mrem/hr neutron. The gamma energy spectrum was assumed to be the same as HLW. The RHTRU waste was assumed to have a maximum surface dose rate of 5,000 R/hr resulting from the decay of cobalt 60.

Figure 5-7 shows the drywell design for storing either skeletons, WV HLW, or RHTRU waste. This geometry was modeled in SCAP and is presented in Figure 5-8. The skeleton source represents the limiting case source for this drywell. The SCAP code was used to calculate the direct and scattered gamma results. These results are shown in Figure 5-7.

Additional analysis was performed to determine the dose rate during emplacement of the skeletons into the drywell. A SCAP model was set up to model the waste partly in the transfer shield and partly in the drywell. This model is shown in Figure 5-9. This SCAP model was used to calculate the direct

Table 5-2 - HLW Source Strength

Group	E (MeV)	Gamma Source Terms 10 yr Decay Time (MeV/w-s/MTU)
1	0.085	8.6 + 5
2	0.125	1.0 + 6
3	0.225	1.9 + 6
4	0.375	1.5 + 6
5	0.575	4.9 + 7
6	0.85	6.1 + 6
7	1.25	3.6 + 6
8	1.75	1.6 + 5
9	2.25	4.3 + 3
10	2.75	3.3 + 2
11	3.5	5.4 + 1

Power = 38.4×10^6 W

2.28 MTU per canister

Note: From Reference 6, the HLW design level neutron source is 1×10^9 neutrons/sec per HLW canister.

Table 5-3 - Gamma Source Terms for 33-10 PWR Skeletons

Group	E (MeV)	Source (gamma/sec/Skeleton)
1	0.05	2.879E + 12
2	0.0575	2.305E + 11
3	0.085	9.070E + 10
4	0.125	3.565E + 10
5	0.225	2.361E + 10
6	0.375	7.561E + 10
7	0.575	9.326E + 10
8	0.85	5.071E + 10
9	1.25	7.765E + 13
10	1.75	2.519E + 2
11	2.25	4.115E + 8
12	2.75	1.273E + 6

Note: (33-10) refers to the skeleton associated with a fuel assembly with 33,000-MWD/MTU burnup with 10 yr out of reactor.

