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Civilian Radioactive Waste Management System
Management & Operating Contractor

License Application Design Selection Feature Report: Waste Package Corrosion Resistant Materials (Metal and Ceramic)

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Prepared for:

U. S. Department of Energy
Yucca Mountain Site Characterization Project Office
P.O. Box 30307
Las Vegas, Nevada 89036-0307

RICK
TRE
BRET
JOHN
CHARLES
DAVE
MERAJ
KIEN
VANICE
DICK

Prepared by:

Civilian Radioactive Waste Management System
Management & Operating Contractor
1261 Town Center Drive
Las Vegas, Nevada 89134

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Prepared by: ______________________________ Date: ______________
Venkataraman Pasupathi

Checked By: ______________________________ Date: ______________
Xxxx

Reviewed by: ______________________________ Date: ______________
Gerald M Gordon,
Waste package Operations

Approved by: ______________________________ Date: ______________
David Stahl, Department Manager
Waste Package Materials

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1. Introduction

1.1 Background

The current waste package design selected for the Viability Assessment (VA) utilizes two concentric barrier layers, an outer predictable but less corrosion resistant ASTM A 516 carbon steel (UNS K01800 or K02700) structural Corrosion-Allowance Material (CAM) and an inner nickel-base Alloy 22 (UNS N06022) Corrosion-Resistant Material (CRM) (Ref. 1, pp. 56, 72, 125). Alloy 22 was chosen for the CRM in part because of its high degree of general and localized corrosion resistance under expected repository environmental conditions. During the past year, performance of the waste package containment barrier materials has been given greater emphasis in the overall repository performance and it is anticipated that lifetime requirements will increase. It is therefore highly desirable to design a waste package to provide substantially complete containment for a significantly extended lifetime.

Based on current waste package degradation models used as input to the Total System Performance Assessment (TSPA), the VA reference design is estimated to undergo first through-wall failure by pit penetration in about 2,700 years, and about 1% of the packages fail in about 10,000 years (Ref. 5, Section 5.11.2). While this low failure rate is acceptable, and the design is judged to meet the current regulatory requirements (Ref.1 p. 20), it is anticipated that these requirements may increase. Further, there is a significant, difficult to resolve open issue (oxide wedging induced failure) with the VA design that could increase the failure rate to unacceptable levels (Ref. 7, p. 519). Accordingly, a selection process for alternative materials and design which will provide a high confidence, extended waste package lifetime has been initiated.

1.2 Objective

The objective of this study is to evaluate potentially longer life alternative waste package materials and design configurations leading to the selection of one option for the reference design feature for site Recommendation (SR). This option will be subjected to detailed design evaluations including structural, thermal and criticality analyses, and accelerated corrosion testing. This study also identifies several back-up design options for further evaluation. Important issues for consideration in the selection of the reference SR design were developed. Consistent with the functions of the containment barriers, corrosion performance was identified as the most important issue.

1.3 Scope

Because some important data on material performance are not yet available and models are still being refined, the scope of this study is limited to qualitative evaluation based on available information and engineering judgement of the various alternative barrier materials and design configurations. The scope includes evaluation of the positive and negative attributes of each alternative and the selection of the option with the greatest potential for successful long term performance.

1.4. Quality Assurance (QA)

The QA program applies to the development of this document. The information provided in the technical document is to be indirectly used in the evaluation of the Mined Geologic Repository. The waste package has been identified as an item important to safety, waste isolation, and physical protection of materials in the QAP-2-3 evaluation entitled *Classification of the Preliminary MGDS Repository Design* (Ref. 2, pp. 83-89). The Waste Package Materials Department responsible manager has evaluated the technical document development activity in accordance with QAP-2-0, *Conduct of Activities*. The QAP-2-0 activity evaluation, *Develop Technical Documents* (Ref. 3), has determined that the preparation and review of this technical document is subject to *Quality Assurance Requirements and Description* (Ref. 4) requirements. As specified in NLP-3-18, *Documentation of QA Controls on Drawings, Specifications, Design Analyses, and Technical Documents,* this activity is subject to QA controls.

1.5 Use of Computer Software

Not applicable. No computer software was used in this study.

2.0 Description of the Corrosion Resistant Material Selection Process

2.1 Approach

The approach used in this study consists of the following steps:

- Select metallic barrier materials which have the potential for providing long waste package lifetimes
- Develop a list of issues to be evaluated
- Develop barrier material configurations (reasonable combinations/material arrangements) for the selected materials including modifications to VA design intended to mitigate potential limitations with the VA design
- Evaluate each design configuration
- Select preferred and backup options

2.2 Criteria to be Considered

With the primary objective of this analysis being the selection of materials and a design configuration with a longer waste package lifetime than the VA design, it was concluded that corrosion performance was the most important criterion. Included in the corrosion performance are the resistance to general and localized corrosion, stress corrosion cracking, and hydrogen assisted cracking and embrittlement (hydrogen damage), as well as long term thermal aging effects on corrosion susceptibility. In addition, the other issues listed below should be applied to combinations and arrangements of the barriers instead of to each barrier by itself because of the potential for ınic/crevice synergistic effects. Overall, the following criteria were identified as important for ıa in the selection of materials:

Corrosion performance
- Resistance to general and local corrosion
- Susceptibility to stress corrosion cracking
- Potential for hydrogen damage
- Thermal aging degradation

Provide defense in depth

Ease of fabrication

Potential impact of thin outer CRM barriers on WP loading, handling and emplacement

Cost

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entioned in Section 1.3, this evaluation is intended to be a qualitative assessment of each option ıst the above criteria. Therefore, no numerical weighting factors are being assigned to the ria. Instead, the evaluation will include positive and negative attributes of each option (as ed to the criteria) and uncertainties or open issues in the expected performance. These butes are derived from prior analyses of material performance data (Ref. 1, pp. 32-80) and ıeering judgment.

Material Options and Design Configurations

ng ..e past ten years, a number of assessments of potential candidate materials for waste age barriers have been carried out. These included screening of the candidates based on surveys :gradation modes of the materials under a variety of applications as described in Ref. 1, p. 57. :view of these surveys/assessments indicates that selected nickel-base and titanium-base alloys he most promising corrosion resistant candidate materials for the expected Yucca Mountain sitory oxidizing environment. The alloys available in both classes of these materials have oited excellent corrosion performance under a variety of applications. However, because of the ively high cost (previous cost estimates [Ref. 1, p. 79] have indicated a two CRM waste package cost over 50% more than the current VA WP design) and limited strength of candidate alloys e nickel-base and titanium-base alloy systems, there may be a need to select an additional more omical material. The material selected will be required to provide the needed structural strength ithstand the range of mechanical loads imposed during loading, handling, emplacement and -term containment.

owing paragraphs discuss various design alternatives including the VA reference design selected valuation. Overall, the alternatives involve only four different metallic materials and a ceramic ıng material (unspecified at this time). Selection of carbon steel, Alloy 22 and Ti Gr. 16 are d on the prior evaluation of candidate materials documented in Ref.1, pp. 39-80. The more osion resistant (but costlier) Ti Gr. 7 was added to the list because both grades of titanium are :cted to meet the corrosion performance needs and its addition provides added flexibility at the of [illegible]al material selection. Type 316 stainless steel was added as a structural material because of its better corrosion performance when compared to carbon steel. However, other stainless steels may be equally acceptable and a final selection of the structural material will evaluate other potential candidate materials. The four specific metallic materials selected for evaluation in this study are:

-Carbon steel (Unified Numbering System for Metals and Alloys (UNS) K01800 or K02700), also referred to as CAM in this document.
-316 Stainless steel (UNS S31603, 316 NG (nuclear grade) with <0.02% C and 0.06-0.10% N), also referred to as structural material or 316 SS.
-Alloy 22 (nickel base) (UNS N06022), also referred to as CRM or Alloy 22.
-Titanium Grade 7 or 16 (UNS R52400 or R52402), also referred to as Ti Gr. 7/16, or simply as Ti or titanium.

