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Evaluation of Copper For Divider Subassembly in MCO Mark 1A and Mark IV Scrap Fuel Baskets

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Abstract:

This document evaluates the effects of using a copper divider subassembly in the Spent Nuclear Fuel MCO Mark 1A and Mark IV scrap fuel baskets. The corrosion, structural, and cost effects are examined.

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EVALUATION OF COPPER FOR DIVIDER SUBASSEMBLY IN MCO MARK 1A AND MARK IV SCRAP FUEL BASKETS

ABSTRACT

The K Basin Spent Nuclear Fuel (SNF) Project Multi-Canister Overpack (MCO) subproject includes the design and fabrication of a canister that will be used to confine, contain, and maintain fuel in a critically safe array to enable its removal from the K Basins. Each MCO consists of a shell, shield plug, fuel baskets (Mark 1A or Mark IV), and other incidental equipment. It was proposed to use copper to construct the divider subassembly in the Mark 1A and Mark IV scrap fuel baskets. The use of copper would increase the amount of heat conducted away from the fuel fines area, thus increasing safety margins during Cold Vacuum Drying (CVD).

Three copper alloys were considered for constructing the divider subassembly: C10200 (oxygen-free copper without residual deoxidants), C10800 (oxygen-free low phosphorus copper), and C12200 (phosphorized, high residual phosphorus copper). The room temperature mechanical properties of the coppers depend upon temper and can approximate those of 304L stainless steel at higher-hardness tempers. C10200 and C10800 have the highest electrical and thermal conductivity, while C12200 is about 15% lower. Elevated temperature yield strength of C12200 is only slightly lower than stainless steel, but the tensile strength is only about one-third that of the stainless steel. The C10200 and C10800 coppers have lower elevated temperature strength levels. The coppers are prone to stress relaxation, but the addition of minute amounts of silver significantly reduce the effects. Thermal expansion coefficients for the coppers are 5-10% larger than stainless steel. Corrosion resistance of the coppers in the MCO environments are acceptable and approximately equal among the alloys; none are prone to hydrogen embrittlement or stress corrosion cracking.

Cost quotes showed C12200 to be about 7% less than C10200. The C10800 copper is excluded because of its lack of availability. The use of C12200 copper is recommended over the C10200 copper as the Mark 1A and Mark IV scrap basket divider subassembly construction material.

**EVALUATION OF COPPER FOR DIVIDER SUBASSEMBLY IN
MCO MARK 1A AND MARK IV SCRAP FUEL BASKETS**

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EVALUATION OF COPPER FOR DIVIDER SUBASSEMBLY IN MCO MARK 1A AND MARK IV SCRAP FUEL BASKETS

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ABBREVIATIONS AND ACRONYMS

Ag	Silver
AISI	American Iron and Steel Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing & Materials
B&PV	Boiler and Pressure Vessel (Code)
CSB	Canister Storage Building
Cu	Copper
CVD	Cold Vacuum Drying
FRS	Fuel Retrieval System
HCS	Hot Conditioning System
HCSE	Hot Condition System Equipment
KE	K East Basin
ksi	kilopound/in ² = 1000 psi (lb/in ²)
KW	K West Basin
MCO	Multi-Canister Overpack
mil	0.001 in.
Ni	Nickel
O	Oxygen
OD	Outside diameter
P	Phosphorus
PCB	Polychlorinated biphenyl
SCC	Stress corrosion cracking
SNF	Spent Nuclear Fuel
SS	Stainless steel
UNS	Unified Numbering System

EVALUATION OF COPPER FOR DIVIDER SUBASSEMBLY IN MCO MARK 1A AND MARK IV SCRAP FUEL BASKETS

1.0 INTRODUCTION

The K Basin Spent Nuclear Fuel (SNF) Project Multi-Canister Overpack (MCO) subproject includes the design and fabrication of a canister that will be used to confine, contain, and maintain fuel in a critically safe array to enable its removal from the K Basins, vacuum drying, transport, staging, hot conditioning, and interim storage (Goldmann 1997). Each MCO consists of a shell, shield plug, fuel baskets (Mark 1A or Mark IV), and other incidental equipment.

The Mark 1A intact and scrap fuel baskets are a safety class item for criticality control and components necessary for criticality control will be constructed from 304L stainless steel. It is proposed that a copper divider subassembly be used in both Mark 1A and Mark IV scrap baskets to increase the safety basis margin during cold vacuum drying. The use of copper would increase the heat conducted away from the fuel fines areas in the baskets out to the wall of the MCO by both radiative and conductive heat transfer means. This copper subassembly will likely be a safety significant component of the scrap fuel baskets. This report examines the structural, cost and corrosion consequences associated with using a copper subassembly in the stainless steel MCO scrap fuel baskets.

2.0 SUMMARY

Three copper alloys (ASTM B152) were examined for use as alternatives to 304L stainless steel in constructing the Mark 1A and Mark IV scrap baskets divider subassembly:

- C10200, an oxygen-free copper without residual deoxidants;
- C10800, an oxygen-free low phosphorus copper; and
- C12200, a phosphorized, high residual phosphorus copper

The room temperature mechanical properties depend upon temper and can approximate those of 304L stainless steel at the higher-hardness tempers. C10200 and C10800 have the highest electrical and thermal conductivity while C12200 is about 15% lower. Elevated temperature yield strength of C12200 is only slightly lower than stainless steel, but the tensile strength is only about one-third that of the stainless steel. The C10200 and C10800 coppers have 5 to 15% lower elevated temperature strength levels. The coppers are prone to stress relaxation but the addition of minute amounts of silver significantly reduce the effects. Thermal expansion coefficients for the coppers are 5-10% larger than stainless steel.

