附錄六.二.B　材料評估

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(斜體字章節內含 NAC Proprietary Information 之相關內容)

六.二.B 材料評估

本章說明本系統元件材料的詳細物理、化學、機械與熱相關材料性質的定義、規格、測試與接受條件，本系統系統元件的選用材料皆已標註於相關圖面。本系統元件材料的設計準則(design criteria)、規範(codes)、標準(standard)與規格詳見第三章說明。

1　材料選擇

基於高強度、韌性、抗腐蝕、抗脆性破壞與金屬冶金穩定性的適合長期貯存的諸多特性，而選用 Type 304 不銹鋼作為密封鋼筒的材料。密封鋼筒各部位材料如以下所示：

殼(Shell)	ASME SA240, Type 304/304L 不銹鋼(dual certified)
底(Bottom)	ASME SA240, Type 304/304L 不銹鋼(dual certified)
密封上蓋(Closure Lid)	ASME SA240/SA336, Type 304/304L 不銹鋼
密封上蓋塞(Closure Lid Plug)	ASTM A276, Type 304 不銹鋼
密封環(Closure Ring)	ASME SA479/SA240, Type 304/304L 不銹鋼 (dual certified)
孔蓋(Port Covers)	ASME SA240, Type 304/304L 不銹鋼(dual certified)

註: 密封上蓋材料之降伏強度與極限強度必須大於或等於 SA240, Type 304 不銹鋼。

基於強度與熱傳導的特性，選用碳鋼作為提籃(Basket)材料。提籃製作後，以無電鍍鎳塗裝(electroless nickel-coated)以增進碳鋼的抗腐蝕性能，並可明顯降低在燃料池裝填燃料時，形成易燃性氣體的可能性。

燃料提籃的製作材料如以下所述：

提籃支撐、板與角板(Basket Supports, Plates and Gussets)	ASME SA537, Class 1, 碳鋼
燃料方管(Fuel Tubes)	ASME SA537, Class 1, 碳鋼
頂部/底部聯結插銷組件 (Top/Bottom Connector Pin Assembly)	ASME SA564 17-4PH 不銹鋼
鑲嵌螺栓(Mounting Bolts)	ASME SA193, Grade B6 不銹鋼
中子吸收物(Neutron Absorber)	硼金屬基材複合材料(Borated Metal Matrix Composite), 硼鋁合金(Borated Aluminum Alloy), 或 Boral

註：聯結插銷組件之插銷(Drive Pin)之材料亦可採用 ASME SA479 不銹鋼

混凝土護箱的製作材料：

殼(Shell)	ASTM A36 碳鋼
底座(Pedestal Plate)	ASTM A36 碳鋼
基板與頂板(Base and Top Plates)	ASTM A537, Class 2, 碳鋼
鋼筋(Reinforcing Bar)	ASTM A615/A615M 碳鋼
混凝土(Concrete)	ASTM C150 Type II 波特蘭水泥

傳送護箱的製作材料：

內殼(Inner Shell)	ASTM A588 低合金鋼
外殼(Outer Shell)	ASTM A588 低合金鋼
底部(Bottom Forging)	ASTM A516, Grade 70/A350 Grade LF 2 低合金鋼
頂部(Top Forging)	ASTM A516, Grade 70/A350 Grade LF 2 低合金鋼
吊耳軸(Trunnions)	ASTM A350, LF2 低合金鋼
滑軌(Rails)	ASTM A350, LF2 低合金鋼
屏蔽門(Shield Doors)	ASTM A350, LF2 低合金鋼
保護環(Retaining Ring)	ASTM A588 低合金鋼
保護環螺栓(Retaining Ring Bolt)	ASTM A193, Grade B8 螺栓用鋼
加馬屏蔽塊(Gamma Shield Brick)	ASTM B29 Lead-Chemical Copper Grade
中子屏蔽(Neutron Shield)	NS-4-FR

<u>**破裂韌性**</u>

密封鋼筒結構材料為沃斯田鐵系不銹鋼(austenitic stainless steel)。依據 ASME Code section III, NB-2311 規範，這類材料無需進行破裂韌性(fracture toughness)測試。

燃料提籃主要由 ASME Code SA537, Class 1 碳鋼製成的銲接燃料方管與支撐所組成。 燃料提籃材料需符合 ASME Code section III, NG-2300 對於材料衝擊測試的要求，並且需要依據 NG-2320 進行測試。採購/製造規範中將會說明使用的燃料提燃材料承受相同成形/彎曲後熱處理的破裂韌性測試，或是熱處理情形。依 ASTM A370, 26.1 節規定制定溫度的接受值(acceptance values)為-40℃(-40°F)，該值符合表 NG-2331 (a) (l)最低服役溫度(Lowest Service Temperature, (LST)) 的要求。

基於材料低溫破裂韌性(low-temperature facture toughness)的考量，選擇低合金碳鋼作為傳送護箱的結構元件材料。這些材料的無延性過渡溫度(nil ductility transition temperature)為-40℃(-40°F)。依據 Regulatory Guide 7.11 [1]的要求，並假設傳送護箱內的物資的熱量對於材料的韌性提升沒有貢獻，使用以上無延性過渡溫度以上 22.2℃(+40°F)的溫度作為傳送護箱的最低操作溫度，最後決定傳送護箱最低的操作周圍溫度(minimum ambient temperature)為-17.8℃ (0°F)。此溫度條件可藉由傳送護箱的操作程序加以規範，並且計算分析時引用的條件也應與此一致。

2 規範與標準

本系統 元件設計主要是依循美國機械工程師協會鍋爐與壓力容器規範(American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code)、美國測試與材料協會(American Society for Testing and Materials, ASTM)與美國混凝土協會(American Concrete Institute, ACI) 的相關規範與標準。選用在製作上經過過程與程序控制的材料產品，並符合以上規範或標準要求所能接受的最小厚度、化學組成與制式規格(formulation specifications)。

密封鋼筒的鋼質元件與相關的銲接材料，除了表 3.1.1-8 所列 ASME 規範替代項目外，皆依據 ASME Code, section III, NB [3]要求。燃料格架之鋼質元件與相關銲接材料，除了表 3.1.1-8 所列 ASME 規範替代項目外，皆依據 ASME Code, section III, NG[4]的要求。

傳送護箱的鋼質元件、相關的銲接材料與鉛加馬屏蔽材料則是依據 ASTM 標準的要求設計製作。傳送護箱中的 NS-4-FR 是用以作為衰減與吸收中子的商用材料。

混凝土護箱鋼質元件與相關的銲接材料皆依據 ASTM 規定使用。混凝土部分則依據 ACI 318 [2]要求，與 ASTM 相關規定使用。

3 材料性質

用於製作本系統鋼元件材料的機械性質表列於表 6.2.B.3-1 到表 6.2.B.3-16。貯存系統製作與分析計算所用的材料熱相關性質則列於表 6.2.B.3-17 到表 6.2.B.3-28。表 6.2.B.3-17 到表 6.2.B.3-28 只表示用於熱傳導分析模型中的熱傳導路徑上的材料性質，相關的有效熱傳導計算陳述於六.三節中。因小元件並未建入有限元素分析模型中，故小元件材料性質並未列於表中。本附錄在材料性質中保留原文獻 ASME Boiler and Pressure Vessel Code, Section II, Part D[5]的英制單位說明。

照射後的鋯合金護套的材料機械性質取自 PNNL Geelhood 與 Beyer 的參考文獻[36]。以最大正常操作溫度下 400℃ (752°F)的最小值的彈性係數與降伏強度，保守作為鋯合金護套材料的彈性係數(Modulus of Elasticity)與降伏強度(yield strength)，各為 $E = 72{,}191$ MPa ($10.47 \times l0^6$psi) 與 $S_y = 480$ MPa (69,600 psi)。

表 6.2.B.3-1　SA240, Type 304 不銹鋼材料機械性質

性質(單位)	溫度值 (°F)									
	-40	-20	70	200	300	400	500	650	800	900
極限強度, S_u (ksi) [a]	75.0	75.0	75.0	71.0	66.2	64.0	63.4	63.4	62.8	60.8
降伏強度, S_y (ksi) [a]	30.0	30.0	30.0	25.0	22.4	20.7	19.4	18.0	16.9	16.2
設計應力強度 (Design Stress Intensity) S_m(ksi)[a]	20.0	20.0	20.0	20.0	20.0	18.7	17.5	16.2	15.2	14.6 [b]
彈性係數, E (× 10^6 psi) [a]	28.8	28.7	28.3	27.6	27.0	26.5	25.8	25.1	24.1	23.5
熱膨脹係數, α (×10^{-6} in/in/°F) [a]	8.13[b]	8.2[b]	8.5	8.9	9.2	9.5	9.7	9.9	10.1	10.2
柏松比(Poisson's ratio) [a]	0.31									
密度 (lb/in^3) [c]	0.29									

[a] ASME Boiler and Pressure Vessel Code [5]

[b] 外插值

[c] Metals Handbook Desk Edition [23]

表 6.2.B.3-2　SA693/SA564, Type 630, 17-4 PH 不銹鋼材料機械性質

性質(單位)	溫度值 (°F)							
	-40	70	200	300	400	500	600	700
極限強度, S_u (ksi) [a]	135.0	135.0	135.0	135.0	131.2	128.6	126.7	123.8
降伏強度, S_y (ksi) [a]	111.7	105.0	97.1	93.0	89.7	87.0	84.7	82.5
設計應力強度, S_m (ksi) [a]	45.0	45.0	45.0	45.0	43.7	42.9	42.2	41.3 [b]
彈性係數, E ($\times 10^6$ psi) [a]	29.4	28.5	27.8	27.2	26.6	26.1	25.5	24.9
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [a]	5.9							
柏松比 [a]	0.31							
密度 (lb/in^3) [c]	0.29							

表 6.2.B.3-3　A350, Grade LF 2, Class 1 低合金鋼材料機械性質

性質(單位)	溫度值 (°F)						
	-40	70	200	300	400	500	700
極限強度, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0
降伏強度, S_y (ksi) [a]	36.0	36.0	33.0	31.8	30.8	29.3	25.8
設計應力強度, S_m (ksi) [a]	23.3	23.3	22.0	21.2	20.5	19.6	17.2
彈性係數, E ($\times 10^6$ psi) [a]	29.7	29.2	28.5	28.0	27.4	27.0	25.3
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.4	6.7	6.9	7.1	7.3	7.6
柏松比 [a]	0.31						
密度 (lb/in^3) [c]	0.284						

[a] ASME Boiler and Pressure Vessel Code [5]

[b] 外插值

[c] Metals Handbook Desk Edition [23]

表 6.2.B.3-4　SA516/A516, Grade 70 碳鋼材料機械性質

性質(單位)	溫度值 (°F)						
	-40	70	200	300	400	500	700
極限強度, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0
降伏強度, S_y (ksi) [a]	40.7	38.0	34.8	33.6	32.5	31.0	27.2
設計應力強度, S_m (ksi) [a]	23.3	23.3	23.2	22.4	21.6	20.6	18.1
彈性係數, E ($\times 10^6$ psi) [a]	29.8	29.3	28.6	28.1	27.5	27.1	25.3
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.4	6.7	6.9	7.1	7.3	7.6
熱傳導係數, k, (Btu/hr-ft-ºF) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0
柏松比 [a]	0.31						
密度 (lb/in^3) [b]	0.284						

表 6.2.B.3-5　SA537, Class 1 碳鋼材料機械性質

性質(單位)	溫度值 (°F)							
	-40	70	200	300	400	500	700	800
極限強度, S_u (ksi) [a]	70.0	70.0	70.0	69.1	68.4	68.4	68.4	65.4
降伏強度, S_y (ksi) [a]	54.9	50.0	44.2	40.5	37.6	35.4	32.3	30.5
設計應力強度, S_m (ksi) [a]	23.3	23.3	23.3	22.9	22.9	22.9	21.4	20.3[c]
彈性係數, E ($\times 10^6$ psi) [a]	30.0	29.5	28.8	28.3	27.7	27.3	25.5	24.2
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [a]	6.1	6.4	6.7	6.9	7.1	7.3	7.6	7.8
熱傳導係數, k, (Btu/hr-ft-ºF) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0	27.5
柏松比 [a]	0.31							
密度 (lb/in^3) [b]	0.284							