In light of the fact that a limited number of materials are used in a significant number of combinations, a single letter designation is assigned to each of the metallic materials so that the sequential arrangement of the materials is easily conveyed. Carbon steel is designated by letter C, 316 stainless steel by S, Alloy 22 (nickel base) by N, and titanium by T. By this method, for example, the VA design would be identified as CN, and the design containing Alloy 22 (outer), 316 stainless steel (middle), and titanium (inner) would be identified as NST. Table 1 shows the details on various alternatives, estimated wall thicknesses assumed, and relative costs. The relative costs are preliminary and are provided here only for rough comparison. Also shown in the table are the significant open issues associated with each option that will have to be evaluated in relation to the criteria.

2.4. Results of Evaluation of Alternatives

Tables 2 shows a summary of the alternatives evaluated and the open issues associated with each. In order to select the most desirable (lowest risk), high performance option, alternatives discussed in Table 1 were qualitatively evaluated against the criteria and the results of this qualitative evaluation are also shown in Table 2. Since all of the alternatives represented increased cost relative to the VA reference design, cost impact was used as secondary criterion. Highlights of the evaluation are summarized below.

Corrosion performance:

The primary positive attribute of the proposed design options with two CRMs and those without the carbon steel CAM is believed to be superior corrosion performance. Replacing carbon steel with 316 SS results in a change in corrosion mechanism emphasis from general to localized corrosion and for the expected environmental conditions, a significant lowering of the corrosion rate as well. This change also eliminates oxide wedging as a major issue.

From a corrosion performance standpoint, the use of a CRM as the outer layer will significantly lower the risk of waste package failure (alternatives 3 (NST) and 4 (TSN) and reverse VA design (NC)). The CRM (either Alloy 22 or Ti) is expected to corrode primarily by general corrosion at very low rates, 0.08 μm or less per year (Ref. 8, Table 2.2-8). Use of two layers of CRM on the outside (alternatives 5 (NTS) and 6 (TNS)) will extend the waste package life further. However, there are potential concerns associated with Alloy 22 aging (embrittlement) and susceptibility to stress corrosion cracking as well as thermal expansion differences. In the case of Ti Gr. 7/16 there is a potential for stress corrosion cracking and for hydrogen pick-up when it is in contact with less noble material such as 316 stainless steel (Ref. 1 p. 62). Further materials testing and predictive modeling is needed to confirm this. However, under the expected repository environment and imposed temperature limits these degradation processes are not likely.

Defense in depth:

Defense in depth is defined as having two different materials with each degrading and potentially failing by a different mechanism. In this sense, the single CRM design (N) will not provide defense in depth. In addition, the reverse VA design (NC) will also be less desirable because once the outer CRM barrier is penetrated, the inner CAM will degrade very rapidly and not provide any significant protection.

Ability to withstand potential rockfalls:

From the discussion above, it appears that either the use of a thick CRM (e.g., Alloy 22) on the outside or protection of at least one layer of CRM by a structural material such as 316 SS (in the absence of backfill) is necessary to avoid potential damage from rockfall. Acceptable design options from the rockfall standpoint include VA reference design (CN), (at least until the outer CAM significantly degrades), options with longer life structural material on the outside (STN and SNT), and sandwich designs with the structural material in the middle (NST and TSN).

Ease of fabrication:

Compared to the VA reference design, all of the design options except one introduce complications in the fabrication process. The single CRM barrier design (N) represents a simpler design, which may be easier to fabricate. However, as mentioned earlier, this option is not deemed acceptable, as it does not provide defense in depth.

The degree of complication with respect to fabrication depends on the number of layers, the materials used, and the arrangement of the barriers. For example, welding of Ti requires greater care compared to Alloy 22 in keeping the weld area purged of air and free of contamination from prior welding operations on other materials (Ref. 1, p. 76). With regard to contamination, it is better to use Ti as the inner barrier where it will be welded first. Differences in thermal expansion characteristics between 316 stainless steel and Alloy 22 and Ti also favors this arrangement because it important to have the materials with larger thermal expansion coefficients as outer layers to avoid thermal tensile stresses.

Impact on lifting/handling and emplacement equipment:

Current designs of the lifting/handling and emplacement equipment are compatible with the VA reference waste package design and other designs with the structural material on the outside. Use of a thin CRM layer on the outside may require significant modification of the equipment to avoid handling damage to the barrier during fabrication, loading, and emplacement.

Cost:

In relation to the VA reference design, all of the design options evaluated are expected to be higher in cost. Table 1 shows the estimated cost of each option in relation to the VA reference design. These figures are preliminary and are provided only for comparison purposes. The most expensive options are the single CRM-only design and the two CRM designs without the structural material with a cost factor of about 1.5 (ratio of cost of alternative to VA design cost). The two CRM options with the structural material have cost factors of about 1.2. It is expected that there may be small variations among them depending on the sequence of barrier arrangement. For the purpose of this analysis, these differences are expected to be very small and all of the two CRM+structural component options can be assumed to have the same cost factor of 1.2.

Based on the qualitative assessment presented above, it is concluded that a CRM layer on the outside is required to meet the desired waste package lifetime goals (see Section 1.2). This conclusion then leads to the selection of options with two CRMs because a single CRM on the outside does not meet the defense in depth requirement. Of the CRM outer layer design options considered, the design options without the structural material appear to be more desirable because of their simpler design and the excellent corrosion performance. Of the two options considered without the structural material (Alternatives 7 and 8 (NT and TN)) the use of Alloy 22 as the outer barrier (Alternative 7 (NT)) is preferred because of the negative attribute (thermal expansion mismatch) associated with the Alternative 8 (TN). Based on these qualitative analyses, it is recommended that the lowest risk design option consisting of two CRMs with Alloy 22 on the outside and Ti (Gr. 7 or 16) on the inside be selected as the most desirable option. This option has the following advantages:

-Alloy 22 has excellent resistance to corrosion by repository environment and metal crevice induced localized corrosion of the material is eliminated
-Ti as the inner barrier is highly resistant to crevice corrosion
  -oxide wedging problem is eliminated because carbon steel is eliminated
-use of Ti on the inside avoids thermal expansion problems
-this option is easier to fabricate than the other two CRM option (TN)