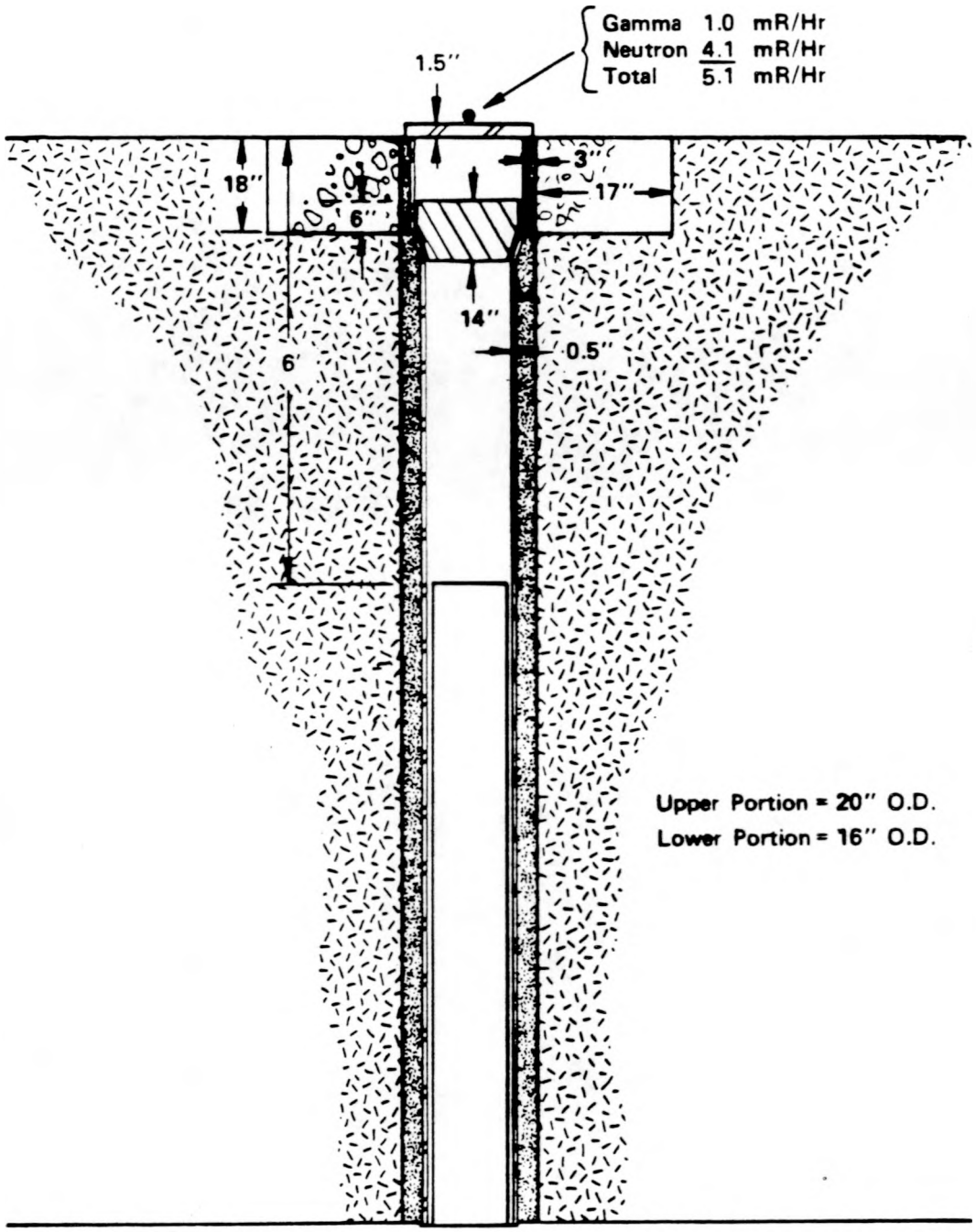


Figure 5-4 - Drywell Design for HLW

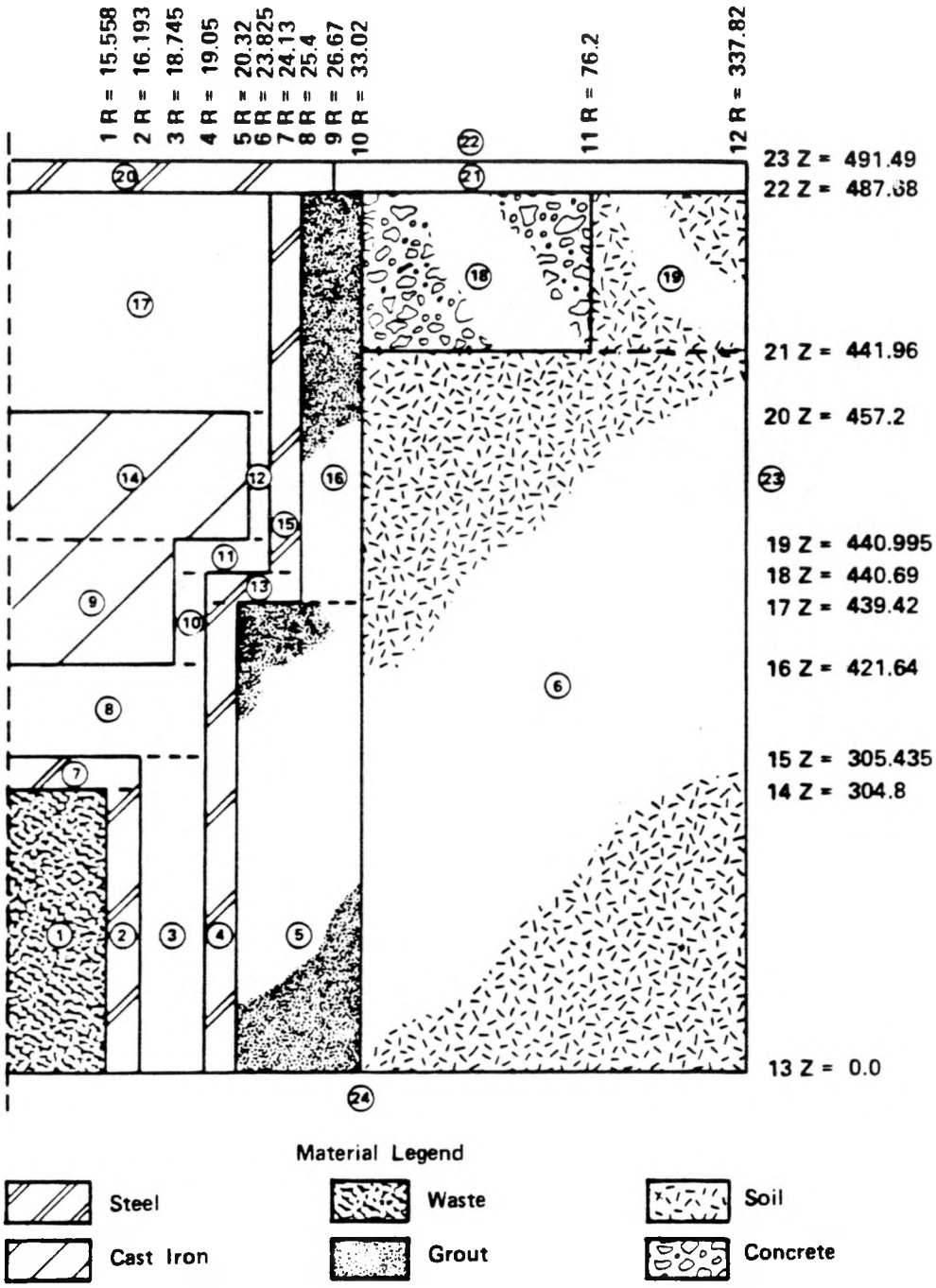


Figure 5-5 - SCAP Model for HLW Drywell

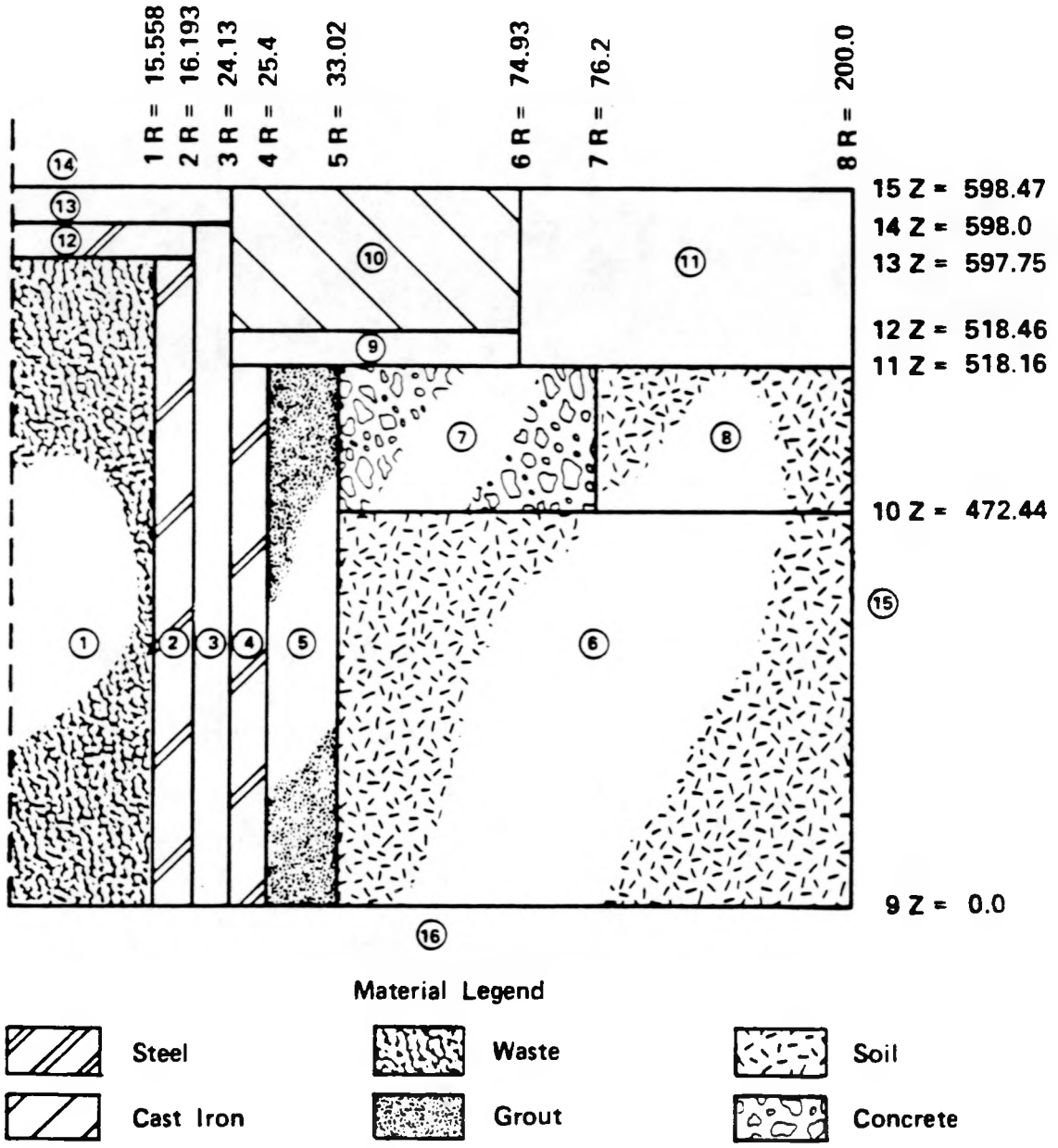
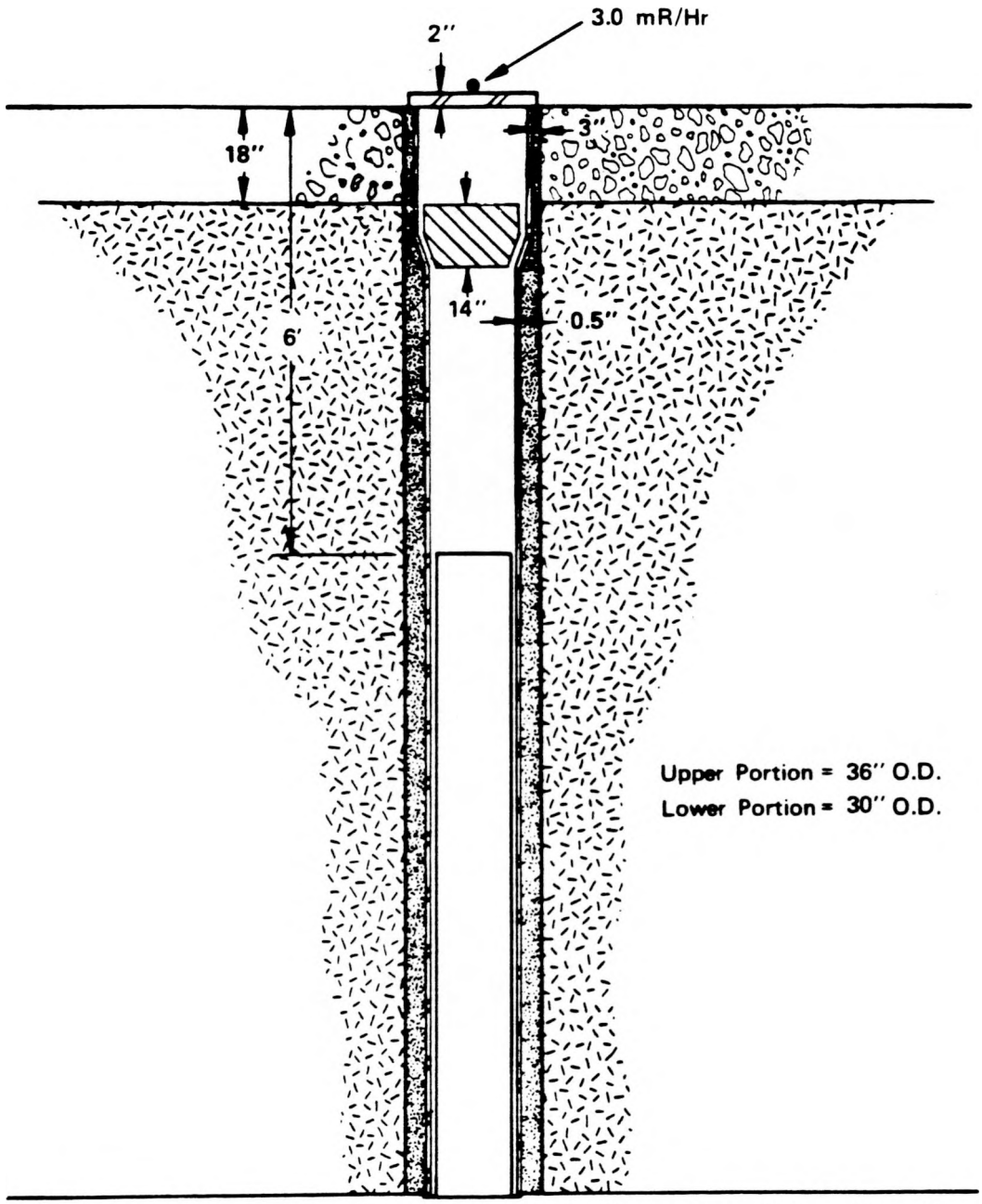


Figure 5-6 - SCAP Model for Direct Gamma Dose Rate Through Concrete Slab During Emplacement of HLW



During Emplacement of Skeletons, Workers Must be Kept at Least 6' from Centerline of Drywell to Limit Dose Rate to <50 mR/Hr