Corrosion resistance of the coppers in the MCO environments are acceptable and approximately equal among the alloys; none are prone to hydrogen embrittlement or stress corrosion cracking.

Cost quotes showed C12200 to be about 7% less than C10200. C10800 is not readily available and would be more expensive as it is a special order alloy. Fabrication costs would be similar for both C10200 and C12200.

3.0 MCO SCRAP FUEL BASKETS DESCRIPTION

The MCO assembly is a single purpose SNF container that is capable of maintaining SNF subcritical at all times and maintaining SNF containment after having been closed and sealed (Goldmann 1996). The MCO is designed for a 40 year lifetime (extendable to 75 years) with a design pressure of 1.0 MPa (150 psig) and a maximum temperature of 375 °C (707 °F). The MCO assembly consists of three parts: shell, shield plug and Mark 1A or Mark IV fuel baskets (both intact and scrap). Both the shell and shield plug are constructed of 304L stainless steel. With the exception of the Mark IV fuel baskets, the MCO must be in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, Subsection NB (ASME 1995) with few exceptions. The copper divider subassembly has no ASME compliance requirements.

The scrap fuel baskets are annular open-top containers with a maximum outside diameter (OD) of 57.5 cm (22.625 in.). There are two types of baskets, intact fuel element and scrap fuel (fragment) element. The baskets are designed such that only one fuel type (Mark 1A or Mark IV) will be loaded into each MCO. The baskets are designed to be stackable (in any order) inside the MCO with the basket centerline coinciding with the MCO centerline. The Mark 1A fuel baskets are sized such that there are six baskets per MCO. The increased height of the Mark IV fuel baskets allows only five baskets per MCO.

Both Mark 1A and Mark IV scrap baskets are of a perforated cylindrical plate design attached to a center post. The perforations support gas flows needed to properly dry and condition the fuel during the vacuum drying and hot conditioning processes. The center post provides axial and lateral support for the baskets and also accommodates miscellaneous process tubing. The copper divider subassembly resembles a donut with an inner tube (fines divider tube) connected to an outer tube (shroud) by six equidistant divider plates. Stainless steel support rods along the inner diameter of the shroud provide stability and prevent basket collapse. The copper divider subassembly is attached to the 304L stainless steel basket base plate by a mechanical joint. Some construction changes may occur as the basket design is still in evolution.

The Mark 1A fuel baskets must maintain criticality control as the Mark 1A fuel has a higher U_{235} enrichment than the Mark IV fuel. Accordingly, the Mark 1A baskets have a larger center post (to provide the criticality control) which affects the inner diameter of the divider subassembly[†]. Table 1 lists the dimensions of the main pieces for both the Mark 1A and Mark IV baskets. The fines inner tube and the shroud are constructed from plate or sheet and silver brazed (see Section 9.0 for corrosion resistance of the braze filler material). For more details on the Mark 1A and Mark IV scrap fuel baskets see drawings H-2-828065 (DESH 1997A) and H-2-828075 (DESH 1997B), respectively.

The copper-to-copper joints in the divider subassembly will be furnace brazed using BCuP-5 filler material (15% Ag, 80% Cu, 5% P). BCuP-5 has a liquidus temperature of 800 °C (1472 °F) (Beal and Cook 1993). Brazing normally takes place at approximately 28 °C (50 °F) higher than the filler material liquidus temperature, in this case, about 828 °C (1522 °F).

[†] The copper subassembly is not needed to maintain criticality control.

Table 1: Dimensions of Main Scrap Basket Components (DESH 1997A and 1997B)

Part	Part Size	
	Mark 1A Scrap Basket	Mark IV Scrap Basket
Center Post*	15.24 cm (6 in.) ϕ pipe, 2.19 cm (0.864 in.) wall	6.98 cm (2.75 in.) ϕ pipe, 1.27 cm (0.5 in.) wall
Base Plate*	57.47 cm (22.625 in.) ϕ , 2.86 cm (1.125 in.) thick	57.47 cm (22.625 in.) ϕ , 3.18 cm (1.25 in.) thick
Support Rods*	7.75 cm x 3.43 cm [trapezoid] (3.053 in. x 1.351 in.)	3.21 cm (1.2625 in.) ϕ bar
Fines Divider Tube**	23.37 cm (9.2 in.) ϕ , 0.32 cm (0.125 in.) wall	19.94 cm (7.85 in.) ϕ , 0.32 cm (0.125 in.) wall
Outer Shroud**	57.47 cm (22.625 in.) ϕ , 0.32 cm (0.125 in.) wall	57.47 cm (22.625 in.) ϕ , 0.32 cm (0.125 in.) wall
Divider Plate**	16.38 cm x 54.23 cm (6.45 in. x 21.35 in.), 0.64 cm (0.25 in.) thick	18.44 cm x 66.68 cm (7.26 in. x 26.25 in.), 0.64 cm (0.25 in.) thick

* Constructed from 304L stainless steel

** Constructed from brazed copper sheet

4..0 MCO PROCESS BACKGROUND

The Integrated Process Strategy For Spent Nuclear Fuel Project Facilities recommended the following path forward for the removal of materials from the K basin:

- desludge and clean the SNF;
- repackage the cleaned SNF into fuel baskets;
- load the fuel baskets into MCOs;
- cold vacuum dry (CVD) the loaded MCOs at the CVD Facility;
- transport the loaded MCOs to the CSB;
- hot condition (additional drying, dehydrating and dehydrating) at a CSB annex facility; and
- transfer MCOs into storage tubes at the CSB for interim dry storage awaiting final disposition.