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

[c] Code Case N-707 [34]. Code Case N-707 要求可以忽略材料的潛變應變。在正常情況下，只有提籃頂部 914 mm (3ft)高度的溫度超出 371℃(700°F)。提籃唯一的主要負載為呆載重，由呆載重所產生的最大應力是 70.5 kPa (36×0.284 或 10 psi)，考慮這個應力程度是可忽略的，並且呆載重對於提籃頂部所形成的潛變程度也是可忽略的，所以滿足 Code Case N-707 規定。

表 6.2.B.3-6　A537, Class 2 碳鋼材料機械性質

性質(單位)	溫度值 (°F)						
	-40	70	200	300	400	500	700
極限強度, S_u (ksi) [a]	80.0	80.0	80.0	78.9	78.2	78.1	78.1
降伏強度, S_y (ksi) [a]	60.0	60.0	53.0	48.6	45.1	42.4	38.7
設計應力強度, S_m (ksi) [a]	26.7	26.7	26.7	26.7	26.7	26.7	24.3
彈性係數, E (× 10^6 psi) [a]	30.0	29.5	28.8	28.3	27.7	27.3	25.5
熱膨脹係數, α (×10^{-6} in/in/°F) [a]	6.1	6.4	5.9	6.3	6.6	6.9	7.4
熱傳導係數, k, (Btu/hr-ft-°F) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0
柏松比 [a]	0.31						
密度 (lb/in^3) [b]	0.284						

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

表 6.2.B.3-7 SA695, Type B, Grade 40 與 SA696, Grade C 碳鋼材料機械性質

性質(單位)	溫度值 (°F)							
	-40	70	200	300	400	500	700	800
極限強度, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0	64.3
降伏強度, S_y (ksi) [a]	40.0	40.0	36.6	35.4	34.2	32.6	28.6	26.8
設計應力強度, S_m (ksi) [a]	23.3	23.3	23.3	23.3	22.8	21.7	19.2	--
彈性係數, E ($\times 10^6$ psi) [a]	29.8	29.3	28.6	28.1	27.5	27.1	25.3	24.0
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.4	6.7	6.9	7.1	7.3	7.6	7.8
熱傳導係數, k, (Btu/hr-ft-ºF) [a]	27.4	27.5	27.6	27.2	26.7	25.9	24.0	27.5
柏松比 [a]	0.31							
密度 (lb/in^3) [b]	0.284							

表 6.2.B.3-8 A588, Type A 與 B 碳鋼小板材材料機械性質

性質(單位)	溫度值 (°F)								
	-40	100	200	300	400	500	600	650	700
極限強度, S_u (ksi) [a]	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
降伏強度, S_y (ksi) [a]	53.5	50.0	47.5	45.6	43.0	41.8	39.9	38.9	37.9
設計應力強度, S_m (ksi) [a]	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3
彈性係數, E ($\times 10^6$ psi) [a]	29.7	29.0	28.5	28.0	27.4	27.0	26.4	25.9	25.3
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.5	6.7	6.9	7.1	7.3	7.4	7.5	7.6
柏松比 [a]	0.31								
密度 (lb/in^3) [b]	0.284								

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

表 6.2.B.3-9 A36 碳鋼材料機械性質

性質(單位)	溫度值 (°F)								
	-40	100	200	300	400	500	600	650	700
極限強度, S_u (ksi) [a]	58.0	58.0	58.0	58.0	58.0	58.0	58.0	58.0	58.0
降伏強度, S_y (ksi) [a]	36.0	36.0	33.0	31.8	30.8	29.3	27.6	26.7	25.8
設計應力強度, S_m (ksi) [a]	19.3	19.3	19.3	19.3	19.3	19.3	18.4	17.8	17.3
彈性係數, E ($\times 10^6$ psi) [a]	29.95	29.3	28.8	28.3	27.7	27.3	26.7	26.1	25.5
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [a]	6.13	6.5	6.7	6.9	7.1	7.3	7.4	7.5	7.6
柏松比 [a]	0.31								
密度 (lb/in^3) [b]	0.284								

表 6.2.B.3-10 SA193, Grade B6 高合金螺栓鋼材料機械性質

性質(單位)	溫度值 (°F)							
	-40	-20	70	200	300	400	500	700
極限強度, S_u (ksi) [c]	110.0	110.0	110.0	104.9	101.4	98.3	95.6	90.6
降伏強度, S_y (ksi) [c]	85.0	85.0	85.0	81.1	78.4	76.0	73.9	70.0
設計應力強度, S_m (ksi) [a]	28.3	28.3	28.3	27.0	26.1	25.3	24.6	23.3
螺栓應力強度, S_{mbm} (ksi) [a]	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2
彈性係數, E ($\times 10^6$ psi) [a]	29.8	29.7	29.2	28.5	27.9	27.3	26.7	25.6
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [a]	5.65 [d]	5.69 [d]	5.90	6.20	6.30	6.40	6.50	6.60
柏松比 [a]	0.31							
密度 (lb/in^3) [b]	0.28							

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

[c] 基於設計應力強度之計算 $\frac{S_{m_{temp}}}{S_{m70°F}}(S_{u70°F}) = S_{u_{temp}}$

[d] 外插值

表 6.2.B.3-11 SB637, Grade N07718 鎳合金螺栓鋼材料機械性質

性質(單位)	溫度值 (°F)						
	-40	70	200	300	400	500	700
極限強度, S_u (ksi) [a]	185.0	185.0	177.6	173.5	170.6	168.7	165.8
降伏強度, S_y (ksi) [a]	150.0	150.0	144.0	140.7	138.3	136.8	134.4
設計應力強度, S_m (ksi) [b]	50.0	50.0	48.0	46.9	46.1	45.6	44.8
彈性係數, E ($\times 10^6$ psi) [a]	29.6 [c]	29.0	28.3	27.8	27.6	27.1	26.4
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [c]	7.0	7.1	7.2	7.3	7.5	7.6	7.8
柏松比 [b]	0.31						
密度 (lb/in^3) [a]	0.297						

表 6.2.B.3-12 A615, Grade 60 材料機械性質

性質(單位)	A615, Grade 60
極限強度 (ksi) [d]	90.0
降伏強度 (ksi) [f]	60.0
彈性係數, E ($\times 10^6$ psi) [d]	29.88
熱膨脹係數, α ($\times 10^{-6}$ in/in/°F) [d]	6.1
密度 (lbm/in^3) [e]	0.284

[a] 基於設計應力強度之計算 $\frac{S_{m_{temp}}}{S_{m70°F}}(S_{u70°F}) = S_{u_{temp}}$

[b] ASME Boiler and Pressure Vessel Code [5]

[c] 外插值

[d] Metallic Materials Specification Handbook [6]

[e] Standard Handbook for Mechanical Engineers [13]

[f] Annual Book of ASTM Standards [25]

表 6.2.B.3-13 Chemical Copper Grade Lead 材料機械性質

性質(單位)	溫度值 (°F)					
	-40	-20	70	200	300	600
降伏強度, S_y (psi) [a]	700 [b]	680	640	490	380	200
彈性係數, E (× 10^6 psi) [c]	2.45 [b]	2.42	2.28	2.06	1.94	1.5
熱膨脹係數, α (×10^{-6} in/in/°F) [c]	15.6 [b]	15.7	16.1	16.6	17.2	20.2
柏松比 [d]	0.4					
密度 (lb/in^3) [d]	0.41					

[a] Determination of the Mechanical Properties of High Purity Lead and a 0.05% Copper-Lead Alloy [26]

[b] 外插值

[c] NUREG/CR-0481 [27]

[d] Standard Handbook for Mechanical Engineers [13]

表 6.2.B.3-14 混凝土材料機械性質

性質(單位)	溫度值 (°F)						
	-40	70	100	200	300	400	500
抗壓強度 (psi) [a]	4000[b]	4000	4000	4000	3800	3600	3400
彈性係數, E (× 10^6 psi) [a]	4.0[b]	3.72 [b]	3.64	3.38	3.09	2.73	2.43
熱膨脹係數,α (×10^{-6} in/in/°F)[a]	5.5[b]	5.5	5.5	5.5	5.5	5.5	5.5
密度 (lb/ft^3) [c]	145						

表 6.2.B.3-15 NS-4-FR 材料機械性質

性質(單位)	溫度值 (°F)			
	86	158	212	302
熱膨脹係數 (×10^{-6} in/in/°F) [d]	22.2	47.2	58.8	57.4
壓縮時之彈性係數 (ksi) [d]	561			
密度 (lbm/in^3) [d]	0.0607			

表 6.2.B.3-16 中子吸收物機械性質

性質(單位)	溫度值 (°F)									
	-320	-112	-18	75	212	300	400	500	600	700
極限抗拉強度, S_u (ksi) [e]	25.0	15.0	14.0	13.0	10.0	8.0	6.0	4.0	2.9	2.1
降伏強度, S_y (ksi) [e]	6.0	5.5	5.0	5.0	4.6	4.2	3.5	2.6	2.0	1.6
2 in 的伸長量, % [f]	50	43	40	40	45	55	65	75	80	85
彈性係數, E (10^6 psi) [f]	11.2	10.5	10.3	10.0	9.6	9.2	8.7	8.1	No value given	
熱膨脹係數, α, (10^{-6} in/in/°F) [f]	8.2	10.3	11.2	12.2	13.0	13.3	13.6	13.9	14.2	N/A
柏松比 [f]	0.33									
密度, (lb/in^3) [f]	0.098									
Boral Core 彈性係數, E (psi)	1000 (assumed)									
Boral Core 降伏強度, S_y (psi)	10 (assumed)									

[a] Handbook of Concrete Engineering [8]
[b] 外插值
[c] 特定值
[d] NS-4-FR Fire Resistant Neutron and/or Gamma Shielding Material [9]
[e] 鋁合金 1100-O 材料性質
[f] ASME Boiler and Pressure Vessel Code, Section II, Part D [5]

表 6.2.B.3-17 乾空氣熱相關性質

性質(單位)	溫度值 (°F) [a]					
	-40	70	100	300	500	700
熱傳導係數 (Btu/hr-in-°F)	0.00101	0.00121	0.00128	0.00161	0.00193	0.00223
比熱 (Btu/lbm-°F)	0.241	0.2417	0.240	0.244	0.247	0.253
密度 ($\times 10^{-5}$ lb/in^3)	5.1	4.19	4.11	3.01	2.38	1.97

表 6.2.B.3-18 氦氣熱相關性質

性質(單位)	溫度值 (°F) [b]			
	80	260	440	800
熱傳導係數 (Btu/hr-in-°F)	0.00751	0.00915	0.01068	0.01355

性質(單位)	溫度值 (°F) [c]			
	260	400	600	800
密度 ($\times 10^{-6}$ lb/in^3)	4.83	3.70	3.01	2.52
比熱 (Btu/lbm-°F)	1.24			

性質(單位)	溫度值 (°F) [d]											
	240	300	350	400	450	500	600	650	700	750	800	900
黏滯係數 ($\times 10^{-7}$ N-s/m^2)	170	199	221	243	263	283	320	332	350	364	382	414

表 6.2.B.3-19 水的熱相關性質

性質(單位)	溫度值 (°F) [e]					
	70	200	300	400	500	600
熱傳導係數(Btu/hr-in-°F)	0.029	0.033	0.033	0.032	0.029	0.024
比熱 (Btu/lbm-°F)	0.998	1.00	1.03	1.08	1.19	1.51
密度 (lbm/in^3)	0.036	0.035	0.033	0.031	0.028	0.025

性質(單位)	溫度值 (°F) [f]											
	273	275	285	295	305	315	325	335	345	355	365	375
黏滯係數 ($\times 10^{6}$ N-s/m^2)	1750	1652	1225	959	769	631	528	453	389	343	306	274

[a] Principles of Heat Transfer, Kreith & Bohn, Fifth Edition, Table 2 [15]

[b] Handbook of Thermal Conductivity of Liquids and Gases [18]

[c] Principles of Heat Transfer, Kreith, Fifth Edition [17]

[d] Introduction to Heat Transfer [22], Table A.4

[e] Principles of Heat Transfer, Second Edition [21], Table 3

[f] Introduction to Heat Transfer [22], Table A.6

表 6.2.B.3-20 NS-4-FR 熱相關性質

性質(單位)	數值 [a]
熱傳導係數 (Btu/hr-in-°F)	0.0311
密度 (borated) (lbm/in^3)	0.0589
密度 (nonborated) (lbm/in^3)	0.0607
比熱 (Btu/lbm-°F)	0.319