Figure 5-7 - Drywell Design for Skeletons

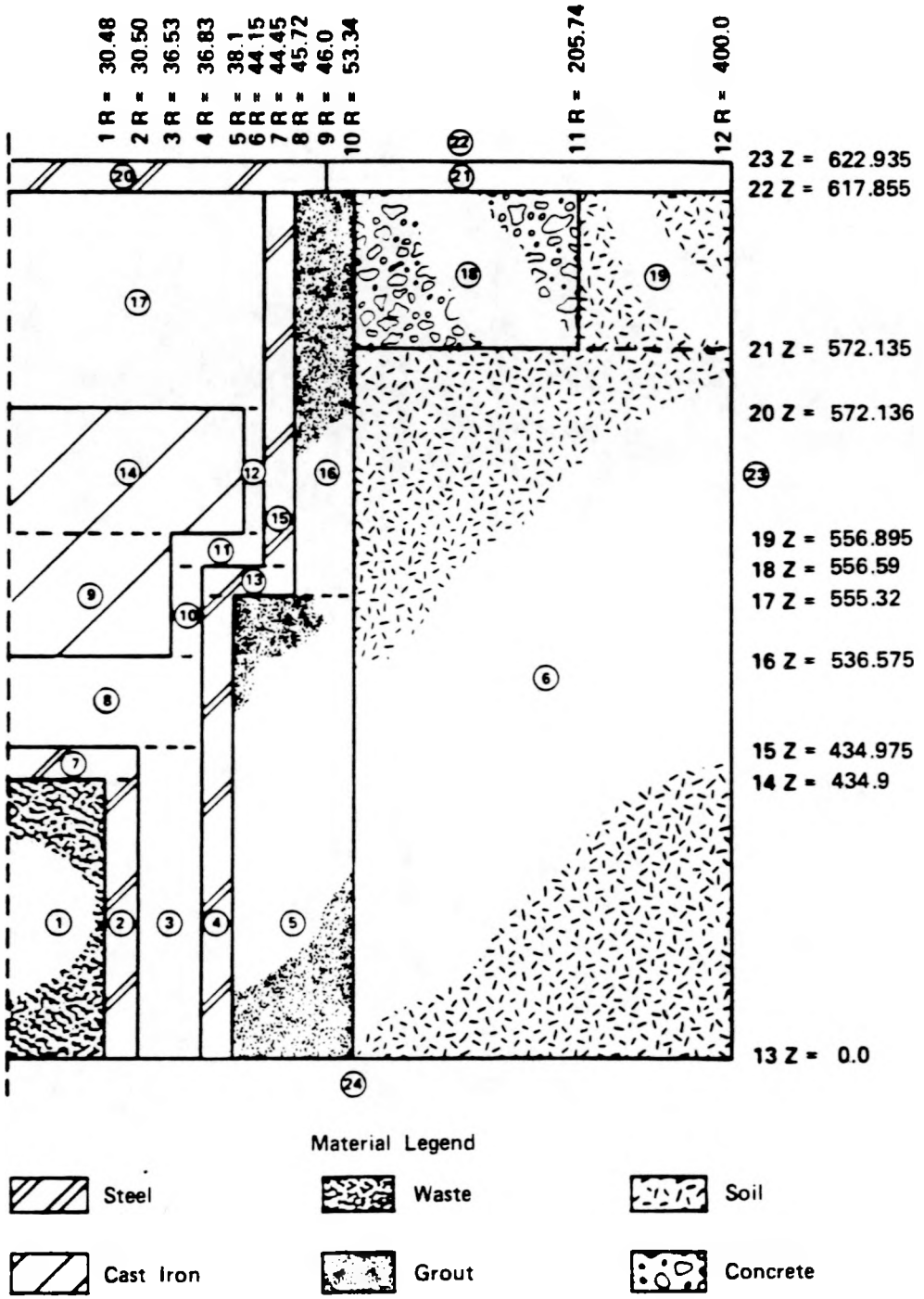


Figure 5-8 - SCAP Model for Drywell for Skeletons

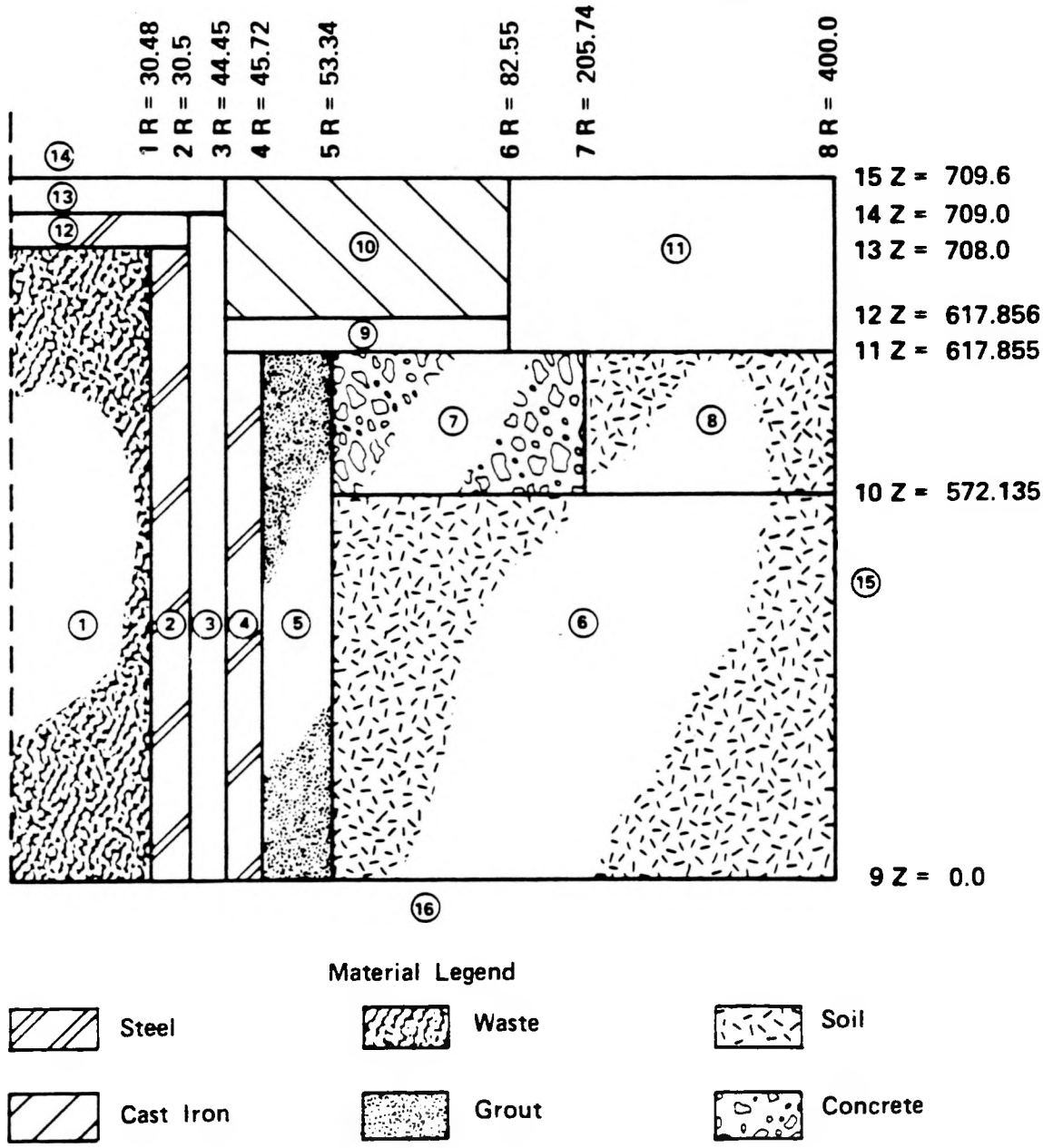


Figure 5-9 - SCAP Model for Direct Gamma Dose Rate Through Concrete Slab During Emplacement of Skeletons

gamma dose rate contributions, from the transfer shield and ground, at the ground surface. It is noted that this analysis assumes that no gap exists between the bottom of the transfer shield and ground surface.

The conclusion from this analysis is that, during emplacement of the waste into the drywell, workers must be kept at least 6 ft from the vertical centerline of the drywell to limit dose rate to less than 50 mrem/hr.

5.2 TRANSFER SHIELDS

Three different transfer shield designs were analyzed for the following waste forms:

(1) Consolidated (33-10) spent fuel
(2) HLW, intact (33-5), and (55-10) spent fuel
(3) Skeletons, WV HLW, and RHTRU

The portion of the transfer shield that normally holds the waste form during transport is made of lead (to provide gamma shielding) and BISCO NS-3 (to provide neutron shielding, if required). The lower portion of the transfer shield is made of cast iron. The design criterion was to limit the dose rate at the surface of the transfer shield to less than 50 mrem/hr.

5.2.1 Consolidated (33-10) Spent Fuel

The method used for sizing the transfer shield, as discussed in Section 4, was to calculate the gamma and neutron dose rate at the surface of the waste package, then determine the thickness of material (and its associated distance) necessary to attenuate the surface dose rate to less than 50 mrem/hr. Only the base-case PWR fuel (three consolidated 33-10 assemblies) was considered in this analysis because it has a higher source than the base-case BWR fuel (seven consolidated 28-10 assemblies). Table 5-1 presents the PWR spent fuel assembly source strength as obtained from Reference 1.

Figure 5-10 presents the transfer shield design for consolidated (33-10) spent fuel, which reduces the dose rate at the surface of the transfer shield to less than 50 mrem/hr.

5.2.2 HLW, Intact (33-5), and (55-10) Spent Fuel

As discussed in Section 4, the method used for sizing the transfer shield was to calculate the gamma and neutron dose rate at the surface of the waste package, then determine the thickness of material necessary to attenuate the surface dose rate to less than 50 mrem/hr.

Table 5-1 presents the intact (33-5) and (55-10) PWR spent fuel assembly source strength. Table 5-2 presents the HLW source strength.

Figure 5-11 presents the transfer shield design that reduces the dose rate at the surface of the transfer shield to less than 50 mrem/hr when loaded with any of the above wastes.