Fuel movement is currently scheduled to start July 30, 1999 and continue for two years. The total number of MCOs to be processed is approximately 200 from K East (KE) basin and 200 from K West (KW) basin (O'Neill 1996B). The following sections are reprinted from a companion report on MCO fuel basket material selection (Graves 1997). Process descriptions and steps presented below are approximate and may change as each step's design is completed.

a. LOADING THE MCO

Once cleaned, the K basin SNF is loaded underwater into the fuel baskets by the fuel retrieval system (FRS). The properties of the K Basin water are shown in Table 2. While still submerged, the loaded fuel baskets are then inserted into the MCO shell. The MCO is temporarily sealed with some water removed prior to shipment (fuel remains flooded) of the MCO/cask assembly to the cold vacuum drying facility.

Table 2: K Basin Water Properties (Goldmann 1997)

<i>Temperature</i>	6 to 38 °C (43 to 100 °F)	
<i>pH</i>	5.5 to 7.5 (Current range)	
<i>Conductivity</i>	KE: $\leq 5 \mu\text{S/cm}$	KW: $\leq 2 \mu\text{S/cm}$
<i>Mineral Content</i>	Chloride: <1 ppm	Nitrate: <1 ppm
	Sulfate: <1 ppm	Phosphate: <1 ppm
	Fluoride: 0.25 ppm	Sodium: 1 ppm
	Calcium: 2 ppm	Iron: 1 ppm

4.2 COLD VACUUM DRYING

Cold vacuum drying (CVD) drains the bulk water and vacuum dries the SNF inside the MCO prior to transportation from the CVD Facility to the CSB (O'Neill 1996B). Prior to drying, bulk water is drained from the MCO via a long axial dip tube while the MCO temperature is held below 50 °C (122 °F). An inert gas purge of helium aids in draining the bulk water.

Drying of the SNF is performed by heating the MCO to 50 °C (122 °F) for 48 hours. A vacuum pumping system removes any gases from the MCO during drying (i.e., offgassing, residual free water, inleakage, etc.). Following fuel drying, the MCO is backfilled with approximately 99.95% purity helium to 400 Pa (0.06 psi) and temporarily sealed. The MCO is then heated to 75 °C (167 °F) for 6 hours to monitor for any pressure buildup (shipping simulation temperature). Following monitoring, the MCO is cooled to 15 °C (59 °F) and prepared for shipment to the CSB to await hot conditioning.

4.3 HOT CONDITIONING SYSTEM

The Hot Conditioning System (HCS) removes chemically bound water from the SNF (O'Neill 1996A). This process also minimizes the potential for subsequent pressurization of the sealed MCO by removing constituents that can change phase to a gaseous state under storage conditions (Garvin 1997). The HCS is performed by the hot condition system equipment (HCSE) which will be located in an annex of the CSB. At this time, the design and procurement of the HCS is on hold pending review.

The hot conditioning cycle takes approximately six days to complete; temperature levels for the different stages of the cycle are shown in Figure 1. Gas purging of the MCO is performed in conjunction with the heating to remove unwanted gases (chemically bound water, fission gases, air, etc.) and to maintain the hydrogen concentration below 2 volume percent. During the backfill stage, the MCO is filled with approximately 99.95% purity helium to a gauge pressure of 21 - 50 kPa (3 - 7.3 psi) and sealed for storage. Once conditioned, the MCO is not expected to need venting during interim dry storage at the CSB (Garvin 1997). However, a pressure relief device will be active at all times in the unexpected event of MCO overpressurization.

4.4 INTERIM STORAGE OF MCO

After sealing, the MCO/cask assembly returns to the CSB for dry interim storage until a suitable long-term repository can be established. Expected storage temperatures at the CSB are -10 to 132 °C (14 to 270 °F).

Figure 1: MCO Hot Conditioning Temperature Cycle (O'Neill 1996A)

5.0 SELECTION OF COPPER ALLOY

Copper and its alloys have found exclusive applications where combinations of excellent electrical and/or thermal conductivity, excellent formability, moderate strength, and good corrosion resistance are required (Chawla and Gupta 1993). The wrought alloys examined in this report all fall into the same copper family, *coppers*, which have a designated minimum copper content of 99.3% and the best thermal conductivity values of copper alloys. These alloys were chosen in order to maintain low oxygen levels to minimize the detonation potential of hydrogen in the MCO.

The chemical composition of the three coppers, as specified by ASTM standard B-152 (ASTM 1997) for copper plate and sheet, is listed in Table 3. C10200 is a high conductivity copper produced by melting and casting in an oxygen-free atmosphere thus preventing oxygen from entering the copper. The addition of phosphorus (C10800 and C12200 coppers) converts available oxygen in the copper to phosphorus pentoxide (P_2O_5). The low residual phosphorus in the C10800 copper maintains the electrical conductivity of copper. High residual phosphorus, C12200 copper, lowers electrical conductivity by about 15%, yet it improves cold-working properties and prevents the adsorption of oxygen at the high temperatures used for forming and welding.