It is to be noted that this recommendation is based on currently available information. Additional test data and detailed analyses (structural, thermal, cost and fabrication process) are required for final selection. Results of the detailed structural and fabrication analyses performed on the above selection may show that the cost of the design is prohibitively high (significantly higher than the preliminary estimate). Under these circumstances, the M&O Management may decide to look for a back up design which meets performance requirements (low risk) but is less expensive. In order to support such a decision, using the same qualitative assessment, a two CRM sandwich design is recommended as back up option for further evaluation. Of the two sandwich design options considered, Alloy 22 is preferable as the outer barrier because of its better thermal expansion coefficient match to 316 SS compared to Ti (16.5×10^{-6} for 316 SS vs 8.2×10^{-6} for Ti vs 12.4×10^{-6} for Alloy 22, all in K^{-1}) (Ref. 10, data sheet for stainless steels; Ref. 11, Table TE-5; and Ref. 12, p. 13). This option provides for a long lived waste package at a relatively lower cost. Alternatives 5 (NTS) and 6 (TNS) are not as desirable because of the thermal expansion mismatch.

In addition to the above, a second back up option containing a different class of material i.e., a ceramic coated design is selected. While the ceramic coating can be used with any of the design options, it is not needed with the two CRM options. Therefore, the design option where most impact is expected (Alternative 11 with 316 SS and Alloy 22) is selected for the second back up option. Ceramic coating on the single CRM design with Alloy 22 was not considered because of the high cost factor. Substitution of 316 SS for carbon steel will minimize problems associated with the spalling of coating due to corrosion product build up on the substrate.

A third backup option namely the reverse VA design (NC) is also recommended for further evaluation. It is recognized that this option does not provide defense in depth. However, if such defense in depth were to be provided by other design features such as a "drip shield" which would protect the waste package from contact with water for extended period of time, this option would become an economical alternative.

3.0 Description of Selected CRM Waste Package Design

An engineering sketch of the selected CRM waste package design (prime alternate) is shown in figure 1. This sketch shows Alloy22 as the outer barrier and Ti Grade 7 as the inner barrier. The thickness of the outer barrier is 40 mm and that of the inner barrier is 15 mm. As in the case of the VA design the lids are thicker than the body of the waste package.

Conceptual drawings of the other back up options selected are shown in figures 2, 3, and 4.

4.0 Supporting Analyses and Total System Performance Assessment (TSPA)

Engineering analyses were carried out on the prime alternate CRM design to evaluate potential design problems that may make the selection unacceptable. These analyses included structural, thermal and shielding calculations. In addition, qualitative evaluations to determine potential impacts on surface facilities and subsurface facilities operations were conducted. Finally, the post-closure performance was evaluated using the TSPA analysis. Results of these are summarized below:

Structural Analysis: Preliminary structural analysis on the design option with 40 mm of Alloy 22 and 15 mm of Ti grade 7 was completed for abnormal events associated with lifting, handling and emplacement operations. Results of this analysis showed that the material thicknesses assumed will be adequate to withstand loads associated with the abnormal events without failure of the waste package. (Ref. 6)

Thermal Analysis: The thermal response internal to the waste package is important when considering a change in the barrier materials. A key thermal goal for the waste package design is a 350 °C temperature limit for the spent fuel cladding. For the four waste package alternatives studied, peak internal temperatures will vary from 346.6 °C to 344.8°C (Ref. 9.). These results suggest that minor changes in barrier thicknesses and effective thermal conductivities have an insignificant contribution to the effective thermal resistance of the inner, middle, and outer barrier materials. In essence, changes to waste package heat dissipation are minimal as shown below.

Peak Internal Temperatures for Waste Package Alternatives

Waste Package Alternatives	Outer Material	Middle Material	Inner Material	Peak Internal Temperature
VA	A516 Carbon Steel		Alloy 22	345.0 °C
Reverse VA	Alloy 22		A516 Carbon Steel	344.8 °C
Sandwich	Alloy 22	SS 316	Ti Grade 7	346.6 °C
Two CRMs only	Alloy 22		Ti Grade 7	344.9 °C

Shielding Analysis: Shielding analyses on the two-CRM design option and the reference VA design were performed to determine the difference in the waste package surface dose rates. The surface dose rates are important for evaluating potential impacts on the surface facilities and subsurface facilities operations. Results of the analyses show that for a 21 PWR waste package containing 5-year cooled fuel, the surface dose rates on the two-CRM and VA design packages are about 7000 and 320 rem/h respectively. These dose rates fall to about 240 and 8 after 100 years (Ref. 13 table 6-3).

Surface and Subsurface Operations: Qualitative evaluation of the impact of the prime two-CRM design option on the surface and subsurface facilities operation was carried out and it was concluded that the selection of this design option has no impact on these operations. It is believed that the decreased waste package weight, reduced material thicknesses may lower the weld times slightly but this was not expected to impact the operations. Increased surface dose rates are also not considered important because of the conservatism in the hot cell and transporter shielding.

TSPA Results: TSPA was carried out on this design feature for the Alloy 22/Ti option . The dose rate for this option is at least two orders of magnitude below the base case for the period between 8,000 and 40,000 years. The dose rate also remains two to four orders of magnitude for the first 400,000 years. The peak dose rate during the first 10,000 years (due to juvenile failures) is calculated to be 0.01389 mrem/yr and this occurs at 5600 years after emplacement. The peak dose rate between 10,000 and 1,000,000 years is 77.955 mrem/yr and this occurs at 717,000 years (Ref. 14, p.14). Overall, the performance of the CRM design option is several orders of magnitude better than the VA design.

TSPA analysis for the backup options have not yet been carried out. It is planned to complete the analysis on the reverse VA design option in the next several weeks. For the next phase, the ceramic coated option will be included and the results of this will be reported in the report for the Design

Feature # 1.

5.0 Conclusions and Recommendation

The classification analysis for the MGR repository (which includes the waste package) carries TBV-228 because of the preliminary status of the basis for the MGR design. Further evolution of the MGR design is required before TBV-228 may be removed from the classification analysis. This technical document conservatively assumes that the resolution of TBV-228 will find the waste package to be quality affecting. With this approach, this document is appropriate regardless of whether the waste package is quality affecting or not. Consequently, outputs of this document do not carry TBV-228.

During the past year, performance of the waste package containment barrier materials has been given greater emphasis in the overall repository performance and it is anticipated that lifetime requirements will increase. In response to this and in response to the requirement for an evaluation of alternative design features, alternative materials and design options were evaluated qualitatively. A number of Design configurations involving highly corrosion resistant materials were evaluated along with the reference VA design. As a result of this evaluation, a prime alternate and three back-up options were selected and are listed below:

Prime alternate – Two CRM design with alloy 22 as the outer barrier and Ti Grade 7/16 as the inner barrier.

Back-up options:
- Sandwich design with Alloy 22 over stainless steel over Ti Grade 7/16.
- Ceramic coating over stainless steel over Alloy 22
- Reverse VA design with Alloy 22 over A 516 carbon steel.