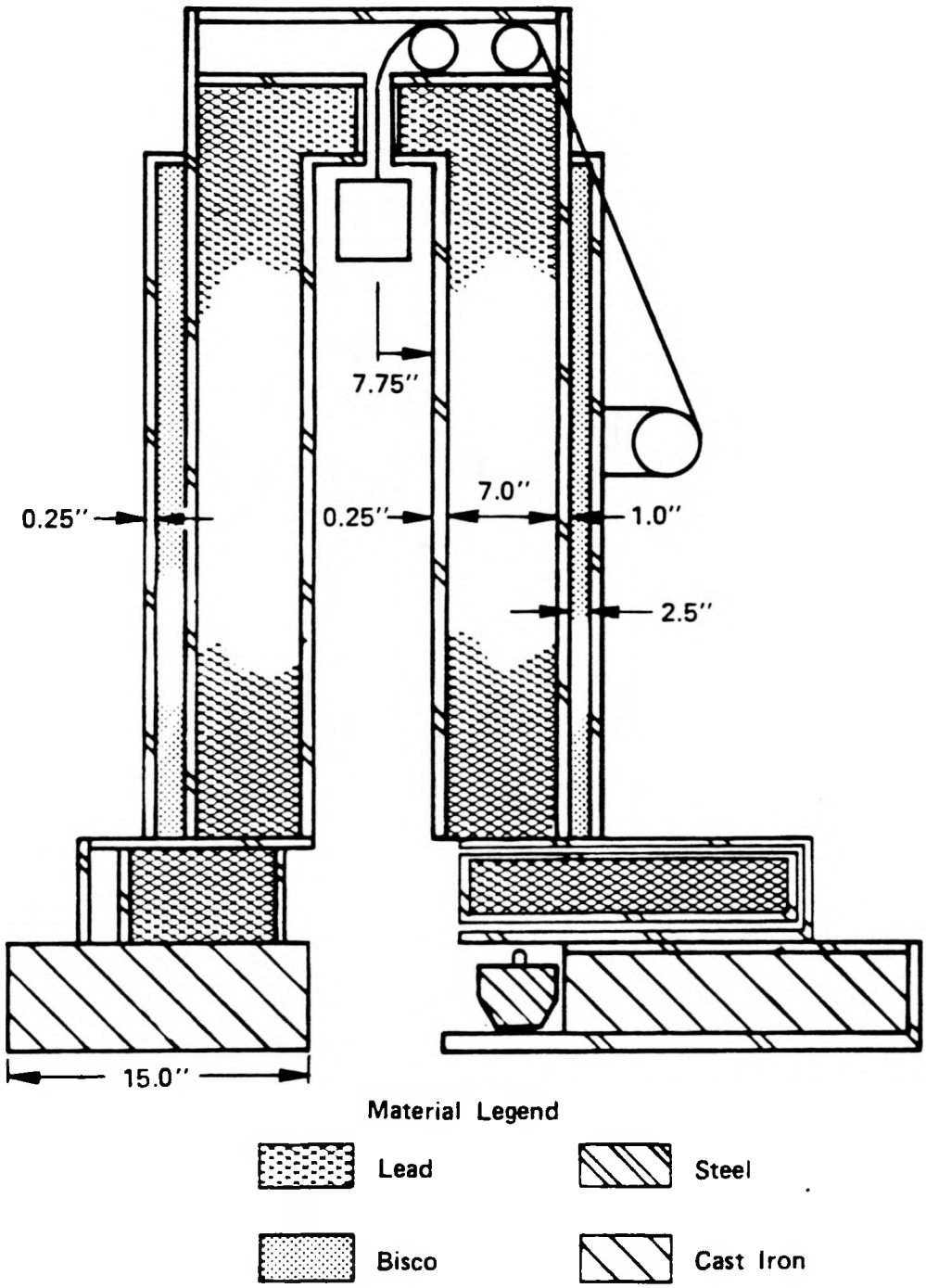


Figure 5-10 - Transfer Shield Design for (33-10) Spent Fuel

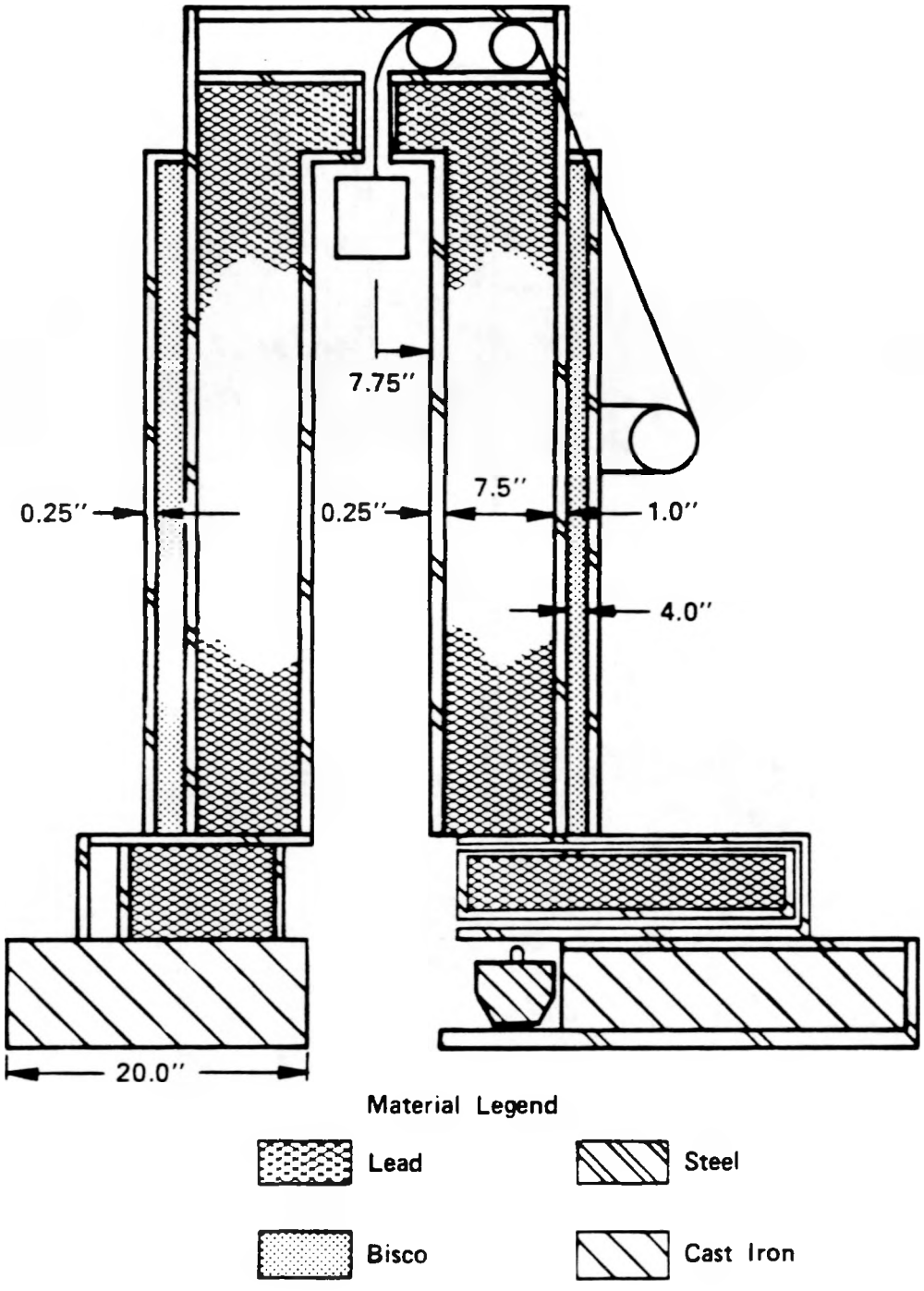


Figure 5-11 - Transfer Shield Design for HLW, Intact (33-5), and (55-10) Spent Fuel

5.2.3 Skeletons, WV HLW, and RHTRU

The method used for sizing this transfer shield was to calculate the gamma dose rate at the surface of the waste package, then determine the thickness of material necessary to attenuate the surface dose rate to less than 50 mrem/hr.

Figure 5-12 presents the transfer shield design that reduces the dose rate at the surface of the transfer shield to less than 50 mrem/hr when loaded with any of the above wastes.

6.0 RADIATION EXPOSURE ASSESSMENT

This section presents an estimate of the total worker radiation exposure for the drywell and transfer shield operations (estimate based on 1,800 MTU/yr throughout rate, excluding onsite-generated HAW).

Table 6-1 and Figure 6-1 describe the locations where worker exposures would occur. The locations and exposure times estimated (time for operations and exposure) are based on the following:

(1) Locations and times are estimated for a crew working 1 shift/day and 5 days/wk, able to load or unload 490 drywells per year. A total of four crews are needed for base-case facility operations.

(2) A crew chief is included to oversee all drywell transfer and sealing operations.

(3) Two men are assumed to be included for transfer shield operations - one to drive the transporter and one to operate the transfer shield.

(4) The transfer shield operator and transporter operator are in the transporter cab for canister transport from the R&H Building to the drywell, for drywell loading (both canister and shield plug), and then return to the R&H Building.

(5) The entire storage crew is assumed to spend 4 hr in the storage area for each drywell loading or unloading operation.

(6) Two handling technicians have been included for drywell cover (temporary and permanent) handling, for welding, and for drywell pressure-checking.

Because of time constraints, a more or less crude estimate was made of the dose rates at the noted locations. The following dose rates were used:

(1) The maximum dose rate of the drywell surface was estimated at 10 mrem/hr (Point D).

(2) The background area radiation level was reduced to 0.1 mrem/hr caused by air scatter (Points B, C, and H).

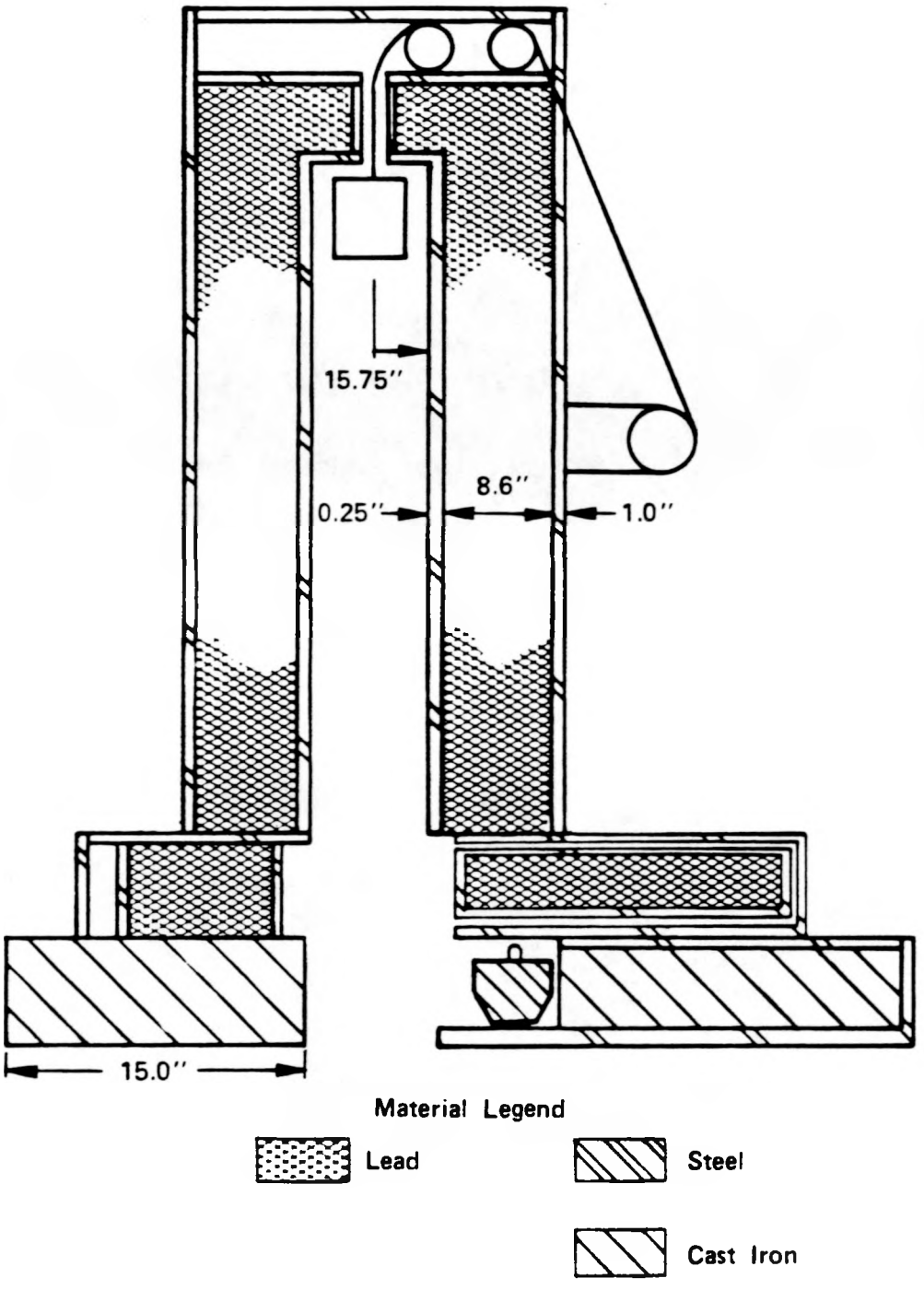


Figure 5-12 - Transfer Shield Design for Skeletons, WV HLW, and RHTRU Waste

Table 6-1 - Drywell and Transfer Shield Radiation Exposure Points Description

Location	Operation
Point A	Above drywell for cover installation, welder setup and weld inspection, cleaning and coating, gas sampling, and pressure test.
Point B or C	Between drywells for welder operation, general overseeing.
Point D	Manual activities for gas sampling, welder setup.
Point E	Inside operator cab on transfer shield transporter.
Point F	3 ft from surface of transfer shield.
Point G	20 ft from surface of transfer shield during emplacement.
Point H	On road between drywell plots (between drywell rows spaced 50 ft apart).