表 6.2.B.3-21 混凝土熱相關性質

性質(單位)	溫度值 (°F)		
	100	200	300
熱傳導係數 (Btu/hr-in-°F) [b]	0.091	0.089	0.086
比熱 (Btu/lbm-°F) [c]	0.20		
輻射率(Emissivity) [c]	0.90		
吸收率(Absorptivity) [d]	0.60		

[a] NS-4-FR Fire Resistant Neutron and/or Gamma Shielding Material [9]

[b] Handbook of Concrete Engineering [8], Figure 6-31, Curve 1

[c] Principles of Heat Transfer, Kreith and Bohn, Fifth Edition [15]

[d] Introduction to Heat Transfer [22]

應廠家要求：
本部分涉及廠家商業機密，屬其智慧財產權，
不予公開。

表 6.2.B.3-23 碳鋼熱相關性質

性質(單位)	溫度值 (°F)						
	-40	100	200	400	500	700	800
熱傳導係數 (Btu/hr-in-°F) [a]	2.28	2.30	2.30	2.22	2.16	2.0	1.92
比熱 (Btu/lbm-°F) [b]	0.113						
輻射率 [c]	0.80						
密度 (lb/in^3) [d]	0.284						

表 6.2.B.3-24 Chemical Copper Grade Lead 熱相關性質

性質(單位)	溫度值 (°F)					
	-40	70	200	400	600	800
熱傳導係數 (Btu/hr-in-°F) [e]	1.767	1.707	1.636	1.526	1.131	0.309
比熱 (Btu/lbm-°F) [e]	0.03 (68°F)					
輻射率 [c]	0.28 (75°F)					
密度 (lb/in^3) [e]	0.411 (68°F)					

表 6.2.B.3-25 SA240, Type 304/304L 不銹鋼熱相關性質

性質(單位)	溫度值 (°F)							
	-40	100	200	400	550	750	800	900
熱傳導係數 (Btu/hr-in-°F) [a]	0.686	0.725	0.775	0.867	0.925	1.0	1.017	1.058
比熱 (Btu/lbm-°F) [f]	0.10[g]	0.116	0.12	0.127	0.131	0.136	0.136	0.138
輻射率 [g, h]	0.36 (300°F)							
密度 (lb/in^3) [h]	0.29	0.29	0.289	0.287	0.286	0.284	0.283	0.283

註：SA240 不銹鋼中的 Type 304 與 304L 皆可。

[a] ASME Boiler and Pressure Vessel Code, Table TCD [5]
[b] Principles of Heat Transfer, Kreith, Fifth Edition [15]
[c] Standard Handbook for Mechanical Engineers [13]
[d] Metallic Materials Specification Handbook [6]
[e] TRUMP, A Computer Program for Transient and Steady State Temperature Distributions in Multidimensional Systems [16]
[f] Nuclear Systems Materials Handbook [14]
[g] Metallic Materials and Elements for Aerospace Vehicle Structures [7]
[h] Metals Handbook Desk Edition [23]

表 6.2.B.3-26 鋯合金護套熱相關性質

性質(單位)	溫度值 (°F)				
	-40[a]	392	572	752	932
熱傳導係數 (Btu/hr-in-°F)[b]	0.594	0.690	0.730	0.800	0.870
比熱 (Btu/lbm-°F)[b]	0.067	0.072	0.074	0.076	0.079
輻射率 [b]	0.75 (302°F)				
密度 (lb/in^3)[c]	0.237				

表 6.2.B.3-27 燃料 (UO_2) 熱相關性質

性質(單位)	溫度值 (°F)					
	-40[a]	100	257	482	707	932
熱傳導係數 (Btu/hr-in-°F)[b]	0.409	0.380	0.347	0.277	0.236	0.212
比熱 (Btu/lbm-°F)[b]	0.053	0.057	0.062	0.067	0.071	0.073
輻射率 [b]	0.85 (1,340°F)					
密度 (lbm/in^3)[c]	0.396					

表 6.2.B.3-28 鎳鋼板之熱相關性質

性質	數值
輻射率 [d]	0.2 – 0.32

[a] 外插值

[b] Matpro-Version 11 A Handbook of Material Properties for Use in the Analysis of Light Water Reactor Rod Behavior [19]

[c] Nuclear Power Plant Engineering [20]

[d] Material Emissivity Properties: Electroless Nickel and Mild Steel [24]

表 6.2.B.3-29 SA336, Type 304 不銹鋼材料機械性質

性質(單位)	溫度值 (°F)								
	-40	100	200	300	400	500	600	650	700
極限強度, S_u (ksi) [a]	70.0	70.0	66.3	61.8	59.7	59.2	59.2	59.2	59.2
降伏強度, S_y (ksi) [a]	30.0	30.0	25.0	22.4	20.7	19.4	18.4	18.0	17.6
設計應力強度, S_m (ksi) [a]	20.0	20.0	20.0	20.0	18.6	17.5	16.6	16.2	15.8
彈性係數, E (× 10^6 psi) [a]	28.9	28.1	27.5	27.0	26.4	25.9	25.3	25.1	24.8
熱膨脹係數, α (×10^{-6} in/in/°F) [a]	-	8.6	8.9	9.2	9.5	9.7	9.8	9.9	10.0
柏松比 [a]	0.31								
密度 (lb/in^3) [b]	0.291								

表 6.2.B.3-30 SA479, Type 304 不銹鋼材料機械性質

性質(單位)	溫度值 (°F)						
	-40	100	200	300	400	500	750
極限強度, S_u (ksi) [a]	75.0	75.0	71.0	66.2	64.0	63.4	63.3
降伏強度, S_y (ksi) [a]	30.0	30.0	25.0	22.4	20.7	19.4	17.2
設計應力強度, S_m (ksi) [a]	20.0	20.0	20.0	20.0	18.6	17.5	15.5
彈性係數, E (× 10^6 psi) [a]	28.8	28.3	27.6	27.0	26.5	25.8	24.4
熱膨脹係數, α (×10^{-6} in/in/°F) [a]	8.1[c]	8.5	8.9	9.2	9.5	9.7	10.0
柏松比 [a]	0.31						
密度 (lb/in^3) [b]	0.291						

[a] ASME Boiler and Pressure Vessel Code [5]

[b] Metals Handbook Desk Edition [23]

[c] Extrapolated value

4 銲接設計與規範

按特定元件的設計與功能需求，依循各種相關規範與標準進行本系統元件的銲接操作。在此說明每一元件必須符合的特定要求。

密封鋼筒與燃料提籃皆以銲接程序完成，其銲接程序、過程與銲接人員資格皆符合 ASME Code, Section IX [29]的相關要求。對於密封鋼筒與燃料提籃特定的銲接與測試要求，皆依照 ASME Code, Section III 進行，其中密封鋼筒適用於 NB 規範，燃料提籃則適用於 NG 規範。應用於系統元件的規範替代要求則列於表 3.1.1-8。製作密封鋼筒時的銲道填充材料與銲接程序皆依照 ASME Code, Section II Part C 要求，AWS ER 308L 與 AWS E308LTX-X 的銲接程序分別符合 ASME Code, Section II Part C, SFA 5.9 與 SFA 5.22 規定。

混凝土護箱鋼元件(即內襯(liner)、與底板(baseplate))與傳送護箱皆由銲接製程完成，銲接程序、過程、與銲接人員資格與認證工作皆依照 ASME Section IX 或 ANSI/AWS Dl.1 [28]相關規定辦理。混凝土護箱鋼元件的銲接設計與規格要求皆符合 ASME Code, Section VIII, Division 1, Part UW [31]或 ANSI/ANS D l.1 的銲接設計準則相關規定。傳送護箱的銲接設計與規範要求則符合 ASME Code, Section III, NF [32]的銲接設計準則相關規定。

對所有本系統元件銲接工作的檢驗與測試的要求、及可接受的準則，詳見本安全分析報告的第五章。

5　螺栓與釦件

本章節在於說明選用的螺栓(bolt)與釦件(fastener)材料的相容性，以防止使用中磨損以及使用上所需要的材料強度。

燃料提籃由 SA-193 Gr B6 不銹鋼螺栓組裝而成，以螺栓妥善組合燃料方管外部與角鋼(gusset)、桿件(rod)、支撐板(support plate)與銲接件(weldment)的組合結構。螺栓的預施力提供燃料提籃在裝入密封鋼筒時所需要的剛性。在於某些特定的意外事故下，螺栓的拉力負載可能會增加，這些意外狀況的評估已在於六.二節中說明了螺栓擁有很大的安全餘裕以承受這類假設性的負載。

在惰性環境中以螺栓組裝燃料提籃，螺栓不會有明顯的腐蝕的可能性，所以螺栓材料不會發生應力腐蝕龜裂(stress corrosion cracking)的現象。上舉螺栓(lifting bolts)並非長時間的裝置，所以由於拉應力與腐蝕環境聯合作用所引發的龜裂現象並不會發生在上舉螺栓。

銲接釘(weld post)由 SA479 Type 304 不銹鋼製成，用以將中子吸收物與保護板(retainer) 貼附於燃料方管內側。銲接釘的組裝，加熱熔解銲接釘的背側以形成一個喇叭頭(flared head)，固定 Type 304 不銹鋼保護板在燃料裝填時保護中子吸收物。銲接釘為中子吸收物提供結構支撐，保護板則防止中子吸收物的移動。經評估正常操作、異常事故與假設性意外事故狀況，銲接釘皆有足夠的強度維護中子吸收物駐留在正確的位置。

完成組裝後的密封鋼筒無需螺栓與釦件。對裝填燃料後的密封鋼筒的垂直吊運與操作，密封鋼筒頂部密封上蓋上的六處適用於吊索(hoist ring)或其他吊舉治具(fixture)的螺紋吊舉位置，其強度已於六.二節中評估過。

混凝土護箱有多個進氣口、出氣口的網板(screen)與一個護箱蓋，以及許多出氣口溫度監視器，沒有針對移除此些溫度監視器的狀況所做的評估。

傳送護箱的設計，包含一組保護環，用以預防已裝填燃料的密封鋼筒在傳送護箱中的吊舉操作時，因吊舉高度過大，造成密封鋼筒吊舉超出規範範圍而頂舉傳送護箱的情形。保護環的設計目的就是提供當密封鋼筒吊舉中頂到保護環時，用來承受傳送護箱的重量；此時，保護環承受剪力負載。保護環由 ASTM A588 低合金鋼製作，在第六.二節本文中已評估其在負載情形下，仍具有足夠的安全餘裕。

藉由程序與技術規範的限制來控制傳送護箱的吊舉操作時的周圍溫度必須高於-17.8℃ (0°F)，這個限制措施可排除碳鋼螺栓與結構元件脆性破壞的可能性。

6　塗裝

本系統的混凝土組件與碳鋼的曝露表面必須要施以特別的塗裝，這類塗裝可以降低碳鋼表面腐蝕的可能性，並且減少水池中裝填用過核子燃料、乾式傳送與貯存時，因元件與操作環境作用的有害影響(adverse interactions)，而引發不同材料間的有害反應(adverse reactions)。以下各節說明應用於本系統各元件的不同形式的塗裝。

(1)　無電鍍鎳

燃料提籃主要由碳鋼製成，在製造、燃料裝填到最終的密封操作過程都存在電位腐蝕的可能。但在密封鋼筒最終密封銲接、乾燥及填充惰性氣體之後，即有效地消除碳鋼提籃腐蝕的可能。

由材料腐蝕與操作的觀點來看，密封鋼筒沉浸在燃料池中裝填燃料的階段是最關鍵的時期。為了要降低燃料裝填時期的池水對密封鋼筒的可能腐蝕現象，提籃碳鋼表面塗裝一層無電鍍鎳(electroless nickel-coated)，該無電鍍鎳塗裝對系統提供良好的保護，阻止材料的腐蝕並減少燃料裝填過程中的水質清晰度的損失，並且無電鍍鎳塗裝亦可降低提籃元件與用過核子燃料池水的可能作用。另在於密封上蓋銲接與密封蓋根部銲道(root pass)移除操作前，應對上蓋底部與鋼筒內水面所形成氣室進行氫含量的取樣檢測。

在燃料提籃組裝過程，可能發生局部塗裝損傷的情形，但這並不足以造成燃料提籃功能或是結構安全上的顧慮。此外，燃料提籃的組成外形上，有一些無法完全鍍鎳的區域，由於這些區域是比較次要的，應不足以影響燃料提籃的功能與操作。