As mentioned earlier the selection process included qualitative evaluation and engineering judgement due to a lack of more specific data on materials performance and model. It is recommended that additional test data be obtained and detailed analyses (thermal, structural and fabrication) be performed prior to finalizing the materials selection for SR.

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*TIC numbers for these references are being obtained and will be added as soon as they are available.

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Table 1 Waste package materials/configuration options

Waste Package Alternatives	*Outer Material (mm)*	*Middle Material (mm)*	*Inner Material (mm)*	*Rel. Cost*	*Significant Open Issues*	*Other Issues Needing Resolution*
VA (CN)*	Carbon steel (100)		Alloy 22 (20)	1	Oxide Wedging,	Alloy 22 aging. May need backfill to avoid CRM rock drop penetration, Stress Corrosion Cracking (SCC)
Reverse VA (NC)	Alloy 22 (20)		C. Steel (100)	~1.15	Oxide Wedging,	VA + different handling req'd
1-Two Inner CRMs (STN)	316NG(55)	Ti Gr. 7/16 (10)	Alloy 22 (20)	~1.2	Ti Hydriding	VA + 316NG^ "life" > 300 Years?
2 - Two Inner CRMs (SNT)	316NG(55)	Alloy 22 (20)	Ti Gr. 7/16 (10)	~1.2	Potentially none	Option 1 + concern for ID hydriding
3 - "Sandwich" (NST)	Alloy 22 (20)	316NG(55)	Ti Gr. 7/16 (10)	~1.2	Potentially none	VA + different handling req'd
4 - "Sandwich" (TSN)	Ti Gr. 7/16 (10)	316NG(55)	Alloy 22 (20)	~1.2	Potentially none	VA + different handling req'd
5 - Two Outer CRMs+ Struct. Material (NTS)	Ti Gr. 7/16 (10)	Alloy 22 (20)	316NG(55)	~1.2	Potentially none	VA + different handling req'd
6 - Two Outer CRMs + Struct. Material (TNS)	Alloy 22 (20)	Ti Gr. 7/16 (10)	316NG^(55)	~1.2	Potentially none	VA + different handling req'd
7 - Two CRMs only (NT)	Alloy 22 (40)	Ti Gr. 7/16 (10)		~1.5	potentially none	VA
8 - Two CRMs only (TN)	Ti Gr. 7/16 (40)	Alloy 22 (20)		~1.5	potentially none	VA +different handling req'd
9 – Large Gap (C-N)	Carbon Steel (100)	Wide Gap	Alloy 22 (20)	~1.1	Potentially none	VA
10 - CRM only (N)	Alloy –22 (55)			1.54	None	VA + no "defense in depth"
Ceramic Coated** Ceramic + Struct + CRM	Ceramic	316 NG	Alloy -22	1.15	Potentially none	VA + ceramic lifetime

* Material Codes (also see 2.3): C = carbon steel, N = Alloy 22, S = 316 NG stainless steel (316NG equivalent to Type 316 Stainless Steel with <0.02% C, 0.06-0.10% N). 316NG/Carbon steel are used as structurals materials and others are used as CRM barriers.
T = Titanium Grades 7 or 16.
** Viable for all alternatives

Table 2 Waste package materials/configuration ranking

Waste Package Alternatives	Outer Material (mm)	Middle Material (mm)	Inner Material (mm)	Rel. Cost	Corrosion Performance	Defense In Depth	Fabrication Ease	Handling Issues	Cost Impact	Estimated PA Lifetime	Potential Basis for Rejection
VA (CN)*	Carbon steel (100)		Alloy 22 (20)	1	o	o	o	o	o	o	Oxide Wedging (OW), Lifetime
Reverse VA (NC)	Alloy 22 (20)		C. Steel (100)	~1?	++	-	O?	-	o	++	Defense in depth
1-Two Inner CRMs (STN)	316NG(55)	Ti Gr. 7/16 (10)	Alloy 22 (20)	~1.2	++	+	--	o	-	++	316NG Pitting, SCC
2 - Two Inner CRMs (SNT)	316NG(55)	Alloy 22 (20)	Ti Gr. 7/16 (10)	~1.2	++	+	--	o	-	++	316NG Pitting, SCC
3 - "Sandwich" (NST)	Alloy 22 (20)	316NG(55)	Ti Gr. 7/16 (10)	~1.2	++	+	--	-	-	++	
4 - "Sandwich" (TSN)	Ti Gr. 7/16 (10)	316NG(55)	Alloy 22 (20)	~1.2	++	+	--	-	-	++	Therm Exp., Handling
5 - Two Outer CRMs+ Struct. Material (NTS)	Ti Gr. 7/16 (10)	Alloy 22 (20)	316NG(55)	~1.2	++	+	--	-	-	++	Therm Exp., Handling
6 - Two Outer CRMs + Struct. Material (TNS)	Alloy 22 (20)	Ti Gr. 7/16 (10)	316NG^(55)	~1.2	++	+	--	-	-	++	Therm Exp.
7 - Two CRMs only (NT)	Alloy 22 (40)	Ti Gr. 7/16 (15)		~1.5	++	+	-	o	--	++	
8 - Two CRMs only (TN)	Ti Gr. 7/16 (40)	Alloy 22 (20)		~1.5	++	+	-	-	--	++	Therm Exp.
9 – Large Gap (C-N)	Carbon Steel (100)	Wide Gap	Alloy 22 (20)	~1.1	+	+	o?	o	-	+?	Fuel Temp. OW
10 - CRM only (N)	Alloy –22 (55)			1.54	++	-	+	o	--	++	Defense in depth, Cost
Ceramic Coated** Ceramic + Struct + CRM	Ceramic	316NG (55)	Alloy –22 (20)	1.15	+?	+?	-	-	-	++	Cer. Performance/application

* Material Codes (also see Section 2.3): C = carbon steel, N = Alloy 22, S = 316NG stainless steel (316NG equivalent to Type 316 Stainless Steel with <0.02% C, 0.06-0.10% N). 316NG/Carbon steel are used as structurals materials and others are used as CRM barriers. T = Titanium Grades 7 or 16.
** Viable for all alternatives
o = equivalent to VA, + = somewhat better than VA, ++ = Significantly better than VA, - = Somewhat worse than VA, -- = Significantly worse than VA.