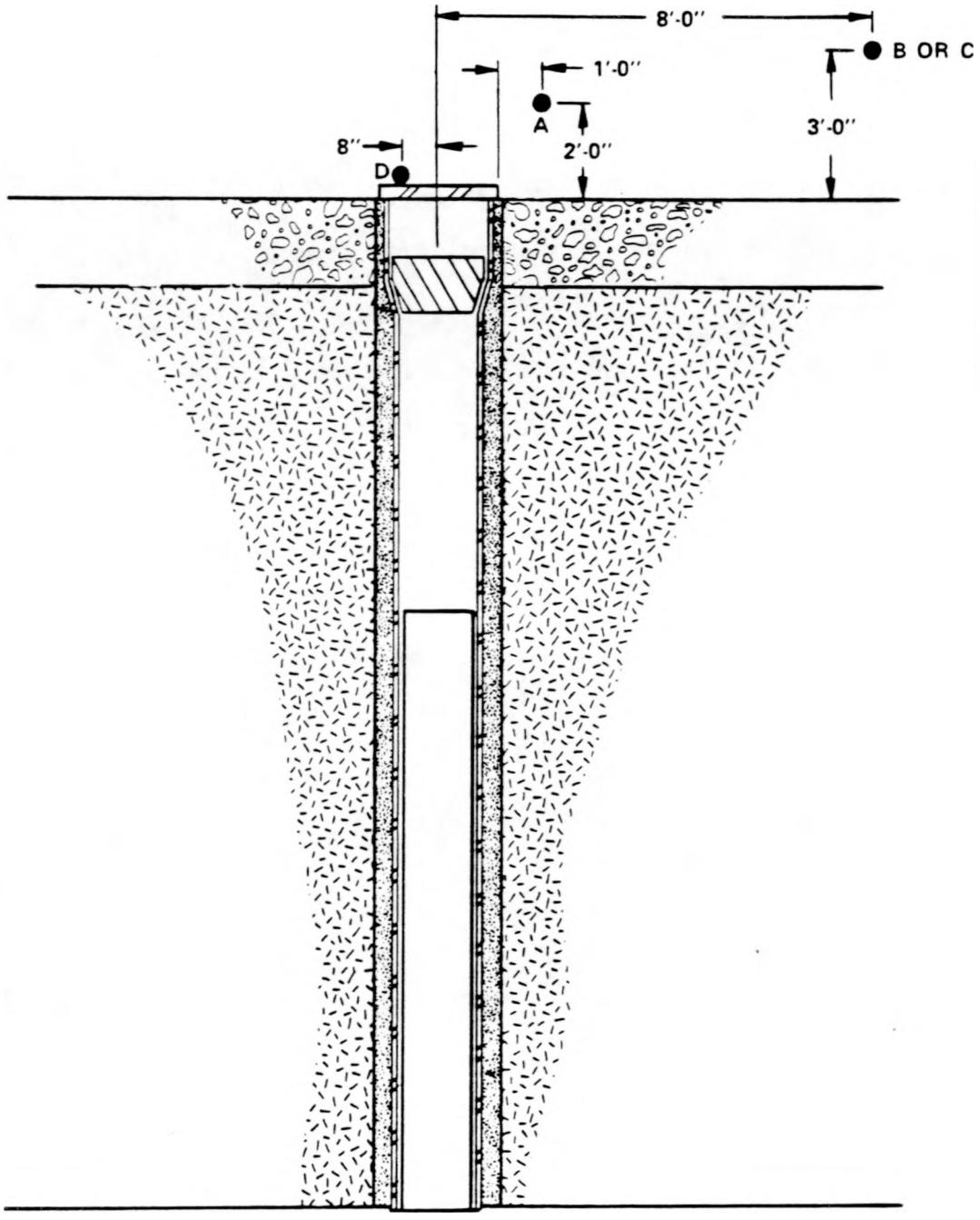


Figure 6-1 - Radiation Exposure Points Description

(3) The dose rate at Point A was assumed to be one-half of the maximum or 5 mrem/hr.

(4) The dose rate in the transporter cab (Point E) was calculated as 2.2 mrem/hr, assuming that the cab is shielded by 1 in. lead, 2 in. BISCO NS-3, and 0.5 in. steel.

(5) The dose rate at Point F was calculated as 17 mrem/hr.

(6) The dose rate at Point G was calculated as 3.6 mrem/hr.

Table 6-2 presents a detailed estimate of the radiation exposures (time for operations and exposure) for each drywell worker.

The values calculated and presented in Table 6-2 are based on hand calculations of dose rates and the assumptions noted above. The results of hand calculated dose rates have been shown to be conservatively higher than those from computer code calculations by about a factor of two. The annual exposures, noted as ranging from 1.03 to 1.48 mrem/yr, are expected to be less than the DOE objective of 1.0 mrem/yr when a more accurate calculation of dose rates is made. For the advanced conceptual design phase, the results of the radiation exposure assessment are considered acceptable.

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Table 6-2 - Exposure Estimates per Crew

Worker	Location	Time (min/drywell)	Rate (drywell/yr)	Exposure (mrem/hr)	Exposure (mrem/yr)
Drywell Handling Crew Chief	G	37	490	4.0	1,208.7
	H	40	490	0.1	32.7
	B	10	490	0.1	8.2
	C	183	490	0.1	149.5
	A	20	490	0.2	32.7
				Total	1,431.7
Transporter Operator and Transfer Shield Operator	E	69	490	2.5	1,408.8
	B	44	490	0.1	35.9
	C	10	490	0.1	8.2
	H	40	490	0.1	32.7
				Total	1,485.6
QA Inspector (weld inspection)	H	40	490	0.1	32.7
	C	20	490	0.1	16.3
	C	135	490	0.1	110.3
	A	48	490	0.2	78.4
	B	10	490	0.1	8.2
	G	37	490	4.0	1,208.7
				Total	1,454.6
Handling Technician 1 (cover welding, pressure check)	H	40	490	0.1	32.7
	C	20	490	0.1	16.3
	F	6	490	17.0	833.0
	C	44	490	0.1	35.9
	G	12	490	4.0	392.0
	A	20	490	0.2	32.7
	D (hands only)[a]	10	490	4.0	326.7
	C	83	490	0.1	67.8
	A	30	490	0.2	49.0
	D (hands only)[a]	10	490	4.0	326.7
	B	10	490	0.1	8.2
				Total	1,465.9
Handling Technician 2 (cover handling)	H	40	490	0.1	32.7
	C	20	490	0.1	16.3
	F	6	490	17.0	833.0
	B	10	490	0.1	8.2
	C	177	490	0.1	144.6
				Total	1,034.8

[a]Not included in total.

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DESIGN STUDY DS-34

CORROSION PROTECTION FOR DRYWELLS

1.0 INTRODUCTION

This design study describes a recommended procedure for providing acceptable corrosion protection to drywell storage structures for near-surface disposal of nuclear waste at a Monitored Retrievable Storage Facility. Two types of drywell configurations are considered:

(1) A nonfuel-bearing drywell.

(2) A spent-fuel canister drywell.

These are 30 and 16 in. dia, respectively; the former is considered to have an external surface temperature only a few tens of degrees greater than soil ambient, whereas the surface temperature of the latter, especially in the region of the canister, may reach temperatures higher than 250°C. It is proposed that, for both types of drywell, corrosion prevention be achieved by a combination of surface coating and cathodic protection.

2.0 BACKGROUND

The purpose of surface coating is to emplace a boundary surface between the material to be protected and the corrosive medium - a boundary not itself subject to corrosion. Ideally, the boundary would be perfect, would be free from holes or other discontinuities ("holidays"), would bond permanently to the protected surface, and would be unaffected by temperature, mechanical changes, or radiation. In practical cases, although modern coatings offer considerable protection, perfection is not achieved: holidays do occur, bonding may not be complete or remain intact, temperatures much higher than 100°C cannot be sustained, and a combination of radiation and oxidative changes may deleteriously affect the ability to sustain mechanical changes. Therefore, surface coating must be backed up by other measures, such as, in the present case, the technique of cathodic protection.

Cathodic protection may be explained by considering the corrosion of a metal in an acid environment. In an anodic region of the metal surface, metal is oxidized:

$$M \rightarrow M^{+n} + n\bar{e} \qquad (1)$$

At a cathodic region, hydrogen (or another positive ion) is reduced:

$$2H^{+} + 2\bar{e} \rightarrow H_2 \qquad (2)$$

The law of mass action indicates that, by adding electrons to the anodic reaction, Equation (1), it will be driven to the left; in other words, corrosion, which is equivalent to the dissolution of the metal, tends to be suppressed. Suppression by this means is called cathodic protection.

There are two ways of supplying electrons to the metal: (1) power-impressed current or (2) sacrificial anodes. Figure 2-1 illustrates the application of method (1), using an external power supply (essentially a rectifier) to provide current to a system consisting of a protected structure and an inert auxiliary electrode; these are connected externally by wire and internally via conducting groundwater. The protected structure is made negative so that it acts as the cathode, and the auxiliary electrode is made the anode, completing the circuit. The electrons move as shown in the external circuit, but cannot exist in the electrolytic solution, where the current is carried by both positive and negative ions. The positive ion current is shown. The anode is normally emplaced in a carbonaceous backfill to improve the electrolytic contact. As shown, the electron current passes into the protected structure, suppressing corrosion.

Figure 2-2 illustrates the second method of applying cathodic protection, using a sacrificial anode. When two metals are electrically connected in an electrolyte, a current flows between them by virtue of their dissimilar electrical potentials with respect to the solution. The more noble (electropositive) metal becomes the cathode and the less noble metal becomes the anode. Accordingly, the latter dissolves, protecting the former, at which only typical cathodic reactions, such as discharge of hydrogen as hydrogen gas, will occur, corrosion being suppressed by the electron flow in the external circuit. The anode, of course, is consumed, and must be replaced periodically.

Cathodic protection may be monitored by measuring the electrode potential of the protected structure, i.e., the electromotive force existing between the structure and a convenient reference electrode. In the impressed-current method of protection, the rectifier current is adjusted to maintain this potential at or above some value estimated to be protective; e.g., -0.85 volt versus the copper/copper sulfate (saturated) electrode, a commonly accepted protective level. The electromotive force must be measured through a high-resistance voltmeter or an electrometer to avoid drawing polarizing currents, which would alter the measured potential. The monitoring can be made automatic by the use of a feedback device called a potentiostat, which continuously adjusts the current to maintain a constant potential.

Stray current effects are frequently encountered in cathodically protected systems, and can result in excessive corrosion in neighboring unprotected or partially protected systems. This occurs because a portion of the underground positive current flow can be diverted to the unprotected structure, which, because it is receiving no compensating flow of electrons from an external source, must increase its corrosion rate in order to maintain electrical neutrality by Equation (1). The solution is to maintain all structures in the field of interest at the same potential, by a common bus, and to arrange anode distribution as symmetrically as possible.