燃料提籃元件的無電鍍鎳塗裝製程是遵循 ASTM B733 [30]的相關規定施作，塗裝的厚度遵循服役狀態(service condition)SC3 與 Alloy Type IV 或 V 規定，無須後續熱處理。製品完成後必須作批量試片測試，並依照製品的外觀與塗裝附著情形驗收，該測試試片必須能代表材料與其塗裝後的狀態。

(2)　其他塗裝

除了屏蔽門與滑軌等摩擦的碳鋼表面外，傳送護箱曝露在外的碳鋼表面不是塗裝 Carboline Carboguard® 890N 就是塗裝 Keeler & Long KLE 系列的環氧化物琺瑯漆(epoxy enamel)或同級品。這兩種塗料皆已經測試與認可，可在核能用途的服役等級 1 (Service Level 1)的情況下使用，這包含了沉浸在用過核子燃料池的情

形。對於未塗裝而曝露在外的摩擦表面而言，傳送護箱在用過核子燃料池操作期間，將視需要塗佈經認可的核能等級潤滑劑，並確認每一個密封鋼筒在裝填燃料過程前都經過仔細的塗佈潤滑劑，以防止池水對於此等金屬表面的腐蝕與有害的影響。琺瑯漆塗裝與摩擦表面的潤滑劑確保設施在水池操作期間，不會因設施表面與池水作用而產生過多的氫氣、腐蝕碳鋼表面或是造成塗裝物質消散於燃料池中。鋪設於傳送護箱內表面與屏蔽門頂部的氮化鋼帶(Nitronic 30 wear strips)可保護塗裝層，避免因密封鋼筒的操作引起塗裝層過多的磨損。

由於傳送護箱銜接器只在於密封鋼筒傳送至混凝土護箱過程，或是鋼筒再取出時的乾燥環境下操作，所以不需要核能等級的塗料。在傳送護箱銜接器(adapter)的曝露碳鋼表面(除了屏蔽門滑軌)塗佈兩層經過認可的塗料，可減少長期曝露於空氣中所造成的腐蝕；但在可能磨耗的表面則可施以核能等級的潤滑劑，以消除銜接器表面與操作環境間可能的有害影響。

混凝土護箱的碳鋼元件在無混凝土覆蓋處，施以抗熱矽氧烷琺瑯漆(PPG silicone enamel) 或同級品塗料。此塗料可提升材料曝露於外在環境下的抗腐蝕能力，使貯存時的混凝土護箱具備抵擋長期曝露於高溫度下的能力。

曝露的混凝土護箱表面塗佈商用級密封塗料(sealant)，用以保護長期貯存的混凝土護箱表面。

至於鍍鎳處理，因其塗裝之特性未被使用於相關之分析中，所以對於輕微的塗裝刮損與磨損並無需即時處理。每年檢查一次本系統的曝露碳鋼元件表面的塗裝，並依據製造商的建議，按維護計畫完整修復塗裝層。

7　加馬與中子屏蔽材料

本系統主要以鉛、混凝土、鋼與 NS-4-FR 作為屏蔽材料。

(1)　加馬屏蔽材料

鉛與鋼是傳送護箱中主要的加馬射線的屏蔽材料。鉛加馬屏蔽是由實心鉛磚(solid Chemical Copper grade lead bricks)所組成，鉛的組成遵照 ASTM B29 (Section 8.13.6) [33]規定製作，成份除了鉛之外，還含有微量銅以改善材料的加工特性。鉛磚屏蔽以巢狀堆疊的方式設計，以杜絕鉛磚之間水平間隙與垂直間隙的發生。鉛磚沿著傳送護箱內側鋼殼屏蔽堆疊安裝，並被底部/上端鍛製件與外側鋼殼所包覆，鉛磚與外殼之間的間隙填充中子屏蔽材料。傳送護箱加馬屏蔽細項請參考相關設計說明。

碳鋼內襯是混凝土護箱主要的加馬射線屏蔽，混凝土護箱的鋼筋混凝土當然也提供可觀的加馬射線屏蔽功能。在傳送護箱與混凝土護箱屏蔽功能分析中，密封鋼筒外殼的屏蔽功能也列入考慮。

(2)　中子屏蔽材料

混凝土護箱中的混凝土中子輻射屏蔽功能取決於矽與水的組成比例。矽、氫與氧為低原子序材料，可有效減速並捕捉活潑(energetic)的中子。由於這些材料的密度與混凝土的混合比之間具有相當程度上的函數關聯性，因此可以藉由設計混凝土殼的厚度來建立所需的中子輻射屏蔽功能。

傳送護箱的 NS-4-FR 中子屏蔽中的硼占有≧0.6 的重量百分比。NS-4-FR 是 NAC International 公司專利的商業產品，主要由鋁合金、碳、氧與氫所組成。

從密封鋼筒散發出的中子和 NS-4-FR 中的低密度成分碰撞後會被熱中子化，澆注於傳送護箱的外殼與鉛加馬屏蔽間的環帶區域的硼可有效的吸收熱中子。NS-4-FR 的配置請參考相關圖面說明。材料的安裝則遵照專利的澆注程序，以確保材料中的間隙與空孔得以消除。

NS-4-FR 材料具有相當的中子吸收功能，此材料已在美國、日本、西班牙與英國等國所核准的貯存護箱中使用超過 15 年的時間，其間沒有報導指出 NS-4-FR 材料在長期做為人類與環境的中子屏蔽用途，會降低其屏蔽效力；NS-4-FR 的聚合物對於系統中的不銹鋼、碳鋼或鉛亦無潛在的反應。

經由長期的功能穩定性測試，證實 NS-4-FR 材料在-40°F 到 338°F 溫度間仍具備可靠的效能。這些測試包括將試片置於開放的大氣與密閉的小空間中，並施

以固定與週期性的熱負載，在隔絕氣體與材料劣化因素下，評估材料的流失。測試的結果顯示，在測試的溫度範圍內，於隔絕氣體的環境下，無 NS-4-FR 材料損失，也未產生任何可量測得到的氣體，材料無劣化與脆化的現象，所以不存在形成易燃性氣體的議題。再者，密閉性的材料測試(即使用於本系統中的情況)結果也明顯的優於曝露於大氣的情況。

NS-4-FR 材料在反應器爐水下的輻射曝露測試結果顯示，沒有明顯的材料劣化與氫原子損失(低於 1%)的現象。這些測試也證實 NS-4-FR 的中子屏蔽能力遠超過系統 50 年使用壽命的設計。NS-4-FR 的輻射曝露測試結果顯示，在於 9×10^{14} n/cm^2 的劑量率下，不會發生材料脆化與氫氣損失，此劑量率超過設計基準的燃料連續貯存 50 年的劑量(預估為 1.7×10^{12} n/cm^2·年)。所以輻射效應應不會造成 NS-4-FR 材料的劣化或脆化。

由於傳送護箱中的 NS-4-FR 是密閉澆注於外殼與鉛屏蔽之間，並以全穿透或填角銲接的方式，以鋼板密封，其可保有原設計形狀的時間超過傳送護箱的預期壽命。另外，NS-4-FR 材料不會在於鉛屏蔽與傳送護箱外殼間的環狀區域中移動。

8 中子吸收物覆材

中子吸收物覆材包覆硼元素，特別是同位素 ^{10}B，因為其具有高度吸收熱中子的能力而被廣泛使用於核能工業，此類材料可確保貯存護箱或傳送護箱中的用過核子燃料在正常操作、異常與意外事故狀態下皆可處於次臨界狀態。臨界安全與否視中子吸收物是否能維持於燃料方管壁上的正確位置與所需的硼的數量是否均佈於中子吸收物覆材而定。中子吸收物 (臨界控制)覆材可製成金屬基材內包覆細小顆粒的複合材料或是由鋁合金板包覆的硼合金。為了要有良好的中子吸收能力，細小的碳化硼顆粒必須很均勻的分佈在於金屬基材中，所需的中子吸收物 ^{10}B 的面積密度視燃料束型式與中子照射程度而定，一般有三種形式的商用中子吸收物使用於用過核子燃料貯存容器燃料提籃與傳送護箱，即硼鋁合金、硼與金屬基材的複合材料(MMC)及 Boral。

中子吸收物覆材所使用的專業術語：

接受–	測試某一製程批次材料是否符合該材料性質與特性，以便接收該批次材料作為商業使用。
面積密度–	中子吸收物的體密度乘以該板的厚度，表示為材料板的面積密度。
設計者–	機構承擔乾式貯存系統或運送容器的設計者或持照者的責任。設計者通常是直接或是間接(透過一製造的次包商)為中子吸收物覆材的買主。
批次–	經取樣確定具一致性並累積到某一數量的產品或材料。
中子吸收物–	具有較大熱中子或/和超熱(epithermal)中子吸收截面的核種(nuclide)。
中子吸收物覆材–	混合物、合金、複合材料或其他材料，用來包覆中子吸收物。
中子穿透/衰減測試–	將材料置於熱中子束下，以量測在一定時間內穿過材料的中子數。經由一系列的校正標準的測試，將受觀察的中子數量率轉換為面積密度。傳送測試所用的最大的中子束斷面為 6.45 cm^2 (1 in^2)。

中子截面–	中子與原子核碰撞的機率，為中子能量與原子核結構的函數。
包裝–	放射性物質的運送過程中，包裝需要完整密封放射性物質。
資格–	經由評估或測試，或二者都做；材料經過特定的製造過程，顯現出材料在於特定用途上的一致性與耐久性。

本貯存系統的中子吸收物裝設在燃料提籃中用過燃料的側邊。中子吸收物的材料與尺寸說明於圖面 NO. 630075-072-0。材料為金屬複合材料(包含硼鋁合金、硼金屬基材複合材料(MMC)與 Boral)，這種可用的材料有多種不同的商標名稱。在設計時即考量可替換不同的中子吸收物，因而提供了組裝的彈性，在符合確保臨界安全所需特性之前提下，選用最經濟與能取得的中子吸收物。中子吸收物重要設計特性為：

- 燃料提籃的 ^{10}B 最小有效面積密度為 0.02 g/cm^2；
- 碳化硼必須均勻分佈；
- 最小強度必須等值於 1100 系列鋁合金 371℃(700°F)時的強度，以足夠維持其形狀；及
- 有效的熱傳導必須大於或等於熱傳分析所用的數值(第六.三節）。

中子吸收物 ^{10}B 最小含量的製造規格，取決於材料的有效吸收能力，法規規定臨界分析對於 Boral 只可取用 75%的吸收效能，硼鋁合金與硼金屬複合材料則可採用 90%的吸收效能。驗證中子吸收物的 ^{10}B 的面積密度的中子穿透/衰減測試，則說明於第 5 章附錄 A。

表 6.2.B.8-1 列表說明各種不同中子吸收物覆材所需的最小有效 ^{10}B 的面積密度與相對應的 ^{10}B 面積密度製造規格。由於金屬複合材料中子吸收物在製造後，很快於金屬表面形成氧化層，使得其與不銹鋼與無電鍍鎳塗裝層的反應受到限制，材料也受到保護而免於劣化。所以，預期中不會有與鋁基臨界控制材料的可能反應發生。貼附於燃料方管上的中子吸收物覆材與保護板的相關圖面，詳見圖面 No.630075-091-0。

吸收中子產品經由標準工業檢查以確認其物質特性的可接受性，諸如依據設計圖面與製造規範之尺寸、真平度(flatness)、真直度(straightness)、熱傳導度、抗拉強度(用於結構考量)與其他有關的機械性質，表面品質與最後加工。接收準則與相關工業標準則說明於第 5 章附錄 A。

在申照時，必須明確說明中子吸收物覆材在定義的環境條件下，該材料在執行設計功能時的限制(Qualification)； 環境條件對於中子吸收材料的限制與確認規格(validation specifications)定義於第5章附錄A，包含短時間的傳送操作、正常狀況、異常狀況與意外事故。

中子吸收物覆材的接收測試說明於第 5 章附錄 A，必須確認材料符合規格要求，包含吸收物覆材的含量、分佈的均勻性、機械性質、熱傳導性、表面光滑度與尺寸。

所有限制與接收條件皆遵照 NAC International 公司的品保計畫。

表 6.2.B.8-1　中子吸收物覆材最小 ^{10}B 裝填

中子吸收物	最小有效面積密度要求(^{10}B g/cm^2)	臨界分析時的有效百分比%	製造時最小面積密度要求(^{10}B g/cm^2)
硼鋁合金	0.02	90	0.022
硼鋁複合材料 MMC	0.02	90	0.022
Boral	0.02	75	0.027