[Figure 1. Engineering sketch]

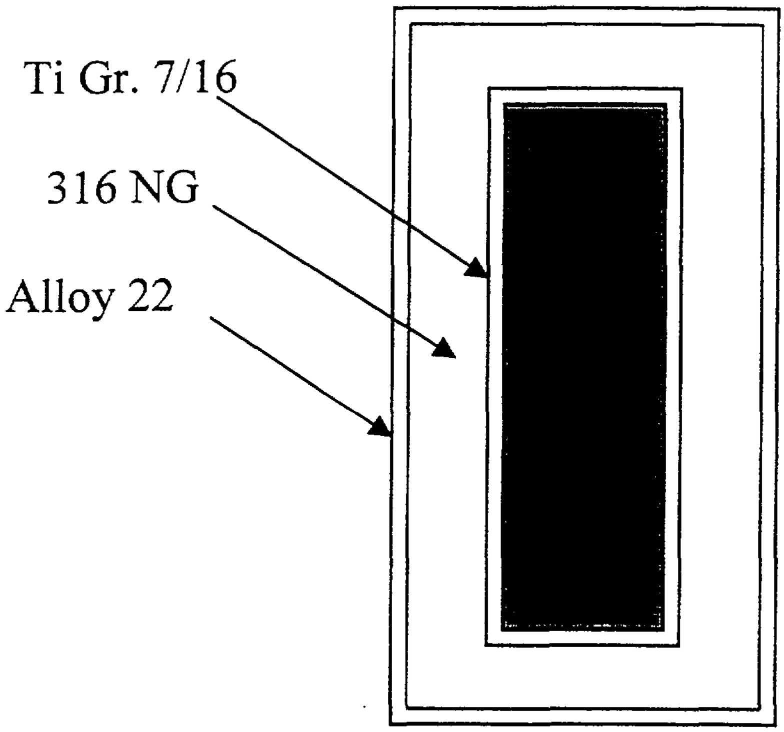


Figure 2. Two CRM design with the structural material in the center- Sandwich design – Alternative 3

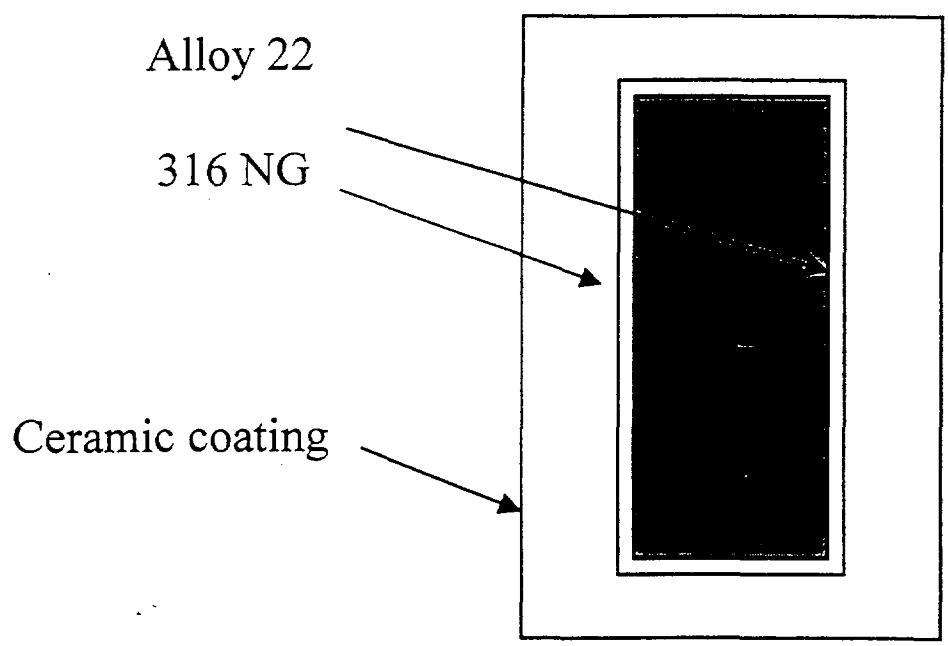


Figure 3. Ceramic coating on a structural material design – Alternative 11

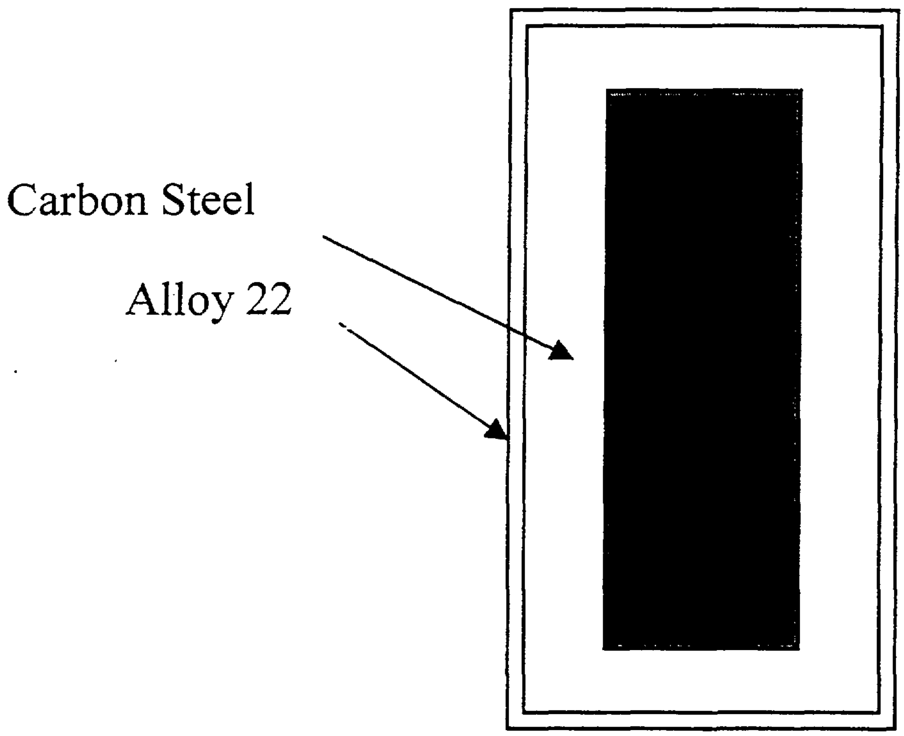


Figure 4. Reverse VA design with the CRM on the outside

Appendix

Design Feature Evaluation Criteria

Design Feature # 14
Waste Package Corrosion Resistant Materials (Metal and Ceramic)

Design Feature Evaluation Criteria

1. Post-Closure Performance

What is the peak dose rate to an average individual of a critical group at a distance of 20 km from the repository site and the time of the peak, considering two time periods: a) 10,000 years and b) between 10,00 years and 1,000,000 years?

Answers:

a) 0.0139 mrem/yr at 5600 years
b) 77.96 mrem/yr at 717,000 years

FOM = 3.33

2. Pre-Closure Performance

What is your assessment of the pre-closure performance of your DF or DA on a 1--5 scale? Please provide a 1--5 assessment of each question using this scale and a brief (one-to-two sentence) written basis for the evaluation. The overall evaluation should be the simple average of the assessments for each question.

- Would your DF or DA increase or decrease the probability of a Design Basis Event (DBE)?

No impact. Rating 3

- Would your DF or DA add a DBE? Is this DBE bounded by other DBEs?

No different from the VA design. Rating 3

- Would your DF or DA increase or decrease the consequences of a DBE?

No different from VA design. Rating 3.

- Does your DF or DA increase or decrease challenges to the repository safety systems?

No different from VA design. Rating 3.

- What expected dose to the public at the pre-closure area boundary is calculated?