Table 3: Copper Alloy Chemical Compositions (ASTM 1997)

UNS* No.	Type of Coppers	Min wt% Cu**	Other
C10200	Oxygen-free without residual deoxidants (OF)	99.95	10 ppm O (max)
C10800	Oxygen-free, low phosphorus	99.95	0.005-0.012 wt% P
C12200	Phosphorized, high residual phosphorus (DHP)	99.90	0.015-0.040 wt% P

* Unified Numbering System

** Includes silver

Table 4 lists the ASTM standard required tensile properties of the three coppers based upon the temper designation. At a H04 temper, the copper tensile strength value is about 60% of the comparable 304L stainless steel value (ASME 1995). The yield strength varies from about 69 to 360 MPa (10 to 53 ksi) depending upon temper (Robinson 1990). Elongation values (in 50 mm [2 in.]) for the coppers will vary from 5 to 55% with the higher values associated with the lower strengths (Robinson 1990). An H04 temper yields elongations values of 10 to 20%, depending upon material thickness (Robinson 1990).

The short time elevated temperature tensile properties of a C12200 copper are presented in Table 5. Similar data for a C10200 copper are listed in Table 6 (data was not available at the higher temperatures). As compared to the C12200 data, the C10200 tensile and yield strengths are about 5% and 15% lower, respectively. The C10800 copper is expected to behave similar to the C10200 copper at elevated temperatures. Note that at the maximum MCO temperature, 375 °C (707 °F), the yield and tensile strengths of C12200 are about 55% of their room temperature values (percentages for C10200 and C10800 are even lower)[†]. At this temperature, the copper yield strength is only about 5% less than the 304L stainless steel; however, the copper tensile strength is 70% less than that of the 304L (ASME 1995). Since the C12200

[†] When temperatures exceed 375 °C (707 °F) the low end of the annealing range of the coppers is reached (Robinson 1990). This initiates recrystallization and softening of the metal (usually done to prepare to metal for further cold working).

copper yield strength is comparable to that of 304L stainless steel, slumping during hot conditioning should not be a problem. However, a simple stress analysis should be performed to determine structural integrity during impact scenarios (i.e., fuel or manipulator impact). As brazing temperatures will cause some recrystallization and softening, a temper of at least H04 (hard) should be used to maximize strength properties during hot conditioning.

Table 4: Tensile Strength Requirements (ASTM 1997)

Temper Designation		Tensile Strength	
Standard	Former	Min, MPa (ksi)	Max, MPa (ksi)
H00	½ hard	221 (32)	276 (40)
H01	¼ hard	234 (34)	290 (42)
H02	½ hard	255 (37)	317 (46)
H03	¾ hard	283 (41)	345 (50)
H04	hard	296 (43)	359 (52)
H06	Extra hard	324 (47)	386 (56)
H08	Spring	345 (50)	400 (58)
H10	Extra Spring	359 (52)	---
M20	Hot-rolled	207 (30)	262 (38)
O25	Hot-rolled and annealed	207 (30)	262 (38)

Table 5: C12200 Elevated Temperature Tensile Properties (Upthegrove and Burghoff 1956)
Temper: Hot-rolled and annealed at 621 °C (1150 °F) then cold-rolled 5-7%

Test Temperature		Elastic Modulus GPa (10 ³ ksi)	Tensile Strength		Yield Strength*		% Elongation in 50 mm (2 in.)
°C	°F		MPa	ksi	MPa	ksi	
24	75	114 (16.6)	229	33.2	174	25.3	52.0
60	140	109 (15.8)	217	31.5	161	23.4	50.9
100	212	119 (17.2)	203	29.5	171	24.8	45.4
149	300	108 (15.7)	189	27.4	151	21.9	46.8
204	400	102 (14.8)	174	25.2	152	22.1	46.5
288	550	103 (15.0)	150	21.7	117	17.0	49.6
371	700	74 (10.8)	121	17.6	97	14.1	57.8
454	850	55 (8.0)	71	10.3	91	13.2	68.0

* 0.2% Offset

Table 6: C10200 Elevated Temperature Tensile Properties (Upthegrove and Burghoff 1956)
Temper: cold-rolled 5-7%

Test Temperature		Elastic Modulus GPa (10 ³ ksi)	Tensile Strength		Yield Strength*		% Elongation in 50 mm (2 in.)
°C	°F		MPa	ksi	MPa	ksi	
24	75	116 (16.8)	218	31.6	153	22.2	50.7
100	212	117 (16.9)	195	28.3	147	21.3	46.8
204	400	98 (14.2)	165	23.9	130	18.8	45.6

* 0.2% Offset

At room and elevated temperatures, copper and its alloys are susceptible to stress-relaxation, the decrease of internal stress over time. For example, upon heating a 0.25 mm (0.01 in.) diameter C11000 annealed wire with an initial stress of 89 MPa (13 ksi) to 149 °C (300 °F), only about 25% of the initial stress remained after 100 hours (Tyler 1990, Figure 11). The stress-relaxation data for C10200 are somewhat better. The addition of minute amounts of silver (<0.08%) significantly reduces the stress relaxation effects in copper (Tyler 1990) and is strongly recommended in this application.

The thermal expansion coefficients for the coppers are shown in Table 7. These values would apply to all three coppers because of the very small amounts of alloying elements. In comparison to stainless steel, the copper values are only 5-10% larger. This difference is small enough and the basket design is such that expansion problems during hot conditioning should not occur.

Table 7: Copper Thermal Expansion Coefficients (Robinson 1990)

Temperature Range		Mean Coefficient of Thermal Expansion	
°C	°F	$\times 10^{-6} (^{\circ}\text{C})^{-1}$	$\times 10^{-6} (^{\circ}\text{F})^{-1}$
20-100	68-212	17.0	9.4
20-200	68-392	17.3	9.6
20-300	68-572	17.7	9.8

6.0 COPPER CORROSION RESISTANCE

Copper and its alloys are corrosion resistant because they are inherently “noble” by virtue of their low driving force toward the oxidized state as measured by the electromotive force series and also because of the formation of adherent impervious films of corrosion product in various media (Lyman 1980). As the three coppers vary only slightly in composition, their corrosion resistance will also be similar (any differences are noted).