9 混凝土與鋼筋

混凝土護箱是以澆注 28 天後具有 4,000 psi 抗壓強度的波特蘭 II 號水泥，並結合垂直與環狀鋼筋箍筋所形成的鋼筋混凝土結構物。護箱依據美國混凝土協會(ACI) "Building Code Requirements for Structural Concrete" (ACI 318) [2]製作。

混凝土的混合比例按相關規範製作，使混凝土具備高防水能力；預期在於護箱壽限的貯存環境下，混凝土外殼不會腐蝕或明顯的劣化。設計與分析中已考慮混凝土可以避免任何明顯水化合損失的最大溫度。

混凝土護箱鋼筋材料為 ASTM A615/A615M, Grade 60，設計時按鋼筋在於混凝土護箱的所在位置，決定鋼筋的直徑與長度。鋼筋完全置入於混凝土材料中，所以在於護箱貯存期間不可能有鋼筋劣化的顧慮，並且鋼筋的裝設皆依照 ACI 318 規定施作。

10 化學與電化學反應

本節評估本系統的製作與運轉所用的材料，在材料彼此間、或與內容物或環境是否會有化學反應、電化學反應或是其他反應發生。所有操作階段-裝填、移除、吊運與貯存，在正常、異常與意外事故狀況之分析中，皆要考慮環境因素的影響。評估結果顯示，確認對於整體混凝土護箱、燃料提籃、密封鋼筒的完整性，以及燃料再取出性與結構完整性，沒有任何可能造成危害的潛在反應，本評估係依照 ISG-15[15]規範進行。

評估結果顯示，預期密封鋼筒與燃料護套的熱相關材料性質不會改變，並且沒有表面腐蝕發生。由於確定沒有潛在的反應存在，所以沒有直接或間接的因素會造成燃料提籃間隙的改變或任何安全性元件的劣化。

(1) 元件操作環境

本系統的大部份材料曝露在兩個操作環境：1. 開放的密封鋼筒內含燃料池水與用過核子燃料；或 2. 密閉的密封鋼筒內含氦氣，但外部環繞空氣/雨水/冰與海(含鹽份)水/空氣。本節評估密封鋼筒各元件在各種操作環境下曝露時的可能反應，這些環境包括燃料裝填、移除、吊運與貯存，及正常、異常與意外事故狀態。

為了使密封鋼筒內部長期處於乾燥的氦氣環境，在封閉密封鋼筒前皆已先行移除鋼筒內部的溼氣與氧氣。以氦氣置換鋼筒內部的氧氣，可以有效抑制化學反應；封閉的鋼筒內部的乾燥環境也可抑制不同金屬接觸時的電化學腐蝕。

(2) 元件材料分類

本節基於元件材料物理、化學性質與元件功能的特性，歸類說明材料化學與電化學腐蝕的可能性。材料歸類為不銹鋼、非鐵材料(nonferrous)、碳鋼、塗料、混凝土與臨界控制材料，以評估各類材料曝露在使用環境的情況。

密封鋼筒元件材料在於正常、異常狀況或意外事故、燃料裝填、燃料移除、吊運與貯存運轉等任何時候，鋼筒元件間或密封鋼筒與操作環境間不會發生反應。由於沒有反應發生，就不會產生氣體或是元件腐蝕。

<u>不銹鋼</u>

預期密封鋼筒的不銹鋼材料在任何環境條件下，除了海水之外，不會與環境作用。當含氯化物的海水噴佈在鋼筒表面，而且氯化物聚集並長期(數週)停留在

鋼筒表面時，是有可能造成鋼筒表面初步的腐蝕，但此作用也只侷限在鋼筒曝露的外表面，並且腐蝕速率很慢，以致令人無法察覺出腐蝕產物或產生的氣體。對此，本系統以平滑的鋼筒外表面，來減少鹽份聚集鋼筒表面的現象。

除了密封上蓋(closure lid) 外，本系統使用 Type 304/304L 不銹鋼做為所有密封鋼筒密封邊界元件材料。不銹鋼材料表面無需塗裝施工，因為 Type 304/304L 不銹鋼在銲接時可防止碳化鉻在晶粒邊界沉澱，其抗粒間應力腐蝕(intergranular stress corrosion)引發材料劣化的能力超過密封鋼筒的使用壽限。製造規範中將最大的沃斯田不銹鋼層間溫度(interpass temperature) 控制在 176.7℃(350°F)以下，除了銲接與熱切割外，材料不會加溫到 426.7℃(800°F)以上的溫度。銲接中會有一些 Type 304/304L 不銹鋼輕微的敏化作用(sensitization)，但在密封鋼筒壽限中不會影響材料的功能。

<u>碳鋼</u>

燃料提籃結構以碳鋼製成。碳鋼與密封鋼筒不銹鋼外殼及燃料方管中保護中子吸收物的不銹鋼薄板間，存在一微小電化學反應。由於碳鋼元件藉由無電鍍鎳塗裝的浸泡程序已確認經過妥善塗裝，可減少元件曝露在空氣或水中的腐蝕的可能性，故當碳鋼在水中與水接觸時，因電化學作用而造成腐蝕現象是相當有限的。BWR 燃料池水為除礦水質，其導電性不足以明顯地引發金屬間的腐蝕。一旦密封鋼筒完成燃料裝填，將很快地移除筒中的水及空氣，並回填氦氣後再密封。水與濕氣的移除，可排除碳鋼與不銹鋼之間的電化學腐蝕的激化因素。另外，氦氣回填亦可有效遏止材料氧化。

傳送護箱結構元件主要以 ASTM A588 與 A36 碳鋼製作。曝露的碳鋼元件不是以 Keeler & Long KLE-Series Epoxy Enamel，就是以 Carboline Carboguard® 890N 塗裝，以保護水中操作時的傳送護箱，並使傳送護箱表面平滑，以利傳送護箱水中操作後的除污工作。

混凝土護箱的混凝土外殼中包覆一組 ASTM A36 碳鋼材料製成的鋼質內襯(steel liner)，以及其他的碳鋼元件。在鋼襯與空氣進出口的碳鋼曝露表面，將塗裝 PPG Silicone Enamel 矽珐瑯漆塗料，隔絕環境中的溼氣，此種矽珐瑯漆是適合於連續高溫環境下使用的塗裝材料。

綜合以上評估，預期操作環境與提籃支撐、燃料方管、傳送護箱或混凝土護箱的碳鋼元件間，不會有反應發生。

<u>**非鐵金屬**</u>

系統中的鋁合金使用於中子吸收物覆材。材料沉浸在水中時，鋁合金材料與中子吸收物的不銹鋼薄片及燃料方管碳鋼接觸時，可能因為電化學因素引發腐蝕現象，此時水的導電性是影 響腐蝕主要的因子。但由於一般 BWR 燃料池水為除礦水質，其導電性不足以引發明顯地金屬間的腐蝕。

鋁合金在製造後，迅速在表面形成一薄薄地氧化層，使材料免於進一步氧化。氧化層緊密地附著在基材上，故鋯合金不易與周圍材料起反應。氧化鋁的體積不會明顯地與時俱增，所以未來由鋼筒中取出用過核子燃料時，不會因為腐蝕產物的增加而造成鋁合金元件的黏著現象。

在電動勢能表中的鋁合金屬於高位，當鋁合金在燃料池中與不銹鋼或碳鋼接觸時，雖然鋁合金形成陽極，但 BWR 燃料池水為除礦水質，其導電性不足以引發明顯地金屬間的腐蝕；另長期貯存環境的乾燥環境也足以抑制電位腐蝕。

由以上的討論，可以得到鋁合金元件表面的原始氧化層與長期貯存的環境可以抑制任何可能的電位反應之結論。

供應商(vendor)與美國核能管制委員會(NRC, Nuclear Regulatory Commission)均推斷鋁合金元件浸泡在用過核子燃料池時，易燃性氣體(主要為氫氣)可能由化學反應與/或輻射照射所產生。進一步評估顯示鋁合金/池水反應產生的氫氣，有可能集中在密封鋼筒中接近甚至超過百分之四氫含量的低易燃極限(LFL, Lower Flammability Limit) ，這種現象在高於 65.6-71.1 ℃(150-160°F)的溫度時較易發生。

所以，密封鋼筒在燃料裝填與移除時，因為燃料提籃中的鋁合金中子吸收器與用過核子燃料池水之間的化學反應，會產生少量的易燃氣體(主要為氫氣)是合理的結論，但產生易燃氣體的現象會因為移除密封鋼筒中的水份與乾燥鋁合金表面而停止。

(3) 操作程序評估

本節評估規劃中操作程序以確認發生電化學反應(galvanic reactions)、腐蝕或易燃氣體的可能。如前所述，已經確認本系統沒有潛在的化學、電化學或其他類似反應會發生；而貯存時乾燥的惰性氣體環境可抑制電化學反應、腐蝕與易燃性氣體形成的可能。在密封上蓋銲接與密封鋼筒燃料移除時的密封上蓋根部銲道(pass root)移除操作時，必須實施氫氣的低易燃性限制(Lower Flammability Limit (LFL))的監測。如果氫氣濃度超過 LFL 的 60% (即 2.4%H_2)時，以上操作就必須停止，並且進行改善直到氫氣降到可接受的濃度。所以在於密封鋼筒的各階段操作

期間，宜採取嚴密監控措施，應不會有可燃性氣體累積至可燃或具爆炸的氣體數量的不利情況發生。

裝填燃料操作評估

在密封鋼筒密封操作過程中，密封鋼筒自燃料池取出後，將先略降鋼筒內的水位 (大約移除了 70 加侖水)，以確保銲接時密封上蓋與鋼筒外殼的銲接區域是乾燥的。鋼筒內的水位雖略降低，但不會使燃料棒曝露於空氣中。由於密封鋼筒的內徑與密封蓋外徑的間隙很小，鋼筒內因化學反應所釋放的氣體可能累積在蓋板底下的無水空間。

當中子吸收板(neutron absorber panel)曝露在空氣中時會造成鋁合金表面氧化；曝露在水中也會有化學反應；當其與不銹鋼或碳鋼接觸時可能也會有電化學反應。鋁合金在水中反應會產生氫氣，過程如下：

$$2\ Al + 3\ H_2O \Rightarrow Al_2O_3 + 3\ H_2$$

當裸露的鋁曝露在空氣或水中時與氧會反應，而在鋁的表面形成不活潑與灰色的氧化鋁($A1_2O_3$)薄膜，這層薄薄地氧化鋁會隔絕鋁金屬與氧氣，而避免進一步氧化。在(pH)中性的溶劑中，此氧化層是穩定的。

BWR 燃料池水未添加硼酸並且水質中性(pH 直接近 7.0)，pH 值、水化學與水溫度隨燃料池而異。因為反應率大多取決於以上的參數，所以參數考慮會因不同的燃料池而異。故可燃氣體(氫)的產生率很難準確地估算，但在 pH 中性燃料池水中反應率勢必較慢。

本系統燃料提籃結構由塗裝無電鍍鎳的碳鋼燃料方管、支撐元件組成。在相對短暫的鋼筒沉浸水中或鋼筒含水時間，碳鋼材料因為無電鍍鎳塗裝，故不與池水反應，與池水接觸時不會產生反應氣體。所以塗裝層與受塗裝的元件皆不會產生可燃氣體。

為了確保用過核子燃料安全裝填於密封鋼筒中，第五章的燃料裝填程序中說明了密封上蓋與鋼筒外殼的根部銲道銲接操作時應執行氫氣監測，監測系統可偵測到氫氣含量在於低易燃性限制(LFL)60% 的氫氣濃度(即 2.4% H_2)。氫氣偵測儀連通到鋼筒內容積，以便在銲接開始前先偵測。在根部銲道銲接操作中，當偵測到氫氣含量超過 2.4%時，將停止銲接操作，並且以新鮮空氣、氮氣、氩氣或氦氣充填密封蓋以下區域以移除氫氣，或使用真空幫浦排除氫氣。

真空幫浦會將密封鋼筒內的氫氣抽至不可能產生爆炸的濃度。一旦根部銲道(root pass)完成，就不再有氣體燃燒爆炸的可能，因為可燃氣體已經與火源(銲槍)隔離，此時可以停止氫氣監測。