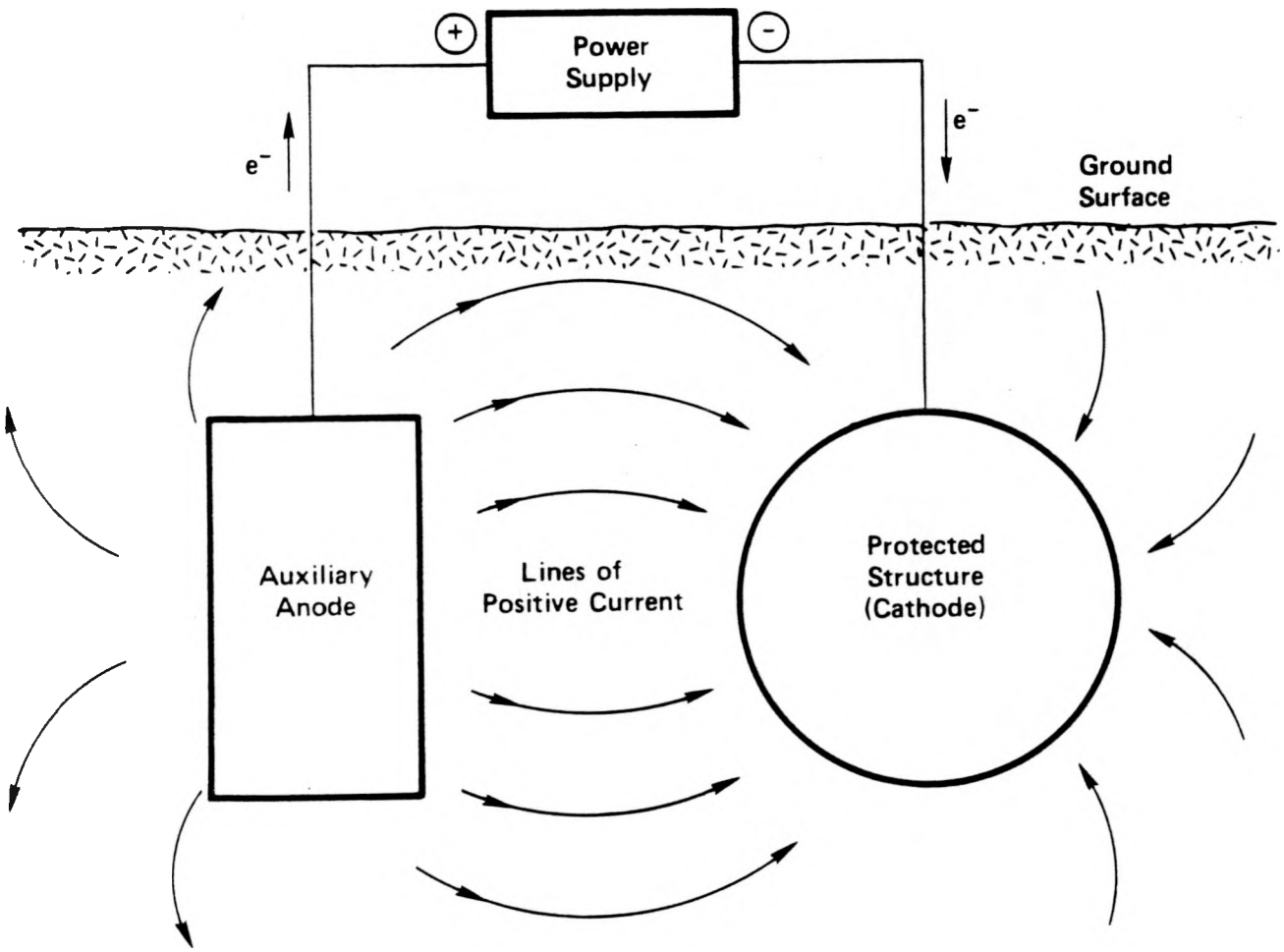

Figure 2-1 - Cathodic Protection With External Power Supply

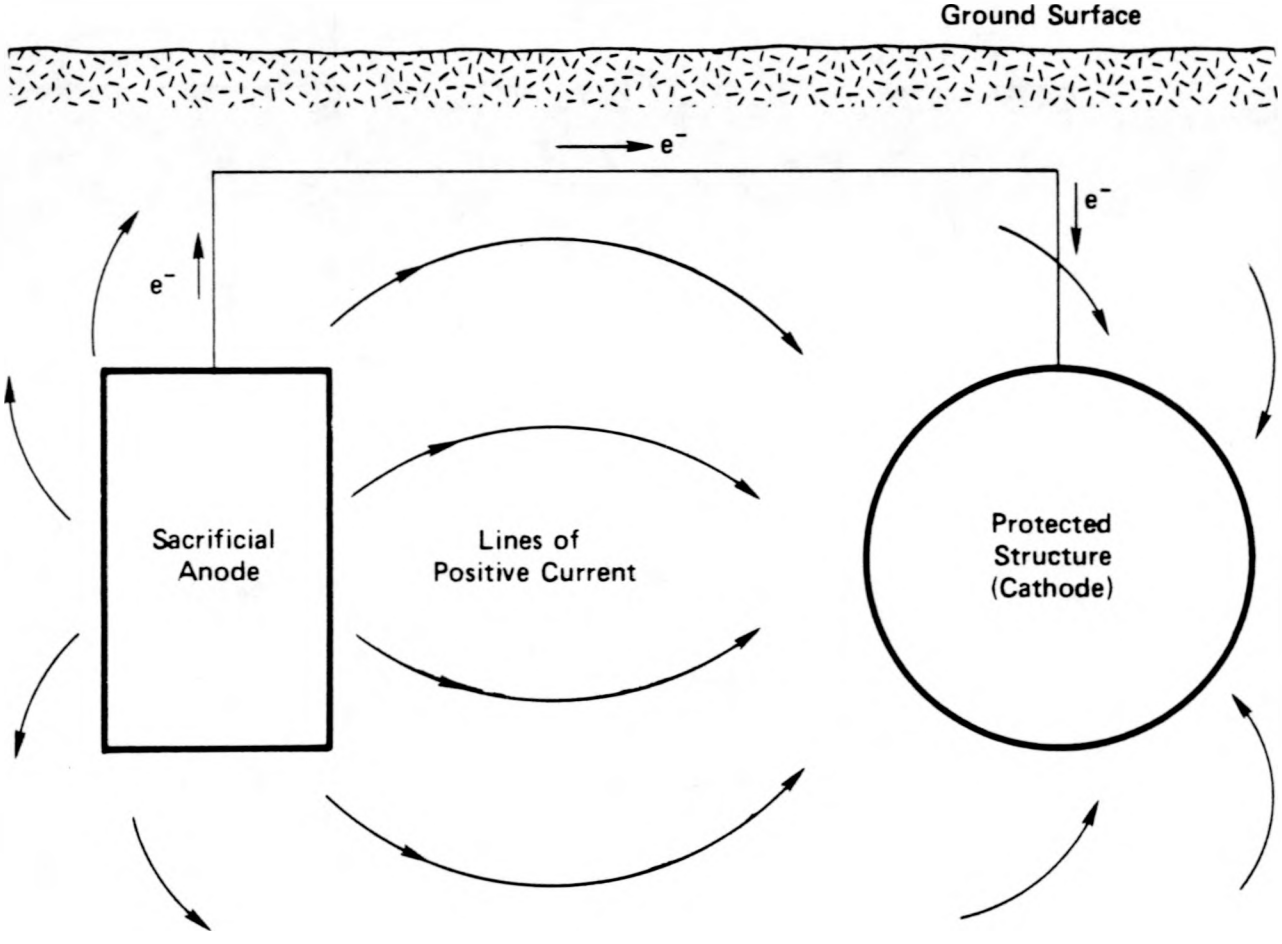

Figure 2-2 - Cathodic Protection With a Sacrificial Anode

3.0 PRESENT APPLICATION

The preceding discussion has described the proposed drywell protection system in general terms. More specific considerations are presented below.

It is proposed that the drywells, both the fuel-bearing and the nonfuel-bearing types, be covered with a corrosion-resistant adhesive coating over all steel surface areas expected to experience temperatures lower than 100°C during drywell lifetime. Effectively, this means the whole of nonfuel-bearing drywells and the upper 1 to 1-1/2 m of fuel-bearing drywells. Such coatings are usually organics, and cannot sustain temperatures much higher than 100°C for long periods. On the other hand, temperatures higher than that figure, at atmospheric pressure, are incompatible with the presence of liquid water, and will create a steam blanket in the nearby soil, extending a distance outward that depends on the amount by which 100°C is exceeded. In this steam zone, there can be no ionization, eliminating the ionic processes necessary for conduction and electrochemical corrosion, and the need for compensating for these phenomena by cathodic protection. The steam oxidation of iron can proceed under these conditions; however, this is normally a far more benign process than corrosion, and will develop at a considerably slower rate. Thus, the applied coating will protect the drywell surface in areas where the temperature is low enough to permit the presence of liquid water; wherever the coating must be omitted because of temperature incompatibility, oxidative attack on the surface will be much less aggressive. The coating to be applied may be in the form of an adhesive-tape wrapping in one or more layers, or a sprayed-on coating, or some combination of these. It may be applied in the field or applied during drywell fabrication. A number of coating companies have developed formulations that are temperature resistant up to 110°C or so, and the recommendations of the chosen vendor on the best method of application and appropriate surface preparation should be followed. The coating chosen must, of course, be compatible chemically with the grouting cement to be used.

The grout itself represents an effective barrier to corrosion, and can be regarded as part of the coating barrier. Although mechanical or other design considerations may dictate the chemical formulation of the grout, minimization of the corrosion problem suggests that mechanical durability is the primary property to be sought. This property is strongly related to maintenance of compressive strength. Therefore, if possible, a grout should be chosen that includes pozzolanic additives, such as flyash, and that employs a low water-to-cement ratio (pozzolans are siliceous materials that form cementitious compounds by reaction with the lime component of portland cement during hardening). The initial water content of the grout will be considerably reduced by the steady temperature in the hot zone of the fuel-element type of drywell, but, provided that sufficient curing time is allowed before fuel canisters are emplaced, little effect on the durability of such a grout is anticipated.