Only certain specific environments appear to produce stress corrosion of copper alloys, notably ammonia (NH_3) or ammonium (NH_4^+) compounds or related compounds such as amines (Gilbert 1994). As none of these environments are expected within the MCO, stress corrosion cracking (SCC) of the copper divider subassembly is not a factor.

6.1 DURING STORAGE PRIOR TO USAGE

Prior to actual fuel loading, the fuel baskets will need to be stored, most likely in a combination of dry (warehouse) and wet (basin) conditions. The Hanford site falls into an arid rural atmospheric corrosion category due to its dry desert atmosphere with a relative absence of industrial pollutants. Atmospheric corrosion of two coppers, 110 and 120, were measured (Polan 1987) to be less than $0.13 \mu\text{m/yr}$ (0.005 mils/yr) in an arid rural environment (Phoenix, Arizona) similar to the Hanford site. Corrosion rates for the C10200, C10800 or C12200 coppers would be similar.

Minerals in water combine with dissolved CO_2 and oxygen and react with copper to form a protective film. In distilled or very soft water, protective films are less likely to form; the corrosion rate may vary from less than 2.5 to $125 \mu\text{m/yr}$ (0.1 to 5 mils/yr) or more, depending on oxygen and CO_2 content (Polan 1987). Even at the higher corrosion rate, impact to the divider subassembly would be minimal due to the relatively short (< 1 year) exposure times.

6.2 MCO CONTAINING LIQUID WATER

The resistance of the copper alloys to water is discussed in the previous section.

As water can function as an electrolytic conductor, the potential for galvanic corrosion must be examined. The main dissimilar metal contact scenario within the MCO is contact between the copper divider subassembly and the 304L stainless steel baskets and shell. Both copper and stainless steel exhibit passive oxide layers on their surfaces. In comparison, passive stainless steel is more noble (corrosion-resistant) than copper in the sea water galvanic series[†]. This results in an accelerated galvanic corrosion of the copper. As there will only be one scrap basket loaded into each MCO, the area ratio of stainless steel to copper is very large, acting to increase the copper corrosion rate even more^{††}. The driving force for this galvanic corrosion will be appreciably lessened due to the much lower conductivity of the K basin water (versus sea water) and the relatively small spread between copper and stainless steel in the galvanic series.

There are three other possible dissimilar metal contact scenarios within the MCO which could result in accelerated galvanic corrosion of the copper divider subassembly:

- 1) *Contact with Zircaloy-2 fuel cladding* -- The zirconium-based cladding forms a passive oxide surface film that is more noble than the copper oxide layer. Thus, accelerated galvanic corrosion of the copper will occur.
- 2) *Contact with aluminum fuel cladding*^{†††} -- The aluminum cladding also forms a protective oxide coating, however, this coating is less noble than the copper oxide layer. In this case, accelerated corrosion of the aluminum would occur.
- 3) *Contact with uranium fuel* -- The uranium is actively corroding with a nonprotective oxide layer resulting in no accelerated corrosion of the copper.

The lower water conductivity will diminish the above mentioned galvanic reactions such that avoiding direct contact with the above materials is not required.

[†] Copper can accelerate corrosion of active stainless steel, particularly in highly chlorinated water. However, as chloride levels of the K Basin water are very low and stainless steel is easily passivated, this scenario is not expected.

^{††} Filling an MCO with more than one scrap basket would reduce the stainless steel/copper area ratio thus reducing the magnitude of the copper corrosion rate increase.

^{†††} Some of the fuel elements have aluminum cladding instead of Zircaloy-2 cladding.

The time period during which a loaded MCO is immersed in or is filled with liquid water is less than 2 days (Garvin 1997). Even with accelerated galvanic corrosion effects, this is an insufficient time period for significant corrosion of the copper divider subassembly to occur. However, should a problem occur during processing causing a backlog, storage of a flooded MCO should be limited to less than 6 months to prevent any corrosion product buildup from hampering process flow paths.

6.3 MCO DURING REMOVAL OF LIQUID WATER

Copper resists attack by pure steam, but if much CO_2 , oxygen, or NH_3 is present, the condensate is corrosive (Polan 1987). Regular gas purging during drying will prevent the buildup of any of these gases.

Less than 48 hours is needed to remove liquid water from the MCO and establish a low water vapor pressure inside (WHC 1996). This period is too short to cause significant corrosion of the copper divider subassembly as there is no significant buildup of aggressive species. The low water vapor pressure, less than 66 Pa (0.01 psi), following cold vacuum drying prevents any condensation inside the MCO. Once the liquid water is removed and condensation is precluded, any liquid [galvanic] corrosion problems cease (Garvin 1997).

6.4 MCO AFTER REMOVAL OF LIQUID WATER

Following hot conditioning, there is the potential for four gases to exist within the MCO in addition to inert gases:

- 1) *Hydrogen gas* - Generated by reactions of the uranium fuel with water vapor or radiolysis of chemically bound water.
- 2) *Chlorine gas* - Produced by thermal or radiolytic decomposition of polychlorinated biphenyls (PCBs), detected in low levels in K basin sludge samples.
- 3) *Iodine gas* - Could be present due to the thermal environment and fuel corrosion.
- 4) *Oxygen gas* - Generated by the radiolysis of water.