在執行密封上蓋與密封鋼筒的外殼根部銲道銲接時，氫氣偵測儀接到通氣管以監測氫氣的濃度。在密封蓋銲接與密封鋼筒水壓測試後，將進行鋼筒洩水。一旦鋼筒乾燥後，就不會再有可燃氣體在鋼筒內形成。

卸除燃料操作評估

在最後的密封銲接操作前，密封鋼筒在乾燥後立刻回填氦氣，從而排除鋼筒中所有水分與氧化氣體，所以在貯存期間內的密封鋼筒中沒有可燃氣體。在第 5 章中已經說明了在密封上蓋銲道切割/移除操作時，應監測氫氣含量以確保移除密封鋼筒燃料操作的安全。

開啟密封鋼筒的主要步驟是移除通氣孔蓋、排水孔蓋與密封上蓋的銲道，預期以切除與研磨方式移除銲道。在通氣孔蓋與排水孔蓋焊道移除後，即對鋼筒做放射性氣體取樣，經由通氣孔注入氮氣與注水孔注入冷卻水至鋼筒內。在切除密封蓋銲道前，已經降低鋼筒內水位，使得密封蓋銲道鑿除位置維持乾燥作業環境，同時氫氣偵測器將連結至鋼筒通氣孔，以進行氣體取樣。如果在密封蓋銲道移除作業中偵測到無法接受的氫氣濃度時，立刻停止銲道移除作業，並以空氣、氮氣、氬氣或氦氣注入鋼筒中，或以真空幫浦抽出鋼筒中氣體。

結語

上述之氫氣偵測措施，可防止密封上蓋銲接或銲道移除時發生任何氫氣燃燒的事故。總結這個評估結果，本系統的密封鋼筒燃料裝填與移除的作業程序管制，足以將危險的發生機率降到最低。

11 護套完整性

本系統與操作過程透過對用過核子燃料貯存環境的控制，使得用過核子燃料護套在傳送與貯存狀態下的劣化(deterioration)行為減到最小。

在乾式貯存時，燃料護套保存在一個高純度氦氣正壓力的環境，以限制密封鋼筒內氧化物總量與控制護套的溫度。氧化物總量限制小於 1 莫耳(mole)；在正常貯存與傳送狀況下，限制最高燃料護套溫度必須小於 400°C；對異常與意外事故狀況下，限制最高燃料護套溫度必須小於 570°C。

真空乾燥作業可移除密封鋼筒中的氧化物。真空乾燥作業中，殘存於密封鋼筒中的溼氣與水因為鋼筒內部壓力降低而氣化，所有的水氣與殘存的氣體經由真空幫浦的運轉而由排氣管與排水管排出鋼筒。在系統乾燥作業過程中，鋼筒內燃料的衰變熱在鋼筒內部提供熱量加速水份的氣化，也提升護套的溫度。真空幫浦連續運轉到鋼筒內部壓力降到 10 torr 以下，此壓力為 22.2℃(72℉)時水的蒸氣壓力的一半。在正常裝填狀況下，密封鋼筒內部的溫度會高於 22.2℃，於達到真空壓力而停止真空系統運作後，如果此時密封鋼筒中有水，水會在於後續至少持續 10 分鐘的乾燥驗證過程中氣化，進而使密封鋼筒內壓力提高超過上述 10 torr 的接受標準。 成功完成以上的乾燥驗證過程後，重新啟動真空幫浦，繼續排除鋼筒內的殘留氣體，直到壓力達到 NUREG-1536 [39]所建議的 3 torr 以下。鋼筒內壓力由 10 torr 降到 3 torr 以下時，將使得鋼筒內殘存的非凝結性(noncondensing)氣體與可能造成氧化的氣體總量少於 1 莫耳(mole)。然後將高純度(≧ 99.995%)的氦氣回填至鋼筒內，使鋼筒維持正壓。完成的真空乾燥作業後將可確保最終密封鋼筒在高純度氦氣、正壓力環境下的氧化氣體少於 1 莫耳，殘存氧化氣體少於 PNL-6365 [40]的 0.25 vol %建議值。

藉由本系統的操作程序與各項操作完成時間的安排，可限制燃料護套的環向應力(hoop stress)與降低護套氫化物方位重排(reorientation)的可能性，以防止熱負載引發的燃料護套劣化。在於六.三節中說明系統在於燃料裝填過程、正常、異常與意外事故狀態下的熱傳分析，本系統相關的溫度限制準則如下所述：

1. 正常貯存狀況與短時間燃料裝填操作下，計算所得的最大燃料護套溫度不可高於 400°C (752℉)。
2. 限制異常狀況與意外事故狀況下的燃料護套溫度不可高於 570°C (1,058℉)。

由本系統鋼筒、燃料提籃與內部燃料的熱傳暫態計算中，可知正常與意外事故在燃料護套上會造成些微的熱負載與應力。在真空乾燥過程中，如果發生環狀

間隙水冷系統(ACWS)失效，則密封鋼筒要回填氦氣至 5.5 bar，並且保持密封鋼筒與傳送護箱間通道暢通以保持氣冷狀態。

由於氦氣與燃料在質量上的差異，大約是一比十萬，氦氣被加熱時僅對燃料溫度有些微的降低作用，更何況填充的氦氣因為燃料提籃、密封鋼筒底板與外殼質量之加溫，故氦氣注入時對燃料護套的衝擊是相當有限的。

在於 5.1.3 節說明密封鋼筒燃料移除的評估中，與以上燃料裝填的說明有相似的結論。當密封鋼筒首次準備移除燃料時，並以氮氣至少循環填灌 10 分鐘來沖除鋼筒中的放射性氣體。氮氣的循環方式有如氦氣的回填，雖然氮氣比氦氣具有較高的熱容量(大約 10 倍)，但當比較於金屬密封鋼筒、燃料提籃與燃料時，氮氣對於燃料護套所造成的熱梯度的影響仍然顯得微不足道。填充氮氣後，以流率 17.3~27.7 l/min (5~8 gpm)的水填灌進密封鋼筒中，此最大水流率是基於密封鋼筒回注水的熱工水力分析(thermal hydraulic analyses)計算，其水溫與壓力已定義於 5.1.3 節的步驟 21，密封鋼筒的燃料濕式移除，最初經由洩水管注入密封鋼筒的水迅速氣化成蒸氣並到達鋼筒底板，鋼筒中的蒸氣可和緩地移除燃料提籃與燃料多餘的熱量，不會對燃料護套應力造成熱衝擊。當鋼筒內溫度逐漸降低，而經由洩水管注入的水可逐漸累積於鋼筒底部。以 RELAP 熱工水力分析評估密封鋼筒的注水操作，結果顯示鋼筒注水期間的護套徑向溫度梯度小於 0.56℃(1°F)，如此小的溫度提升的結果，符合以蒸氣冷卻後再以水冷卻的逐步冷卻措施的效果。燃料束軸向的溫度梯度雖大於徑向的溫度梯度，但由於燃料棒在軸向可自由地膨脹，所以不會引發熱應力。先以氮氣稀釋放射氣氣體，接著以蒸氣移除鋼筒內的熱量，這種冷卻方式相對於水冷卻顯得比較和緩，並且對護套不會產生明顯的熱應力。

綜合上述正常狀況、傳送狀況、異常狀況或意外事故下，均未有造成燃料護套劣化或破損。

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13 材料供應商文件

本節提供六.二.B.6 節塗裝技術資料。

(1) 無電鍍鎳塗裝

Nonelectrolytic Nickel Plating

*By the ASM Committee on Nickel Plating**

THREE METHODS may be employed for depositing nickel coatings without the use of electric current:

1. Immersion plating
2. Chemical reduction of nickelous oxide at 1600 to 2000 F
3. Autocatalytic chemical reduction of nickel salts by hypophosphite anions in an aqueous bath at 190 to 205 F ("electroless" nickel plating).

All three methods are, under certain limited conditions, useful substitutes for nickel electroplating; they are particularly useful in applications in which electroplating is impracticable or impossible because of cost or technical difficulties. Of the three methods, electroless nickel plating is in widest use, and is the method to which the most attention is devoted in this article.

Immersion Plating

The composition and operating conditions of an aqueous immersion plating bath are as follows:

Nickel chloride ($NiCl_2 \cdot 6H_2O$)	80 oz per gal
Boric acid (H_3BO_3)	4 oz per gal
pH	3.5 to 4.5
Temperature	160 F

When using this bath, it is desirable, but not mandatory, to move the work at a rate of about 16 ft per min.

This solution is capable of depositing a very thin (about 0.025 mil) and uniform coating of nickel on steel in periods of up to 30 min. The coating is porous and possesses only moderate adhesion, but these conditions can be improved by heating the coated part at 1200 F for 45 min in a nonoxidizing atmosphere. (Higher temperatures will promote diffusion of the coating.)

High-Temperature Chemical-Reduction Coating

By the reduction of a mixture of nickelous oxide and dibasic ammonium phosphate in hydrogen or other reducing atmosphere at 1600 to 2000 F, a nickel coating can be deposited without the use of electric current. This method (U. S. Patent 2,633,631) consists of applying a slurry of the two chemicals to all or selected surfaces of the workpiece, drying the slurry in air, and performing the chemical reduction at elevated temperature. No special tanks or other plating facilities are required. Some diffusion of nickel and phosphorus into the basis metal occurs at elevated temperature; when the coating is applied to steel, it will consist of nickel, iron, and about 3% phosphorus. The slurry may be used for brazing.

Electroless Nickel Plating

The electroless nickel plating process employs a chemical reducing agent (sodium hypophosphite) to reduce a nickel salt (such as nickel chloride) in hot aqueous solution and to deposit nickel on a catalytic surface. The deposit obtained from an electroless nickel solution is an alloy containing from 4 to 12% phosphorus and is quite hard. (As indicated later in this article, the hardness of the as-plated deposit can be increased by heat treatment.) Because the deposit is not dependent on current distribution, it is uniform in thickness, regardless of the shape or size of the plated surface.

Electroless nickel deposits may be applied to provide the basis metal with resistance to corrosion or wear, or for the buildup of worn areas. Typical applications of electroless nickel for these purposes are given in Table 1, which also indicates plate thicknesses and postplating heat treatments.

Surface Cleaning. In general, the methods employed for cleaning and preparing metal surfaces for electroless nickel plating are the same as those used for conventional electroplating. Heavy oxides are removed mechanically, and oils and grease are removed by vapor degreasing. A typical precleaning cycle might consist of alkaline cleaning (either agitated soak or anodic) and acid pickling, both followed by water rinsing.

Prior to electroless plating, the surfaces of all stainless steel parts must be chemically activated in order to obtain satisfactory adhesion of the plate. One activating treatment consists of immersing the work for about 3 min in a hot (200 F) solution containing equal volumes of water and concentrated sulfuric acid. Another treatment consists of immersing the work for 2 to 3 min in the following solution at 160 F:

Sulfuric acid (66° Bé)	25% by volume
Hydrochloric acid (18° Bé)	5% by volume
Ferric chloride hexahydrate	0.53 oz per gal

Pretreatments that are unique to electroless nickel plating include:

1. A strike copper plate must be applied to parts made of or containing lead, tin, cadmium or zinc, to insure adequate coverage and to prevent contamination of the electroless solution.
2. Massive parts are preheated to bath temperature to avoid delay in the deposition of nickel from the hot electroless bath.

Bath Characteristics. A simplified equation that describes the formation of electroless nickel deposits is:

$$NiSO_4 + NaH_2PO_2 + H_2O \xrightarrow[\text{catalyst}]{\text{heat}} Ni + NaH_2PO_3 + H_2SO_4$$

The essential requirements for any electroless nickel solution are:

1. A salt to supply the nickel
2. A hypophosphite salt to provide chemical reduction
3. Water
4. A complexing agent
5. A buffer to control pH
6. Heat
7. A catalytic surface to be plated.

Detailed discussions of the chemical characteristics of electroless baths, and of the critical concentration limits of the various reactants, can be found in several of the references listed at the end of this article.

Both alkaline (pH, 7.5 to 10) and acid (pH, 4.5 to 6) electroless nickel baths are used in industrial production. Although the acid baths are easier to maintain and are more widely used, the alkaline baths are reported to have greater compatibility with sensitive substrates (such as magnesium, silicon and aluminum).

Catalysis. Nickel and hypophosphite ions can exist together in a dilute solution without interaction, but will react on a catalytic surface to form a deposit. Furthermore, the surface of the deposit is also catalytic to the reaction, so that the catalytic process continues until any reasonable plate thickness is applied. This autocatalytic effect is the principle upon which all electroless nickel solutions are based.