To support the corrosion resistance of the coating by providing protection at any holidays that occur in the coating, and to compensate for degenerative coating changes that might occur over the 100-yr drywell lifetime, a supplementary cathodic-protection system should be installed. This system

should be of the impressed-current type, for a variety of reasons: (1) for large installations, such as the one for an MRS Facility, the large number of anodes required makes the use of a sacrificial-anode system unduly expensive; (2) such systems are of little use in high-resistivity soils owing to the small driving electromotive force available; (3) anode replacement is required at frequent intervals, as is implied by the designation "sacrificial," and, aside from the expense of replacement, a regular inspection procedure must be adhered to, which is especially onerous for underground anodes in a possible radiation area. Impressed-current anodes, on the other hand, do not require frequent replacement, and the impressed-current method is eminently suitable for high-resistivity soils because the control system maintains the desired potential drop automatically. Finally, the current actually being applied represents an index of corrosion activity, and thereby permits following the course of corrosion transients, should any occur. To be sure, regular maintenance and inspection will be required; however, except for the rare replacement of a nonsacrificial anode, these checks will be made on the surface, and not underground.

It is expected that, in a drywell installation of the size contemplated, an extensive network of impressed-current devices and nonsacrificial anodes will have to be emplaced, each serving a group of drywells. Nevertheless, running costs would not be high because the effect of the coating (discussed above) confines the needed corrosion protection, for the most part, to holidays and other defects. The nonconsumable electrodes of choice for the present application would be graphite or high-silicon iron, buried in a carbonaceous backfill. Typical current densities for graphite electrodes in mud or fresh water are less than 1 mA/sq cm, and this level would probably be even lower for an intermittently moistened dry soil. For graphite, the approximate electrode consumption rate is less than 1 kg/yr (this figure has nothing to do with a sacrificial corrosion rate, but with other life-limiting factors associated with burial of a metal structure in soil). Current densities and consumption rates will be roughly the same for high-silicon iron. Thus, as long as the coating remains intact, the corrosion area will be nearly negligible, and the current will be in the low-milliampere range.

The detailed engineering of a suitable cathodic-protection system requires considerable data on the specific soil properties of the chosen site, as well as parameters from the layout of the protected structures themselves. Soil properties of importance include moisture level (perhaps in the form of seasonal variation charts), soil chemistry, and soil resistivity as a function of moisture level. Engineering parameters include drywell size, depth, materials, and surface temperatures; calculated soil temperatures; distribution of drywell locations; pitch of individual drywells; and the total number of drywells. From these data and a knowledge of the local electrical power distribution system, a cathodic-protection system can be properly designed. Design activities would include the following steps:

(1) Estimate the total current-density requirement.

(2) Compute the total current requirement.

(3) Design the groundbed system, with attention to selection of the optimum number of drywells per subsystem.

(4) Design the dc wiring system for economical cable size.

(5) Estimate circuit IR drop.

(6) Select rectifier voltage and current outputs.

(7) Design electrical circuits, fittings, and switchgear, including potentiostat (if one is to be used to control current).

(8) Prepare drawings and specifications, including maintenance and inspection program plan.

It should be understood that certain aspects of the cathodic-protection and corrosion-resistant coating proposal offered here are unusual, even unique, from the point of view of conventional installations. The two most unusual aspects are:

(1) The extremely long lifetime of the installation: 100 yr or more. Little experience exists for cathodic protection or coating protection over such an extended period.

(2) The expected temperature gradient over the length of the spent-fuel drywells, running from ambient to several hundred degrees Celsius, represents a situation seldom encountered in underground protection systems.

Accordingly, it would be well to conduct a small-scale simulation test, to be carried out in the soil of the selected site, using electrical heating to simulate the decay heat, and experimenting with various coatings and cathodic-protection techniques.

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DESIGN STUDY 35

IMPACT OF HEAT AND RADIATION ON DRYWELL SOIL AND GROUT

1.0 PURPOSE

The purpose of this design study is to explore the effects of heat and radiation on soil surrounding MRS drywells. This study examines the relevant soil behavior that may be encountered during exposure of soil around the drywell to heat and radiation so that the impact of this behavior can be considered in the design and so that subsoil behavior can be considered in perspective during the site-selection process.

2.0 APPROACH

Given are the following known general physical properties of the site soil, the site climate, and the design functions of the grout liners:

(1) Soil thermal conductivity = 1.2 W/m °K (Ref. 1).

(2) Design functions of the grout liner and soil (Ref. 2).

(3) Generic site location in terms of climate (Ref. 1).

(4) Generalized mineralogy of the soil (primarily a function of temperature, rainfall, and drainage; secondarily of rock type) (Ref. 3).

(5) Soil and grout ambient temperature between 0 and 250°C.

The goal of this study is to:

(1) Define the mechanisms by which soil and grout can affect drywell performance.

(2) Identify the effect of heat and radiation upon these mechanisms, and identify subsequent negative effects on drywell performance.

(3) Define any design measures that could be taken to counter negative effects.

3.0 DISCUSSION

3.1 SOIL AND GROUT FUNCTIONS IN DRYWELL DESIGN

Initially, this assessment was to be confined to the soil surrounding the drywell; however, the potential effects of heat and radiation on grout have also been considered, and are reported herein. Thermal performance of this

grout is important because it provides the thermal link between the drywell liner and the soil. This is the most important design criterion for the grout liner. Three other design criteria for the grout are (1) to buffer the environment to an alkaline pH in order to protect the metallic liner, (2) to mechanically connect the metallic liner with the soil system, and (3) to protect the steel liner from moisture in order to forestall corrosion.

The soil has three assumed design functions: It attenuates radiation, conducts heat away from the drywell, and mechanically stabilizes the drywell system.

3.2 EFFECTS OF HEAT AND RADIATION ON SOIL AND GROUT

3.2.1 Introduction

Three things can occur whereby the grout and soil can affect the drywell. Two are physical (shrinkage or expansion of those materials), and a third is primarily chemical in nature (alteration of the soil or grout composition).

First, heat can induce shrinkage and subsequent cracking of the grout and/or soil. Second, heat application, water addition, or soil water chemistry changes, under certain conditions, can induce expansion or contraction in grout or soil. Finally, heat or radiation could alter the structure of the materials in the grout or soil. In the discussion that follows, conditions that favor such occurrences are identified and suggestions are developed to avoid those conditions.

3.2.2 Grout

Any portland-cement-based system (grout, concrete, or mortar) exhibits complex and variable behavior upon heating to a continuous elevated temperature. Exposure of a set portland-cement paste to elevated temperatures reduces its thermal conductivity (Ref. 4). Thermal conductivities at 750°C (substantially higher than MRS drywell design temperature) have been shown to be 50% of those at room temperature (Ref. 5). Some investigators have suggested that microcracks, caused by loss of water and shrinkage, account for this decrease in thermal conductivity. Differential thermal expansion, occurring between the cement paste and the aggregate, could also produce microcracks and further reduce the thermal conductivity (Ref. 6). Another study showed that the first significant loss of thermal conductivity (33%) occurs between 400 and 500°F. The grout composition was two parts cement to one part sandy soil (Ref. 12). In the MRS drywell designs, the maximum grout temperature is near the top of this range. Consequently, we can probably expect similar conductivity attenuations.

Figure 3-1 illustrates the length change of hardened cement paste upon heating. In the MRS drywell temperature range, the grout binder (cement paste) will expand slightly and then contract. The cement paste in the grout could experience shrinkage up to 0.3% of its thickness. Figure 3-2 shows relative expansion and contraction, as might occur in a mixture of cement paste and siliceous aggregate (Ref. 6). This shrinkage could cause the

development of a microcrack structure; it might also lead to an intermittent and slight separation between the soil or steel liner and the grout, further reducing thermal conductivity. Expansion of the grout may also be a problem. If it is, it should only occur in the small portion of the grout immediately above the waste-containing zone in the temperature interval of 0 to 100°C (Figure 3-1). If the grout is 5 in. in radial thickness and set in place at 20°C, it could expand 0.15% in radial thickness, or about 0.008 in.

The force this would exert on the steel liner is probably insignificant. It is not known, however, whether or not the expansion would induce fractures in the grout.

Chemical alteration of the grout would probably be a result of hydrothermal action. Calcium silicate phases would be altered to lime-rich, less-cementitious calcium silicate phases (Ref. 7). Although this will affect the strength of the grout, it will probably not change its volume, unless sufficient water is present to actually transport weakened grout away. This is very unlikely.

No information was found in the literature that documented radiolytic alteration of portland-cement-based materials.

3.2.3 Soils

Three significant things can happen to soils when exposed to the drywell design temperature levels. The soil can be physically or chemically altered, it can expand, or it can contract. In most typical hydrated soils, these three categories of change are controlled by, or linked to, behavior of clay minerals in the soil.

Clay minerals are hydrated sheet silicates; that is, laminated crystal structures of aluminum oxide octahedra and silica tetrahedra. The three main generic types of clay are kaolinite, illite, and smectite. Kaolinitic clay minerals simply alternate layers of silica-alumina, silica-alumina, etc. Smectitic clays use a repeating, three-layered unit of silica-alumina-silica, silica-alumina-silica, etc. Illite is similar to smectite, except that some silicon (Si) is always replaced with aluminum (Al), resulting in a charge deficiency covered by potassium (K). Smectite is most prone to cationic substitution for the Al in the aluminum hydroxide-oxide octahedra, and will occasionally have Al replacing Si in the silica tetrahedra. Illite can usually also have extensive cationic substitution for Al and Si (Ref. 3). Most of the behavior discussed below is influenced by the interactions of water, water-carrying cations, clay, and heat.