No calculation. Conducted. However, this case is no different from the VA design. Rating 3.

Overall rating 3.

3. Assurance of Safety

What is your assessment of the assurance of safety of your DF or DA on a 1--5 scale. Please provide a 1--5 assessment of each question using this scale and a brief (one-to-two sentence) written basis for the evaluation. The overall evaluation should be the simple average of the assessments for each question

- Does your DF or DA have uncertainties in post-closure performance.

This design feature will improve post closure performance significantly. Therefore, the uncertainties have much less impact. Rating 4.

- What is the potential to reduce the uncertainties by the time of construction and of closure?

Significant. Additional performance confirmation data will be available and the uncertainties will be reduced. Rating 4.

- How sensitive is your DF or DA to disruptive events? (volcanism, earthquakes, or criticality)

No more sensitive than the VA design. Rating 3.

Overall score 3.7

4. Engineering Acceptance

What is the potential for acceptance of the engineering design of your DA or DF in a regulatory environment? Please provide a 1--5 assessment of each question using this scale and a brief (one-to-two sentence) written basis for the evaluation. The overall evaluation should be the simple average of the assessments for each question.

- Can the function of each element in the design be clearly communicated?

Same as for the VA design. Rating 3.

- Which of the four attributes of the repository safety strategy does it support (limit water contacting waste packages, limit water contacting waste, limit mobilization and transport of radionuclides within the EBS, dilute radionuclide concentrations)

Limit water contacting waste. Same as the VA design. Rating 3.

- If applicable , what is the effective lifetime of the feature or major component of the alternative in supporting the particular element of the repository safety strategy?

Resistance to corrosion by dripping water significantly improves waste package lifetime and therefore limits water contacting the waste for 50,000 years or more. Rating 4.

- Does the engineering analysis follow accepted methods?

Same as the VA design. Rating 3.

- Is the post-closure function simple to demonstrate?

Same as the VA design. Rating 3.

- Is there regulatory and/or engineering precedence for your design?

Same as the VA design. Rating 3.

- What is the availability of qualified data to support your design likely to be in the LA time-frame?

Will be available as in the case of VA design. Rating 3.

- Is the design constructable with proven methods?

Yes. Same as the VA design. Rating 3.

- Are any requirements for the MGR violated by the use of this design?

No. Rating 3.

Overall rating 3.1.

5. Construction, Operations, and Maintenance

Are there any particular difficulties or advantages that your DF or DA has relative to the VA reference design for the following construction, operations, and maintenance characteristics:

- Would your DA or DF increase or decrease worker radiation safety and/or industrial safety?

Increase in waste package surface does rate is expected. The operations, however, are designed to account for this. So no change is expected. Rating 3.

- Would this DA or DF increase or decrease reliability, availability, maintainability, and inspectability of manufactured and constructed items?

Same as the VA design. Rating 3.

- Would this DA or DF increase or decrease throughput capability?

Same as the VA design. Rating 3.

- Would this DA or DF improve or decrease the ability to perform performance confirmation activities?

Same as for the VA design. Rating 3.

Overall rating 3.

6. Schedule

For your DF or DA, how does the L.A. schedule compare to that for the VA reference design.

No change from the VA schedule.

7. Cost

What is the difference in estimated total cost relative to the VA Reference Design?

Cost of the design feature is expected to be about 1.6 times that of the VA design.
Rating 2.

8. Environmental Considerations

What are the environmental impacts associated with your DF or DA relative to the VA Reference Design?
This feature considers waste package containers with two corrosion resistant materials, inner layer of titanium and outer layer of nickel-base Alloy 22, with a combined thickness of about 55 mm.

The current waste package design selected for the Viability Assessment (VA) utilizes two concentric barrier layers, an outer predictable but less corrosion resistant 100 mm thick A516 carbon steel structural Corrosion-Allowance Material (CAM) and an inner 20 mm thick nickel-base Alloy 22 Corrosion-Resistant Material (CRM). It was expected that these two barriers would provide for substantially complete containment of the waste for the a lifetime goals established at that time. TSPA-VA calculations show that the predicted lifetimes are acceptable from the regulatory standpoint, initial waste package failures will occur in less than 3,000 years. During the past year, however, performance of the waste package containment barrier materials has been given greater emphasis in the overall repository performance. It is anticipated that lifetime requirements will increase. Therefore, it is highly desirable to design a robust waste package with the capability to provide substantially complete containment for a significantly extended lifetime.

A possible variation of the VA waste package design is to replace the corrosion allowance barrier with a second corrosion resistant barrier. This design could provide defense in depth if the second corrosion resistant barrier is independent of the first (e.g., made of a different metal or ceramic). This approach, if employed, could be highly important to post-closure performance.

1. Impacts to land use and ownership

Land use – No changes relative to the VA reference design.

2. Impacts to air quality

Nonradiological impacts - No changes relative to the VA reference design.

Non-radiological - No changes relative to the VA reference design

3. Impacts to hydrology, including surface water and groundwater

No changes to hydrology relative to the VA reference design. Feature is expected to prolong waste package lifetimes and so ground water contamination will be minimized and delayed.

4. Impacts to biological resources and soils

No changes relative to the VA reference design

5. Impacts to cultural resources

No changes relative to the VA reference design

6. Socioeconomic impacts

No changes relative to the VA reference design

7. Impacts to occupational and public health and safety

Potential changes in radiological dose to workers.
With dual CRM feature total thickness of the waste package container would likely be only 55 mm, while the VA reference design included 100 mm of carbon steel and 20 mm of nickel-base Alloy 22. This will likely result in higher dose rates at the waste package surface. Appropriate shielding may have to be provided for the workers engaged in waste package handling and emplacement operations.
This design feature will have potential impact on the occupational dose to the workers because the calculated dose rates at the waste package surface are higher. It is estimated that

the total dose rates at the waste package surface using the design feature #14 at the time of emplacement will be 6,970 rem/h compared to that for the VA design of 323 rem/h.

8. Noise impacts

No changes relative to the VA reference design

9. Impacts on aesthetics

No changes relative to the VA reference design

10. Impacts to utilities, energy, materials, and site services

No changes in usage of water, fossil fuel, and demand for power. Industrial suppliers of titanium and Alloy 22 indicated that these materials will be readily available.

11. Impacts to management of repository generated waste and the use of hazardous materials

No changes relative to the VA reference design

12. Impacts to environmental justice

No changes relative to the VA reference design

13. Summary of primary impacts on 3 thermal loads (high, medium, low)

This feature can be used with any thermal loading.