Metals that catalyze the plating reaction are members of group VIII in the periodic table, which group includes nickel, cobalt and palladium. A deposit will begin to form on surfaces of these metals by simple contact with the solution. Other metals, such as aluminum or low-alloy steel, first form an

* See page 432 for committee list.

Table 1. Typical Applications of Electroless Nickel Plating

Part and basis metal	Typical plate thickness, mils	Postplating heat treatment(a)
Plate Applied for Corrosion Resistance		
Valve body, cast iron	5.0	None
Printing rolls, cast iron	1.0	None
Electronic chassis, 1010 steel	1.0	None
Railroad tank cars, 1020 steel	3.5	1 hr at 1150 F
Reactor vessels, 1020 steel	4.0	1 hr at 1150 F
Pressure vessel, 4130 steel	1.5	3 hr at 350 F
Tubular shaft, 4340 steel	1.5	3 hr at 375 F
Plate Applied for Wear Resistance		
Centrifugal pump, steel	1.0	2 hr at 400 F
Plastic extrusion dies, steel	2.0	2 hr at 375 F
Printing-press bed, steel	1.0	None
Valve inserts, steel	0.5	2 hr at 1150 F
Hydraulic pistons, 4340 steel	1.0	1 hr at 750 F
Screws, 410 stainless	0.2	None
Stator and rotor blades, 410 stainless	0.8 to 1.0	1 hr at 750 F
Spray nozzles, brass	0.5	None
Plate Applied for Buildup of Worn Areas		
Carburized gear (bearing journal)	0.8 to 1.0	5 hr at 275 F
Splined shaft (ID spline), 16-25-6 stainless	0.5	1 hr at 750 F
Connecting arm (dowel-pin holes), type 410	5.0	1 hr at 750 F

(a) Heat treatments above 450 F should be carried out in an inert or reducing atmosphere.

immersion deposit of nickel on their surfaces, which then catalyzes the reaction; still others, such as copper, require a galvanic nickel deposit in order to be plated. Such a galvanic nickel deposit can be formed by the plating solution itself, if the copper is in contact with steel or aluminum.

Plastics, glass, ceramics and other nonmetallics also can be plated, if their surfaces can be made catalytic. This usually is done by the application of traces of a strongly catalytic metal to the nonmetallic surface by chemical or mechanical means.

There is, however, a group of metals that not only do not display any catalytic action, but also interfere with all plating activity. The salts of these metals, if dissolved in a solution even in comparatively small amounts, are poisons and stop the plating reaction on all metals, thus necessitating the discarding of the solution and the formulation of a new one. Examples of these anticatalysts are Pb, Sn, Zn, Cd, Sb, As and Mo.

Paradoxically, the deliberate introduction of extremely minute traces of poisons has been practiced by a number of users of electroless nickel, with the intent of stabilizing the solution. Being an inherently metastable mixture, electroless nickel solutions are likely to decompose spontaneously, with the nickel and hypophosphite reacting on trace amounts of solid impurities present in any plating bath. In order to minimize this problem, a poisoning element is added in trace concentrations of parts per million (or per trillion) to the original make-up of the solution. The poison is adsorbed on the solid impurities in quantities large enough to destroy their catalytic nature. This selective adsorption on catalytic centers decreases the concentration of the catalytic poison to a level below the critical threshold, so that normal deposition of nickel is not impeded, although the rate of deposition is somewhat reduced. The deliberate introduction of catalytic poisons for the purpose of stabilization is covered by several patents, including U. S. Patents 2,762,723 and 2,847,327.

Table 2. Alkaline Electroless Nickel Baths

Constituent or condition	Bath 1	Bath 2	Bath 3
Composition, Grams per Liter			
Nickel chloride	30	45	30
Sodium hypophosphite	10	11	10
Ammonium chloride	50	50	50
Sodium citrate	..	100	..
Ammonium citrate	..	..	65
Ammonium hydroxide	to pH	to pH	to pH
Operating Conditions			
pH	8 to 10	8.5 to 10	8 to 10
Temperature, F	195 to 205	195 to 205	195 to 205
Plating rate (approx), mil per hr	0.3	0.4	0.3

Alkaline Baths. Most alkaline baths in commercial use today are based on the original formulations developed by Brenner and Riddell. They contain a nickel salt, sodium hypophosphite, ammonium hydroxide, and an ammonium salt; they may also contain sodium citrate or ammonium citrate. The ammonium salt serves to complex the nickel and buffer the solution. Ammonium hydroxide is used to maintain the pH between 7.5 and 10. Table 2 gives the compositions and operating conditions of three alkaline electroless baths.

At the operating temperatures of these baths (about 200 F), ammonia losses are considerable. Thorough ventilation and frequent adjustment of pH are required. The alkaline solutions are inherently unstable and are particularly sensitive to the poisoning effects of anticatalysts such as lead, tin, zinc, cadmium, antimony, arsenic and molybdenum — even when these elements are present in only trace quantities. However, when depletion occurs, these solutions undergo a definite color change from blue to green, indicating the need for addition of ammonium hydroxide.

Acid baths are more widely used in commercial installations than alkaline baths. Essentially, acid baths contain a nickel salt, a hypophosphite salt, and a buffer; some solutions also contain a chelating agent. Frequently, wetting agents and stabilizers also are added.

These baths are more stable than alkaline solutions, are easier to control, and usually provide a higher plating rate. Except for the evaporation of water, there is no loss of chemicals when acid baths are heated to their operating range. Table 3 gives the compositions and operating conditions of several acid electroless baths.

Table 3. Acid Electroless Nickel Plating Baths(a)

Constituent or condition	Bath 4	Bath 5	Bath 6	Bath 7	Bath 8	Bath 9
Composition, Grams per Liter						
Nickel chloride	30	..	..	30	..	30
Nickel sulfate	..	21	20	..	15	..
Sodium hypophosphite	10	24	27	10	14	12
Sodium acetate	..	..	..	..	13	..
Sodium hydroxyacetate	50	..	..	10	..	..
Sodium succinate	..	..	16	..	..	..
Lactic acid (80%)	..	34 ml	..	..	..	..
Propionic acid (100%)	..	2.2 ml	..	..	..	10
Operating Conditions						
pH	4 to 6	4.3 to 4.6	4.5 to 5.5	4 to 6	5 to 6	4.5 to 5.5
Temperature, F	190 to 210	203	200 to 210	190 to 210	190 to 210	190 to 210
Plating rate (approx), mil per hr	0.5	1.0	1.0	0.4	0.7	0.6

(a) Baths 4 and 7 are covered by U. S. Patent 2,532,283 (a public patent assigned to the National Bureau of Standards); bath 5, by U. S. Patents 2,822,293 and 2,822,294, and bath 6 by U. S. Patents 2,658,841 and 2,658,842.

Solution Control. In order to assure optimum results and consistent plating rates, the composition of the plating solution should be kept relatively constant; this requires periodic analyses for the determination of pH, nickel content, and phosphite and hypophosphite concentrations. The rate at which these analyses should be made depends on the quantity of work being plated and the volume and type of solution being used. The following methods have been employed:

pH — Standard electrometric method

Nickel — Any one of the colorimetric, gravimetric or volumetric methods is satisfactory; the cyanide method is probably the most popular.

Phosphite — A 10-ml sample of the plating solution is combined with 20 ml of a 5% solution of sodium bicarbonate and cooled in an ice bath. Next, 50 ml of 0.1*N* iodine solution is added and the flask containing this mixture is stoppered and permitted to stand for 2 hr at room temperature. Then the flask is cooled for 15 min in ice water, after which it is unstoppered, the mixture is acidified with acetic acid, and the excess iodine is titrated with 0.1*N* sodium thiosulfate, with starch as an indicator. Determination is then made as follows:

$$NaH_2PO_3 \text{ per liter} = \frac{\text{net ml of } 0.1N \text{ iodine} \times 6.3}{\text{ml of plating solution}}$$

Hypophosphite (U. S. Patent 2,697,651) — A 25-ml sample of the plating solution is diluted to 1 liter. A 5-ml aliquot of the

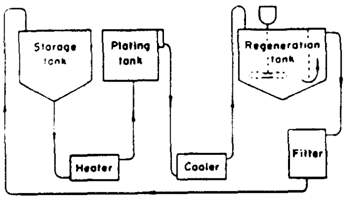


Fig. 1. Schematic of continuous-type system for electroless nickel plating. See text.

dilution is combined with 10 ml of a 10% solution of ammonium molybdate and 10 ml of fresh 6% sulfurous acid. The sample is covered and heated to boiling, and a deep blue color develops. The sample is cooled and diluted to 100 ml, and transmittance at a wave length of 440 microns is determined. The calibration curve on semilog paper is linear.

Hypophosphite (alternative method) — A 5-ml sample of the plating solution is mixed in a beaker with 5 ml of methyl orange solution made up of 1 gram of methyl orange in 1 liter of water. In another beaker is placed 15 ml of an acid solution made up by (*a*) dissolving 40 grams of sodium metabisulfate in 200 ml of water, (*b*) slowly adding the sodium metabisulfate solution to a cold solution of 82 ml of sulfuric acid in 650 ml of water, and then (*c*) diluting this mixture with water to 1 liter. When the acid solution and the solution containing the sample and methyl orange reach a temperature of 77 F in a thermostat, the two solutions are mixed. The time between mixing and the disappearance of the red color is recorded. The hypophosphite concentration is a function of this time and is read from a concentration-time curve made from known standards.

Equipment Requirements. The precleaning and post-treating equipment for an electroless nickel line is comparable to that employed in conventional electrodeposition. The plating tank itself, however, is unique.

The preferred plating tank for batch operations is constructed of stainless steel or aluminum and is lined with a coating of an inert material, such as tetrafluoroethylene or a phenolic-base organic. The size and shape of the tank are usually dictated by the parts to be plated, but the surface area of the plating solution should not be so large that excessive heat loss occurs as a result of evaporation.

A large heat-transfer area and a low temperature gradient are necessary between the heating medium and the plating solution. This combination provides for a reasonable heat-up time without local hot spots that could decompose the solution. It is accepted practice to surround the plating tank with a hot-water jacket or to immerse it in a tank containing hot water. Heating jackets using low-pressure steam also have been used successfully. The use of immersed steam coils is not favored, however, because it entails the sacrifice of a large amount of working area in the tank.

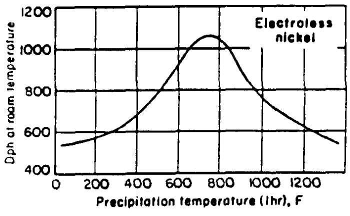
Accessory equipment required or recommended for the tank includes:

1 An accurate temperature controller
2 A filter to remove any suspended solids
3 A pH meter
4 An agitator to prevent gas streaking
5 On small tanks, a cover, to minimize heat loss and exclude foreign particles.
6 On large tanks, a separate small tank to dissolve and filter additives before they are put into the plating tank.

Considerably more equipment is required for a continuous-type system, such as that shown in Fig. 1. The bath is prepared and stored in a separate tank and flows through a heater (which raises its temperature to 205 F) into the plating tank. From the plating tank, the solution is pumped through a cooler, which decreases its temperature to 175 F or below, and then to an agitated regeneration tank, where reagents are added in controlled amounts to restore the solution to its original composition. The solution is then directed past a vertical underflow baffle and out of the regeneration tank to a filter, and then returned to storage.

In externally heated continuous-type systems such as the one shown in Fig. 1, the plating tank and other components of the system that come in contact with the plating solution are constructed of type 304 stainless steel and are not lined or coated; these components are periodically deactivated by chemical treatment. Details of this type of system are covered by several patents, including U. S. Patents 2,941,902; 2,658,839 and 2,874,073.

Properties of the Deposit. Electroless nickel is a hard, lamellar, brittle, uniform deposit. As plated, the hardness



Effect of temperature of 1-hr precipitation heat treatment on room-temperature hardness of a typical electroless nickel deposit (Eberbach tester, 100-gram load). Above 450 F, heat treatment was in an inert atmosphere.

Fig. 2. Heat treatment of coating

varies over a considerable range (425 to 575 dph), depending primarily on phosphorus content, which ranges from 4 to 12%. This hardness can be increased by a precipitation heat treatment. As indicated in Fig. 2, which shows temperature-hardness relationships for a typical deposit, by heating at 750 F for ½ to 1 hr, hardness can be increased to about 1000 dph.