A common form of hydrogen damage in copper is known as steam embrittlement and is observed only when copper contains oxygen. Hydrogen entering the metal reacts with the oxygen to form water; above 374 °C (705 °F) steam forms and the pressure generated is sufficient to produce microcavity formation and cracking. The use of oxygen-free coppers (C10200 and C10800) essentially eliminates susceptibility to steam embrittlement (Craig 1987). Deoxidized coppers with high residual deoxidizer contents (such as C12200) are not considered susceptible to hydrogen embrittlement because the oxygen is tied up in complex oxides that do not react appreciably with hydrogen (Polan 1987).

A maximum-use temperature of 205 °C (400 °F) is suggested for copper in dry chlorine (Liening 1987). Water vapor at room temperature accelerates attack of copper, however, above 250 °C (480 °F) water vapor and oxygen in chlorine reduce copper attack. However, PCBs are not expected in the K basin canister sludge, so they should not be present within the MCO. This, coupled with cleaning of the fuel prior to MCO loading and regular gas purging during processing, further reduces the possibility of chlorine gas corrosion problems. The fabrication specification (WHC 1996) also precludes the use of high halogen cleaners/materials in the MCO construction.

A literature search did not yield any recommendations concerning copper service in iodine gas. Since iodine is less aggressive than chlorine (assuming an equivalent partial pressure) and iodine levels are very low, corrosion attack of copper from iodine is unlikely.

When copper is used at high temperatures in oxygen scaling results. Below 100 °C (212 °F), the oxide film increases in thickness logarithmically with time (Polan 1987). At medium temperatures the scaling rate increases following the parabolic law. Regular gas purging during hot conditioning will reduce or eliminate scaling of the copper.

In addition to gaseous corrosion reactions, contact between the copper divider subassembly and the fuel elements could cause liquid metal embrittlement by fuel fission products. Cesium and tin are the lower melting point fission products, less than 205 °C (400 °F), generated in the greatest amounts (Garvin 1997). Tin is reported to embrittle copper, while cesium does not (Nicholas 1984). However, as the tin and cesium levels in the fuel elements are low, content in a contact area would be far too small for significant damage of the divider subassembly to occur.

7.0 COPPER RADIATION RESISTANCE

Similar to aluminum, copper is hardened by irradiation. A literature search did not yield any quantitative information on the magnitude of irradiation hardening. This additional strength would aid in divider stability during the hot conditioning processing temperatures.

8.0 MCO THERMAL TRANSIENT EFFECTS

After drying of the MCO and on initial heat up, the fuel particulates inside the MCO will release water from crystalline forms. This free water vapor will then react with any bare uranium metal or hydrides to produce heat which may result in a thermal transient. The upper temperatures inside the MCO may then momentarily exceed 300 °C (570 °F). This generated a concern that the thermal transient temperatures could approach the eutectic (solid to liquid) temperature of the divider subassembly material.

Calculations performed by Thurgood (1997) showed that for the bounding case (staging) the peak fuel temperature was 443 °C (830 °F) and the peak MCO wall temperature was 261 °C (500 °F). The calculations used the surface area and water inventory of the scrap fuel basket (worst case scenario) and the following assumptions: maximum sludge amount of 54.4 kg (120 lb), a water mass fraction of the sludge equal to or less than 10%, and individual scrap pieces do not exceed 20% oxide. Calculations for shipping yielded lower peak temperatures than for staging (calculations for CVD are not yet complete). Both of these calculated peak temperatures fall well below the documented safety limit temperatures. The maximum MCO operational limit temperature is 375 °C (700 °F), as documented by Goldmann (1996). The maximum fuel safety limit temperature of 725 °C (1340 °F) is the uranium-iron eutectic temperature as documented in the MCO Topical Report (Garvin 1997).

The minimum eutectic transformation temperature is 1084.5 °C (1984 °F), equal to copper's melting point, for both the copper-iron and copper-nickel systems (ASM 1990). For the copper-uranium and copper-zirconium systems the minimum eutectic transformation temperatures are slightly lower, 950 °C (1742 °F) and 885 °C (1625 °F), respectively. As all of the transformation temperatures are considerably above the calculated thermal transients, the likelihood of any copper eutectic reactions is negligible.

9.0 BRAZE MATERIAL CORROSION RESISTANCE

The atmospheric, gaseous, and water corrosion resistance of the braze filler metal (BCuP-5) should be equal to or greater than that of the coppers. The addition of phosphorus will tie up any oxygen as P_2O_5 , thus avoiding hydrogen embrittlement concerns. The addition of silver increases the filler material's galvanic corrosion resistance as it is more noble than either copper or stainless steel. Even with an unfavorable area ratio, this increased nobility will help protect the brazed areas from accelerated galvanic corrosion during the period when the MCO is immersed.

10.0 COST ANALYSIS

Three West Coast copper suppliers were contacted to obtain price information on the coppers:

- Alaskan Copper & Brass; Seattle, WA (oral quote given on August 27, 1997)
- Copper and Brass Sales; Portland, OR (oral quote given on August 27, 1997)
- Olin Brass; Cupertino, CA (see Appendix A)

These suppliers were local offices of eastern United States fabricators. Pricing estimates for the C10200 and C12200 coppers are compared below in Table 8. None of these suppliers were able to quote prices for the C10800 copper as it is a special-order alloy that is not readily available (and thus would be much more expensive than either the C10200 or C12200 coppers). The C12200 copper is about 7% less in price than the C10200 copper. Fabrication costs for the C10200 and C12200 coppers would be similar.