14. Summary of primary impacts on packaging options for transportation:

No changes relative to the VA reference design

15. Summary of primary short term impacts (including operations, retrieval, and closure)

No changes relative to the VA reference design

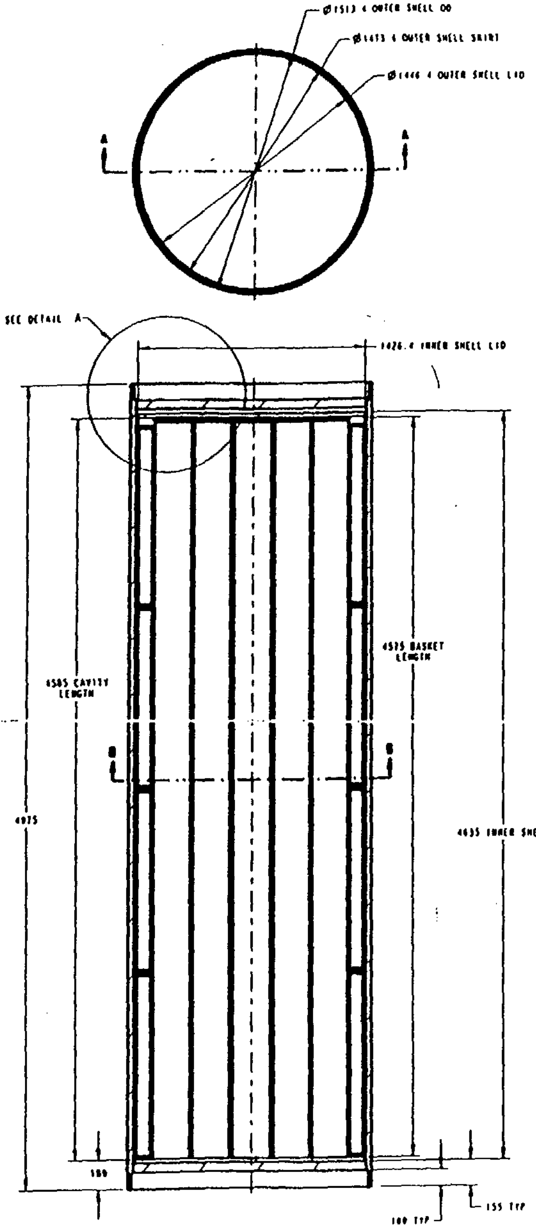
16. Summary of primary long term impacts (after closure)

Enhancement of long term performance by retardation of corrosion of the waste package. Overall rating 3.

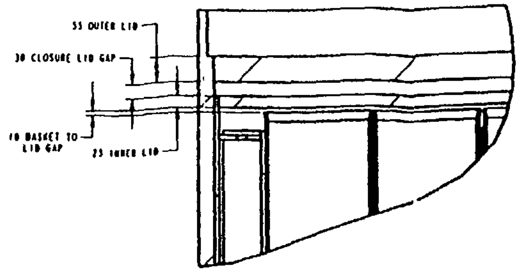
REFERENCES

B00000000-01717-4600-00140 REV 00, Technical Document Preparation Plan For The License Application Design Selection Feature Report: Waste Package Corrosion Resistant Materials (Metal and Ceramic)

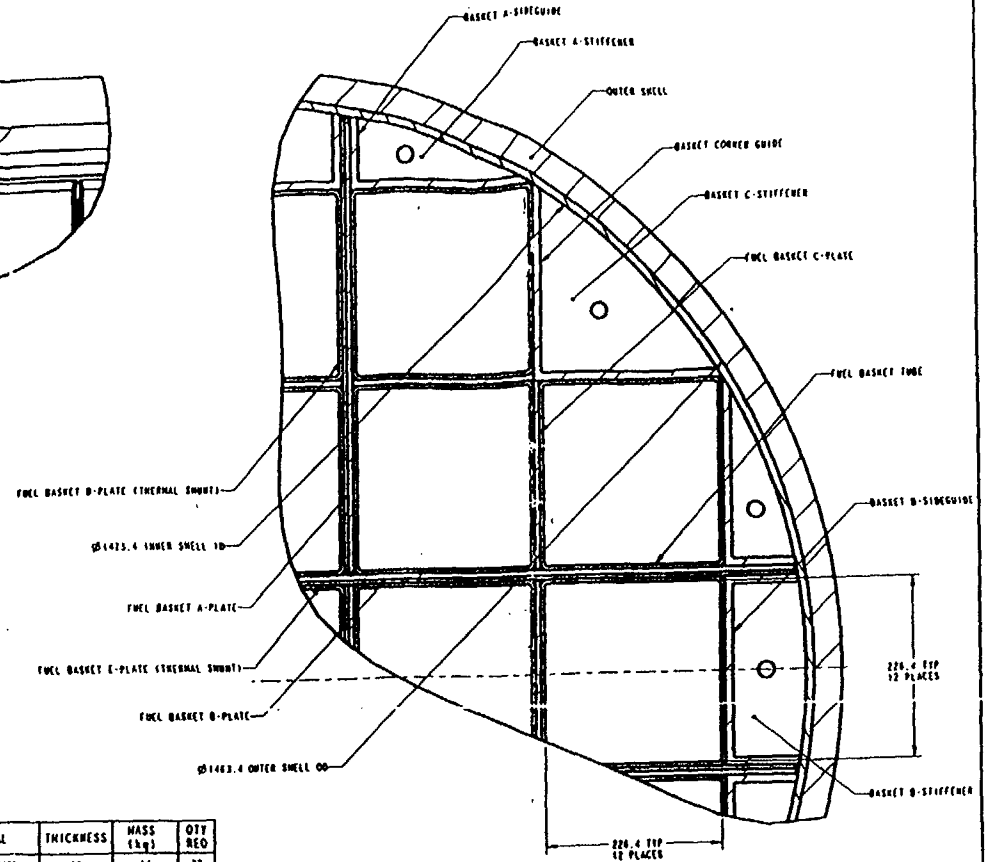
- 00216 Rev



SECTION A-A



DETAIL A



SECTION B-B

COMPONENT NAME	MATERIAL	THICKNESS	MASS (kg)	QTY REQ
BASKET A-SIDEGUIDE	SB-265 R52400	10	14	32
BASKET A-STIFFENER	SB-265 R52400	10	41	44
BASKET B-SIDEGUIDE	SB-265 R52400	10	20	16
BASKET B-STIFFENER	SB-265 R52400	10	85	32
BASKET C-STIFFENER	SB-265 R52400	10	1	32
BASKET CORNER GUIDE	SB-265 R52400	10	24	16
FUEL BASKET A-PLATE	SA-516 K02700	7	86	8
FUEL BASKET B-PLATE	SA-516 K02700	7	86	8
FUEL BASKET C-PLATE	SA-516 K02700	7	45	16
FUEL BASKET D-PLATE	SB-209 A96061 T4	5	21	8
FUEL BASKET E-PLATE	SB-209 A96061 T4	5	21	8
FUEL BASKET TUBE	SA-516 K02700	5	164	21
INNER SHELL	SB-265 R52400	15	940	1
INNER SHELL LID	SB-265 R52400	25	180	2
OUTER SHELL	SB-575 N06022	40	7486	1
OUTER SHELL LID	SB-575 N06022	55	785	2

DO NOT SCALE FROM SKETCH

UNITS: mm

"FOR INFORMATION ONLY"