Clay minerals hold water in three general ways: in pores and on edges, between structural layers, and in structural tubes (minerals in the sepiolite-attapulgite-palygorskite family) (Ref. 3). Water is also held on mineral particle surfaces. Structurally different clay minerals retain varying amounts of water in each of the above-mentioned categories. If water evolution as a function of temperature is examined, it is discovered that surface, pore, and edge waters evolve from clay minerals over a temperature

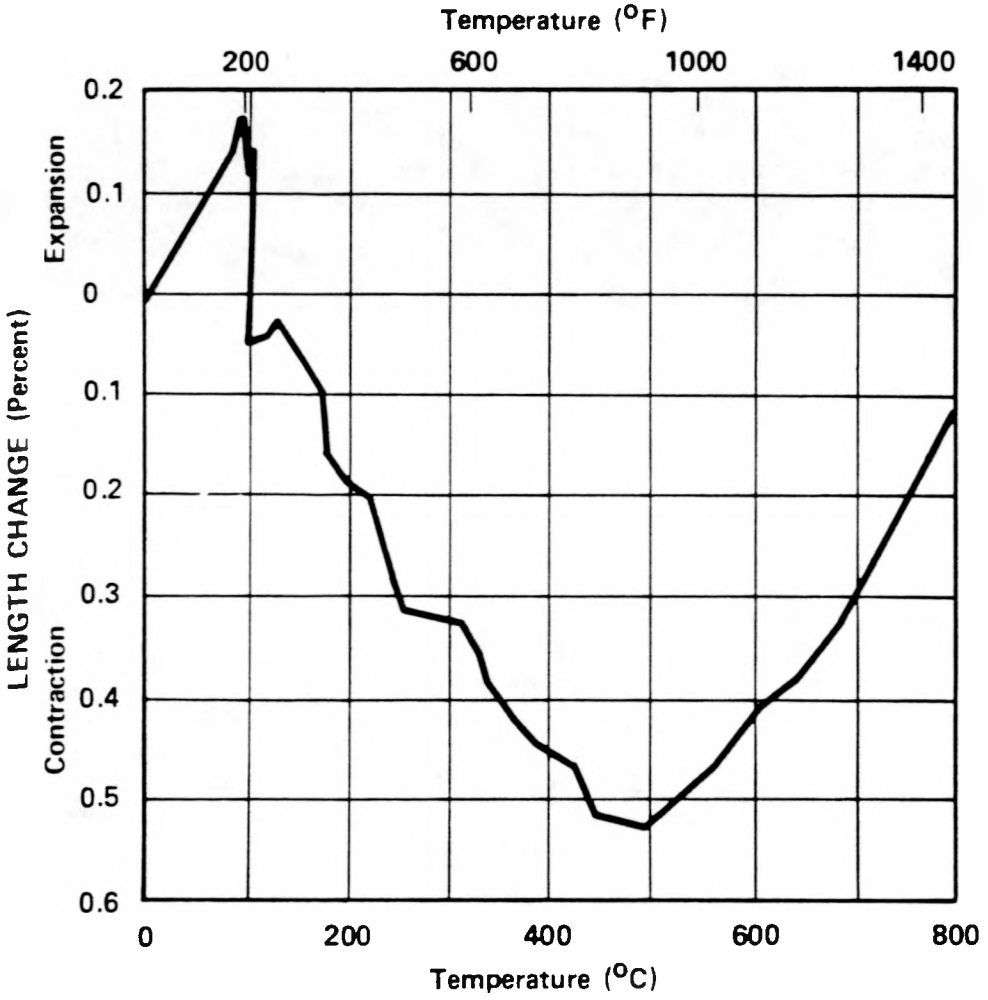

Figure 3-1 - Length Change of Hardened Cement Paste Upon Heating

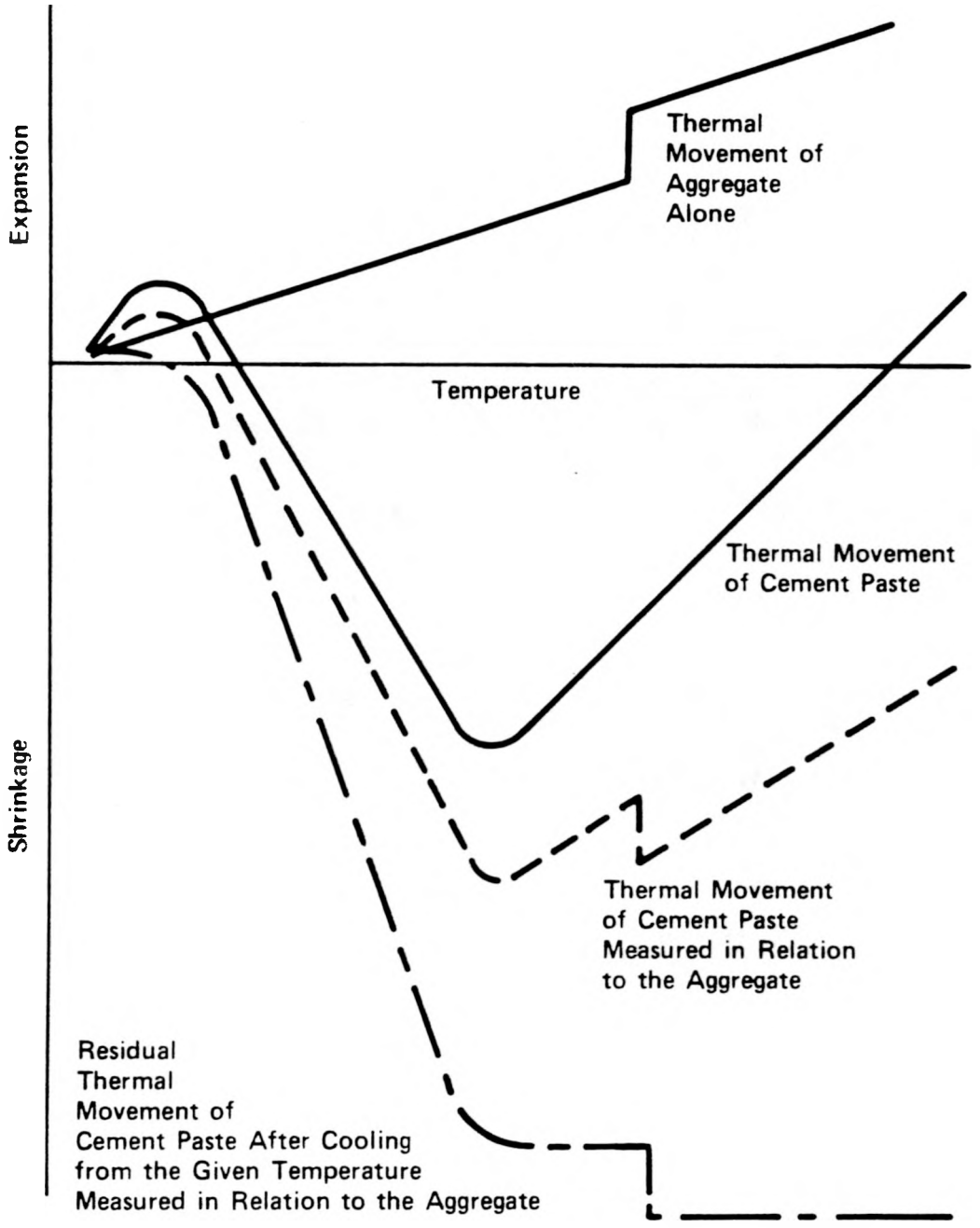

Figure 3-2 - Thermal Movement of a Cement Paste Measured Relative to a Typical Siliceous Aggregate

range from 80 to 150°C. Interlayer or OH lattice water departs at temperatures greater than 300°C. Kaolinite shows no appreciable water-loss weight until 400°C, when it begins to dehydrate (Ref. 10). Smectite shows considerable water loss in the 100 to 200°C range (Ref. 11). Illite displays water-loss characteristics upon heating similar to those of smectite (Ref. 3). Because the design environment will not reach temperatures greater than 300°C, there is no need to worry about loss of interlayer or lattice water. Kaolinitic clays are favored for an MRS drywell site because they show no water loss in the design temperature range.

Water loss causes varying amounts of shrinkage in the clay, depending on the type of water that is lost and the particular clay mineral losing the water. Shrinkage can crack the soil, which will reduce the thermal conductivity. In addition, smectitic clay minerals exhibit expansion upon wetting. If soil expands, unanticipated stress on the steel liner would result. Sodium (Na) smectite (e.g., bentonite) is well known for the myriad uses created by this property (Ref. 3). The swelling property can be altered by substituting K or magnesium (Mg) for Na in a smectitic, swelling clay.

Another potential problem may be hydrothermal alteration of minerals in the soil. This process (hot water dissolution, transportation, and/or replacement of minerals) could result in shrinkage, expansion, or net removal of materials in the soil. The result depends on the physical and chemical properties of the alteration product formed in the soil. For example: if a mineral is altered to a second mineral with a lower unit volume, the host material will exhibit some shrinkage. If a mineral is altered to a soluble material, it may be removed by groundwater flow, and thus change the nature of the soil. Hydrothermal alteration would require sufficient water with flow velocity slow enough to keep the temperature higher than 100°C and enough pressure to prevent steam generation.

Radiolytic alteration of the soil is a remote possibility. Results of one study (Ref. 8) indicate that intense gamma radiation can induce increased hydrogen ion concentration on kaolinite particle surfaces. This could increase the corrosiveness of the immediate environment, provided that water is present.

Changes in mineralogy resulting from heat, excepting the water gain or loss and hydrothermal alteration previously discussed, are unlikely in the design situation. Soils with large amounts of halite or gypsiferous minerals may be an exception, but they are rare.

4.0 CONCLUSIONS AND DESIGN IMPACTS

4.1 GROUT

A portland-cement-based grout will probably expand slightly at the lower end of the temperature range (ambient to 100°C) when thermal loading of the drywell begins. This expansion will reverse as the temperature increases; the grout will return to the original size and shrink slightly as the steady-state temperatures are achieved. This thermal transient may create stresses that could generate fractures in the grout.

An alternative to portland-cement-based grout is a dry- or damp-packed, noncementious filler between the drywell liner and the soil. A material could be selected with a satisfactory thermal conductivity, a low permeability, and a buffering capacity to protect the steel liner from corrosion. Sand, pulverized limestone, and MgO are possibilities that could be examined further.

4.2 SOIL

Three mechanisms exist whereby the soil can affect drywell performance: shrinkage of the soil, expansion of the soil, and soil alteration.

Shrinkage of the soil would be caused by desiccation of the clay minerals within it. The shrinkage would cause a crack structure to be developed, which could affect the thermal conductivity of the soil, and could result in soil compaction or deformation under transporter or vehicular loads. Smectites are susceptible to such behavior; illites are also susceptible to a lesser degree. Kaolinites will only begin to desiccate at temperatures higher than 300°C.

Expansion of the soil could be caused by water addition or water-chemistry-change-induced swelling of clay minerals within it. This could subject the steel liner to mechanical stresses greater than the design limit. Smectites are, again, the material most likely to exhibit this behavior.

Alteration of the soil could be caused by the combined effects of heat and water on clay or other major mineral components in the soil. Radiolytic alteration is also a possibility. Alteration could result in a decrease in the thermal conductivity of the soil or in corrosion of the liner by the radiolytic alteration products.

5.0 RECOMMENDATIONS

Once a group of sites has been selected, appropriate soil-characterization tests should be conducted to determine clay mineral composition and expansive or contractive properties of the soils. Standard- ized (accepted) tests should be used, where available. If standardized tests are not available, however, suitable tests should be devised to quantify the following soil properties:

(1) Soil thermal conductivity
(2) Expansive or contractive properties of the soil
(3) Clay mineral characterization
(4) Soil-water chemistry
(5) Hydrogeology
(6) Overall soil mineralology

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