Table 8: Cost Quotes for ASTM B-152 Coppers

Supplier	Alloy	Plate/Sheet Size	Price
Alaskan Copper & Brass*	C10200	0.64 x 91 x 305 cm (0.25 x 36 x 120 in.)	\$6.62/kg (\$3.01/lb)
	C10200	0.32 x 61 x 244 cm (0.125 x 24 x 96 in.)	\$7.68/kg (\$3.49/lb)
Copper and Brass Sales*	C10200	0.64 x 91 x 244 cm (0.25 x 36 x 96 in.)	\$8.21/kg (\$3.73/lb)
Olin Brass**	C10200	0.32 x 61 x 244 cm (0.125 x 24 x 96 in.)	\$6.36/kg (\$2.89/lb)
	C12200	0.32 x 61 x 244 cm (0.125 x 24 x 96 in.)	\$5.95/kg (\$2.70/lb)

* Price is per plate/sheet and would decrease with a larger order.

** Price is based upon a minimum quantity of 3856 kg (8,500 lbs).

11.0 CONCLUSIONS

The room temperature mechanical properties of the C10200, C10800, and C12200 coppers depend upon temper and can approximate those of 304L stainless steel at the higher-hardness tempers. C10200 and C10800 have the highest electrical and thermal conductivity while C12200 is about 15% lower.

Elevated temperature yield strength of C12200 is only slightly lower than stainless steel, but the tensile strength is only about one-third that of the stainless steel. The C10200 and C10800 coppers have 5 to 15% lower elevated temperature strength levels. The coppers are prone to stress relaxation but the addition of minute amounts of silver significantly reduce the effects. Thermal expansion coefficients for the coppers are 5-10% larger than stainless steel; copper expansion effects should be minimal.

By virtue of composition, all three coppers are resistant to hydrogen embrittlement. The MCO environments are such that ammonia and its compounds are not present, therefore stress corrosion cracking will not occur.

Atmospheric corrosion of the coppers is negligible. Corrosion of the coppers is minimal during the short time period that the MCO is filled with water and during water removal.

Once water is removed from the MCO accelerated galvanic corrosion of the coppers ceases. Corrosion of the coppers by chlorine and iodine gas is not expected, however, some scaling due to oxygen is expected. The effect of liquid metal embrittlement by either cesium or tin is negligible. Radiation effects will strengthen the coppers and aid in the divider stability during hot conditioning.

Cost quotes showed C12200 to be about 7% less than C10200. C10800 is not readily available and would be more expensive as it is a special order alloy. Fabrication costs would be similar for both C10200 and C12200.

Based upon better elevated temperature strength properties and lower material cost, at the sacrifice of some conductivity, the use of C12200 copper is recommended over the C10200 and C10800 coppers as the Mark 1A and Mark IV scrap basket divider subassembly construction material.

12.0 REFERENCES

- ASM, 1990, *Binary Alloy Phase Diagrams*, Second Edition, T. B. Massalski Editor-in-Chief, American Society for Metals, Metals Park, Ohio.
- ASME, 1995, *Boiler & Pressure Vessel Code*, American Society of Mechanical Engineers, New York, New York.
- ASTM, 1997, "Standard Specification for Copper Sheet, Strip, Plate, and Rolled Bar" in *Annual Book of ASTM Standards*, Specification B-152-97, American Society for Testing and Materials, Philadelphia, Pennsylvania.
- Beal, R. E. and R.E. Cook, 1993, "Brazing of Copper, Copper Alloys, and Precious Metals" in *ASM Handbook, Volume 6: Welding, Brazing, and Soldering*, Tenth Edition, American Society for Metals, Metals Park, Ohio, pg. 931-936.
- Chawla, S. L. and R. K. Gupta, 1993, *Materials Selection for Corrosion Control*, American Society for Metals, Materials Park, Ohio, pg 195-211.
- Craig, B., 1987, "Hydrogen Damage" in *Metals Handbook, Volume 13: Corrosion*, Ninth Edition, American Society for Metals, Metals Park, Ohio, pg. 163-171.
- DESH, 1997A, *K-Basin SNF Scrap Basket Mark 1A*, H-2-828065, Rev. 1, Duke Engineering and Services Hanford, Richland, Washington.
- DESH, 1997B, *MCO Mark IV SNF Scrap Basket*, H-2-828075, Rev. 1, Duke Engineering and Services Hanford, Richland, Washington.
- Garvin, L. J., 1997, *Multi-Canister Overpack Topical Report*, HNF-SD-SNF-SARR-005, Fluor Daniel Hanford, Richland, Washington.
- Gilbert, P. T., 1994, "Copper and Copper Alloys" in *Corrosion Volume 1: Metal/Environment Reactions*, Third Edition, L. L. Shrier Editor, Butterworth Heinemann, Boston, MA, pg. 4:38-4:75.
- Goldmann, L. H., 1997, *Performance Specification for the Spent Nuclear Fuel Multi-Canister Overpack*, WHC-S-0426, Revision 3, Westinghouse Hanford Company, Richland, Washington.
- Graves, C. E., 1997, *Evaluation of Carbon Steel for MCO Mark IV Fuel Basket Construction*, HNF-SD-SNF-ER-017, Revision 0, Duke Engineering & Services Hanford, Richland, Washington.
- Liening, E. L., 1987, "Corrosion by Chlorine" in *Metals Handbook, Volume 13: Corrosion*, Ninth Edition, American Society for Metals, Metals Park, Ohio, pg. 1170-1174.
- Lyman, W. S., 1980, "Copper and Copper Alloys" in *Encyclopedia of Chemical Processing and Design*, Volume 11, J. J. McKetta Executive Editor, Marcel Dekker, inc, New York, New York, pg. 422-450.
- Nicholas, M. G., 1984, "A Survey of Literature on Liquid Metal Embrittlement of Metals and Alloys" in *Embrittlement by Liquid and Solid Metals*, M. H. Kamdar Editor, The Metallurgical Society, Warrendale, PA, pg. 27-50.