21-PWR ABSORBER PLATES DUAL CORROSION RESISTANT MATERIAL UCF WASTE PACKAGE ASSEMBLY

SKETCH NUMBER: SK-0116.Rev01

SKETCHED BY: GENE CONNELL BPC 11/19/98 SMB 11/19/98 DL for TWD 11/19/98

DATE: 11/18/98

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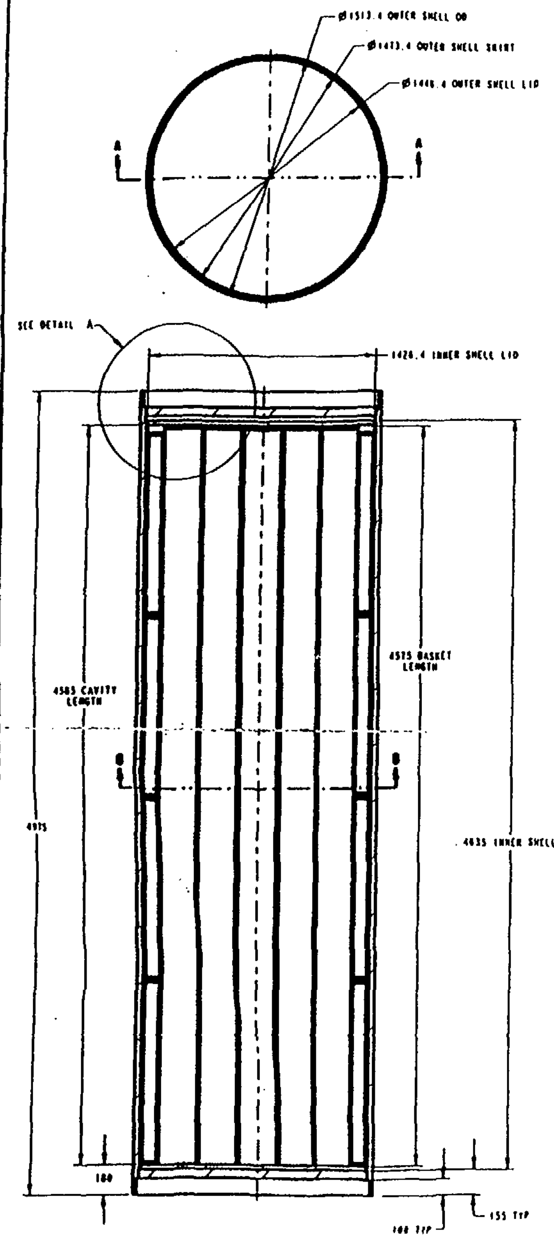

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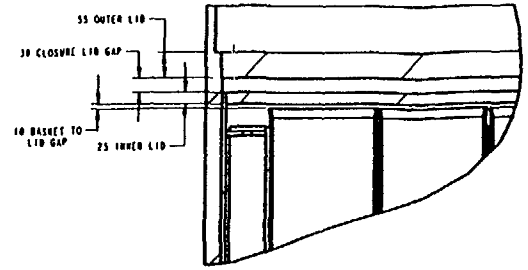
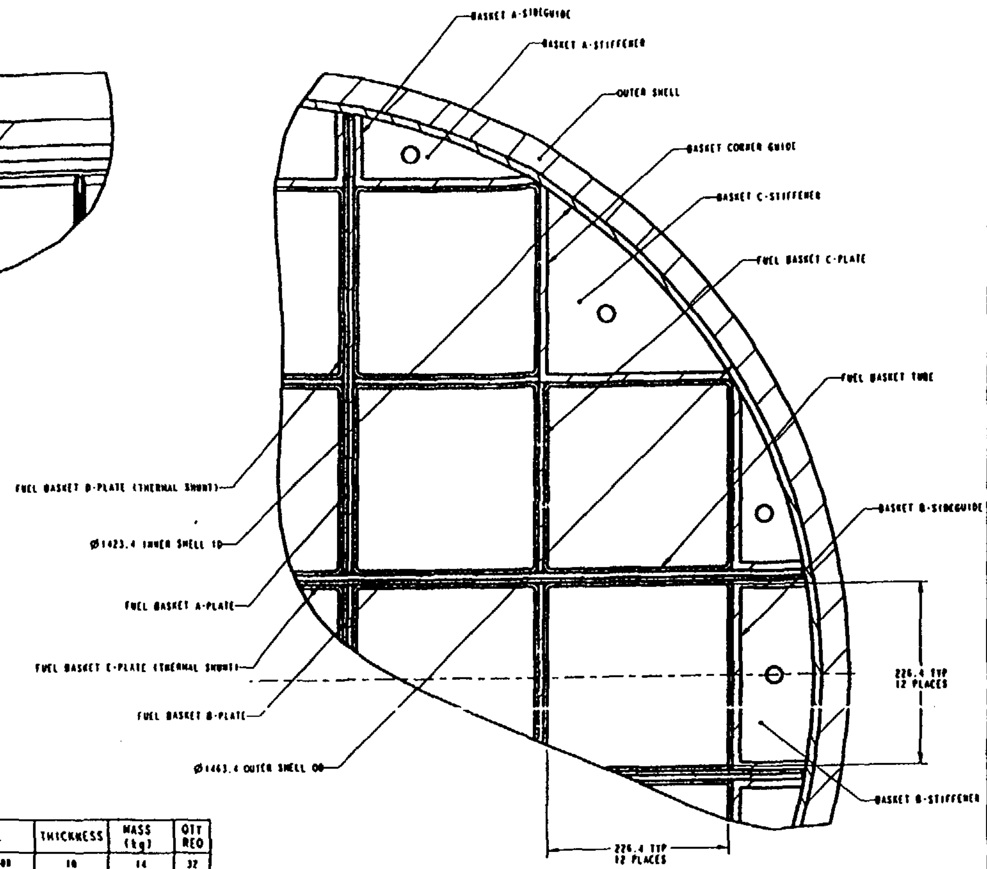


DETAIL A



SECTION B-B

COMPONENT NAME	MATERIAL	THICKNESS	MASS (kg)	QTY REQ
BASKET A-SIDEGUIDE	SB-265 R52400	10	14	32
BASKET A-STIFFENER	SB-265 R52400	10	41	64
BASKET B-SIDEGUIDE	SB-265 R52400	10	20	16
BASKET B-STIFFENER	SB-265 R52400	10	85	32
BASKET C-STIFFENER	SB-265 R52400	10	1	32
BASKET CORNER GUIDE	SB-265 R52400	10	24	16
FUEL BASKET A-PLATE	SA-516 K02700	7	86	8
FUEL BASKET B-PLATE	SA-516 K02700	7	86	8
FUEL BASKET C-PLATE	SA-516 K02700	7	45	16
FUEL BASKET D-PLATE	SB-209 A96061 T4	5	21	8
FUEL BASKET E-PLATE	SB-209 A96061 T4	5	21	8
FUEL BASKET TUBE	SA-516 K02700	5	164	21
INNER SHELL	SB-265 R52400	15	940	1
INNER SHELL LID	SB-265 R52400	25	180	2
OUTER SHELL	SB-575 N06022	40	1406	1
OUTER SHELL LID	SB-575 N06022	55	785	2

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