- O'Neill, C. T., 1996A, *Performance Specification for the K-Basin Spent Nuclear Fuel Hot Conditioning System Equipment*, WHC-S-0460, Revision 1, Westinghouse Hanford Company, Richland, Washington.
- O'Neill, C. T., 1996B, *Performance Specification for the K-Basin Spent Nuclear Fuel Vacuum Drying Module*, WHC-S-0435, Revision 0, Westinghouse Hanford Company, Richland, Washington.
- Polan, N. W., 1987, "Corrosion of Copper and Copper Alloys" in *Metals Handbook, Volume 13: Corrosion*, Ninth Edition, American Society for Metals, Metals Park, Ohio, pg. 610-640.
- Ricksecker, R. E., 1979, "Wrought Copper and Wrought Copper Alloys" in *Kirk-Othmer Encyclopedia of Chemical Technology*, Third Edition, Volume 7, M. Grayson Executive Editor, John Wiley & Sons, New York, New York, pg 1-68.
- Robinson, P., 1990, "Properties of Wrought Coppers and Copper Alloys" in *ASM Handbook, Volume 2: Properties and Selection: Non-Ferrous Alloys and Special-Purpose Materials*, Tenth Edition, American Society for Metals, Metals Park, Ohio, pg. 265-270.
- Thurgood, M. J., 1997, *Bounding Temperatures and Gas Generation Rates During CSB Staging*, HNF-SD-SNF-CN-005, Revision 0, Fluor Daniel Hanford, Richland, Washington.
- Tyler, D. E., 1990, "Wrought Copper and Copper Alloy Products" in *ASM Handbook, Volume 2: Properties and Selection: Non-Ferrous Alloys and Special-Purpose Materials*, Tenth Edition, American Society for Metals, Metals Park, Ohio, pg. 241-264.
- Upthegrove, C. and H. L. Burghoff, 1956, *Elevated Temperature Properties of Coppers and Copper-Base Alloys*, ASTM STP #181, American Society For Testing Materials, Philadelphia, PA, pg. 17, Data sheet #7 and pg 31, Data sheet #4.
- WHC, 1996, *Fabrication Specification for the Spent Nuclear Fuel Project Multi-Canister Overpack*, WHC-S-0453, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A - COST QUOTE

HNF-SD-SNF-ER-019
Revision 0**OLIN BRASS -Cupertino, CA****To: Carolyn Graves
Fluor Daniel Northwest****From: Donna**

20370 Town Center Lane
Suite B-235
Cupertino, CA 95014
(408)257-5820
(408)255-9690 fax

Date: 9/05/97
Copper Base: \$1.13
Subject: Quote
Ship: 10-12 weeks ARO
Freight: Prepaid

<u>Item</u>	<u>Release Quantity</u>	<u>Description</u>	<u>Price/Lb.</u>
1.	8,500lbs. (Minimum)	.125 ± .0025" x 24.00" x CTL of 96.00" Soft Temper, Alloy C102 ASTM-B152	\$2.8863/lb
2.	8,500lbs. (Minimum)	.125 ± .0025" x 24.00" x CTL of 96.00" Soft Temper, Alloy C122 ASTM- B152	\$2.6963/lb

<OLIN STANDARD TERMS AND CONDITIONS OF SALE APPLY>

Additional Remarks:

- *Price in effect date of ship shall apply
- *F.O.B. East Alton, IL
- *Freight prepaid on 8M# and above
- *No quote on the .25" material - too heavy

Sheet - Strip - Rod - Wire - Pipe - Tube
OLIN BRASS CORPORATION

DISTRIBUTION SHEET

To Distribution	From Mechanisms Engineering, Fluor Daniel Northwest	Page 1 of 1 Date September 25, 1997
Project Title/Work Order "Evaluation of Copper for Divider Subassembly in MCO Mark 1A and Mark IV Scrap Fuel Baskets" HNF-SD-SNF-ER-019, Revision 0		EDT No. 604540 ECN No. N/A

Name	MSIN	Text With All Attach.	Text Only	Attach./ Appendix Only	EDT/ECN Only
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Central Files (Org. +2)	A3-88	X
WC Alaconis	R3-85	X
GD Bazinet	B4-55	X
KH Bergsman	R3-48	X
DM Chenault	R3-86	X
RG Cowan	R3-86	X
DR Duncan	R3-86	X
JR Frederickson	R3-86	X
LH Goldmann	R3-86	X
CE Graves (2)	H5-70	X
CR Hoover	H1-15	X
FF Huang	H5-70	X
JJ Irwin	H0-34	X
AT Kee	R3-86	X
M. Kummerer	A3-34	X
BD Lorenz	R3-15	X
TD Merklng	X3-79	X
CR Miska	R3-86	X
RW Rasmussen	R3-86	X
ES Ruff	H5-70	X
RE Russell	H5-70	X
EJ Shen	R3-86	X
DA Smith	R3-15	X
KE Smith	R3-86	X
CE Swenson	S8-07	X
JA Swenson	R3-11	X
CA Thompson	R3-85	X