The corrosion resistance of electroless nickel deposits is superior to that of electrodeposited nickel of comparable thickness, but this superiority varies with exposure conditions. Outdoor exposure and salt spray corrosion data indicate that about 25% more resistance is given a steel panel by electroless nickel than by electrolytic.

Table 4. Physical Properties of Electroless Nickel Deposits

Property	Value
Specific gravity	7.8 to 8.5
Melting point	1635 to 1850 F
Electrical resistivity	60 microhm-cm
Thermal expansion	13×10^{-6} per °C
Thermal conductivity	0.0105 to 0.0135 cal/cm sec/°C

Table 5. Costs for Electroless Nickel Plating (Example 2) (a)

Cost factor		Cost per year(b)
Original investment	$18,000	
Fixed costs:		
Depreciation (10 years)		$ 1,800
Insurance		450
Floor space (200 sq ft)		192
Repairs and maintenance		450
Variable costs:		
Raw material		6,100
Utilities		740
Labor costs:		
Direct		10,400
Indirect		2,630
Total		$22,762
Total cost per hr		$9.48
Total cost per sq ft coated to 1 mil		$1.00

(a) Exclusive of costs for: overhead and administration; racking, cleaning and unracking; and preplating and postplating processes. (b) Based on deposition of 1 mil on 0.1-sq-ft parts at rate of 0.8 mil per hr (capacity: 117 pieces, or 9.4 sq-ft/mil, per hr), on a schedule of 10 hr per day, 20 days per month, 2400 hr per year.

Some of the physical properties of electroless nickel are listed in Table 4.

Advantages and Limitations. Some advantages of electroless nickel are:

1 Good resistance to corrosion and wear
2 Excellent uniformity
3 Solderability and brazability
4 Good oxidation resistance.

Limitations of electroless nickel are:

1 High cost
2 Brittleness
3 Poor welding characteristics
4 Lead, tin, cadmium and zinc must be copper strike plated before electroless nickel can be applied
5 Slower plating rate (in general), as compared to electrolytic methods
6 Full brightness in deposit cannot be obtained without extreme brittleness.

Cost. Electroless nickel is considerably more expensive than electrodeposited nickel. Actual costs for electroless nickel plating, as reported by two users, are given in the following examples.

Example 1. Based on the experience of one manufacturing plant, it costs $1.20 to deposit an electroless nickel coating 1 mil thick on a square foot of surface area: 37¢ for chemicals, 59¢ for labor, and 24¢ for equipment and maintenance.

Example 2. Another manufacturing plant reports that it costs $1 per sq ft to plate a 1-mil thickness of electroless nickel on specific parts with a surface area of 0.1 sq ft, on the basis of data obtained over a one-year period (2400 working hours). An analysis of their costs is given in Table 5.

Selected References

A. Brenner, Electroless Plating Comes of Age, *Metal Finishing*, November 1954, p 68-76; December 1954, p 61-68

A. Brenner and G. Riddell, Nickel Plating on Steel by Chemical Reduction, *J Res Nat Bur Stds*, July 1946, p 31-34, and *Proc Am Electroplaters' Soc*, 1946, p 23-29; Deposition of Nickel and Cobalt by Chemical Reduction, *J Res Nat Bur Stds*, Nov 1947, p 385-395, and *Proc Am Electroplaters' Soc*, 1948, p 156-169

G. Gutzeit, Industrial Nickel Coating by Chemical Catalytic Reduction, *Trans Inst Metal Finishing*, 33, 383-423 (1955-1956), and *Corrosion Technol*, 3, 208 (1956)

G. Gutzeit, An Outline of the Chemistry Involved in the Process of Catalytic Nickel Deposition from Aqueous Solution, *Plating*, Oct 1959, p 1158-1164; Nov 1959, p 1275-1278; Dec 1959, p 1377-1378; Jan 1960, p 63-70

C. H. de Minjer and A. Brenner, Studies on Electroless Nickel Plating, *Plating*, December 1957, p 1297-1305

Symposium on Electroless Nickel Plating (Catalytic Deposition of Nickel-Phosphorus Alloys by Chemical Reduction in Aqueous Solution), ASTM STP No. 265 (1959)

(2) PPG METALHIDE®

PPG METALHIDE® 97-694 Series

HPC/Industrial Maintenance

METALHIDE® 2000 Inorganic Zinc Rich Coating

GENERAL DESCRIPTION

Heavy duty corrosion resistant primer for ferrous metal surfaces in industrial environments. Provides galvanic protection similar to galvanizing. Particularly suited as a lining for the interior, and as a primer to be topcoated for the exterior of tanks containing organic solvents, gasoline, and other fuels. It is also excellent for application in coastal, marine, and other offshore environments.

RECOMMENDED USES

Ferrous Metal

FEATURES AND BENEFITS

Provides galvanic corrosion protection
Excellent resistance to organic solvents
Can be handled with slings in 5-6 hours (77°F at 50% relative humidity)
Class B Slip Coefficent under ASTM A-325

PACKAGING

1-Gallon (3.78L)
3-Gallon (11.3L)
5-Gallon (18.9L)

Not all products are available in all sizes. Not all containers are full-filled.

TINTING AND BASE INFORMATION

97-694	Liquid Component A - Red
97-695	Liquid Component A - Green
97-697P	Powder Component

DO NOT TINT.

PRODUCT DATA

PRODUCT TYPE: Inorganic self-curing ethyl silicate-metallic zinc
GLOSS: Matte
VOC*: 3.88 lbs./gal. (466 g/L)
COVERAGE: 330 to 500 sq. ft./gal. (31 to 46 sq.m/3.78L)

WEIGHT/GALLON*: 20.3 lbs. (9.2 kg) +/- 0.3 lbs. (136 g)
WEIGHT SOLIDS*: 80.3% +/- 2%
Results will vary by color, thinning and other additives.
*Product data calculated on mixed 97-695/97-697P.
Dry Film Thickness*: 2 to 5 mils not to exceed 8 mils on spot readings

POT LIFE: 16 hours
MIX RATIO: Mix as packaged. See mixing instructions.
IN SERVICE TEMPERATURE: 750°F (399°C) Dry heat; 140°F (60°C) Wet heat
DRYING TIME@ 77°F (25°C); 50% relative humidity.

To Touch:	15 minutes
To Handle:	4 hours
To Recoat:	24 hours

Drying times listed may vary depending on temperature, humidity, color and air movement.

CLEANUP: 97-727 PPG Thinner
FLASH POINT: 97-695 60°F (15.6°C)

METALHIDE® 97-694 Series

METALHIDE® 2000 Inorganic Zinc Rich Coating HPC/Industrial Maintenance

GENERAL SURFACE PREPARATION

Remove all paint, mill scale, and rust. The surface to be coated must be dimensionally stable, dry, clean, and free of oil, grease, and other foreign materials.

WARNING! If you scrape, sand, or remove old paint, you may release lead dust or fumes. LEAD IS TOXIC. EXPOSURE TO LEAD DUST OR FUMES CAN CAUSE SERIOUS ILLNESS, SUCH AS BRAIN DAMAGE, ESPECIALLY IN CHILDREN. PREGNANT WOMEN SHOULD ALSO AVOID EXPOSURE. Wear a properly fitted NIOSH-approved respirator and prevent skin contact to control lead exposure. Clean up carefully with a HEPA vacuum and a wet mop. Before you start, find out how to protect yourself and your family by contacting the USEPA National Lead Information Hotline at 1-800-424-LEAD or log on to www.epa.gov/lead. In Canada contact a regional Health Canada office. Follow these instructions to control exposure to other hazardous substances that may be released during surface preparation.

STEEL: Non-Immersion Service -- The minimum surface preparation for ferrous metal substrates is SSPC-SP6 Commercial Blast cleaning. Service life of coating is in direct proportion to surface preparation. Immersion Service -- Near White Metal Blast SSPC-SP10 is mandatory for ferrous metals. The surface to be coated must be clean, dry, and well prepared to receive the coating. For specific recommendations, see your PITTSBURGH® Paints dealer or call 1-800-441-9695.

RECOMMENDED PRIMERS

Self priming on properly prepared surfaces.

MIXING AND APPLICATIONS INFORMATION

MIXING INSTRUCTIONS: Mix the 97-694 or 695 opaque liquid base using a mechanical mixer until no pigment remains at the bottom of the container. Transfer to a large container to facilitate mixing, and slowly sift in the zinc dust, 97-697P under continuous agitation. Mix until blend is uniform and free of lumps. Strain through a 30-60 mesh screen. DO NOT MIX IN REVERSE ORDER. Maintain constant agitation during use to prevent zinc dust from settling. The liquid component and the mixed paint must be protected from moisture. Relatively small amounts of contamination will cause gelation.

Changes in application equipment, pressures and/or tip sizes may be required on ambient temperatures and application conditions.

Airless Spray: Pressure 1500 psi, tip 0.017" - 0.021" Filter: 30 mesh

Conventional Spray: Fluid Nozzle: DeVilbiss MBC-510 gun, with 64 air cap with E tip and needle, or comparable equipment. Atomization Pressure: 55 - 70 Fluid Pressure: Can not specify, dependent on numerous factors.

Spray equipment must be handled with due care and in accordance with manufacturer's recommendation. High-pressure injection of coatings into the skin by airless equipment may cause serious injury.

Brush: Not recommended

Roller: Not recommended

Thinning: Thinning not normally required. If thinning is desired do not thin more than 12% with 97-727.

MIXING AND APPLICATIONS INFORMATION (cont.)

Permissible temperatures during application:

Material:	50 to 90°F	10 to 32°C
Ambient:	0 to 100°F	-18 to 38°C
Substrate:	0 to 140°F	-18 to 60°C

LIMITATIONS OF USE

Apply in good weather when air and surface temperatures are between 50°F (10°C) and 100°F (37.8°C) with maximum relative humidity of 85%. Optimum paint temperatures is 70°F (21°C) - 80°F (26.7°C). Surface temperatures must be at least 5°F (3°C) above the dew point. Do not expose container to temperatures greater than 135°F (57°C). Do not use for potable water.

For Professional Use Only; Not Intended for Household Use.

SAFETY

Proper safety procedures should be followed at all times while handling this product. USE WITH ADEQUATE VENTILATION. KEEP OUT OF REACH OF CHILDREN. Explosion-proof equipment must be used when coating with these materials in confined areas. Keep containers closed and away from heat, sparks, and flames when in use. Spray equipment must be handled with due care and in accordance with manufacturer's recommendation. High-pressure injection of coatings into the skin by airless equipment may cause serious injury. Read all label and Material Safety Data Sheet for important health/safety information prior to use. MSDS are available through our website www.ppghpc.com or by calling 1-800-441-9695.

PPG Industries, Inc.
Architectural Coatings
One PPG Place
Pittsburgh, PA 15272
www.ppghpc.com

Technical Services
1-800-441-9695
1-888-807-5123 fax

Architect/Specifier
1-800-PPG-IDEA

PPG Canada, Inc.
Architectural Coatings
4 Kenview Blvd
Brampton, ON L6T 5E4

I23 11/2011
Supersedes (2/2009)

(3) PPG PITT-THERM®

PITT-THERM® — **97-724 Series**

HPC/Industrial Maintenance — PITT-THERM® High Heat & Stress Corrosion Coating

Generic Type

Air Dry Silicone, One Component

Tinting and Base Information

97-724	Black
UC51492	White
UC59571	Gray

General Description

This coating is intended for use on austenitic stainless and carbon steel to provide protection against chloride attack and stress corrosion cracking on both insulated and uninsulated surfaces. PITT-THERM® has excellent thermal shock and barrier properties, and may be used as a heat resistant coating for carbon steel.

Recommended Uses

Austenitic Stainless Steel
Carbon Steel

Product Data

Gloss:	Matte
VOC*:	4.62 lbs/gal 554.00 g/L
Coverage:	279 to 372 sq ft/gal (26 to 35 sq. m/3.78L)

Note: Does not include loss due to varying application method, surface porosity, or mixing.

DFT:	1.5 minimum to 2.0 maximum
Weight/Gallon*:	9.6 lbs. (4.5 kg) +/- 0.2 lbs. (91 g)
Volume Solids*:	34.8% +/- 2%
Weight Solids*:	52.1% +/- 2%
Clean-up:	97-727 PPG Xylol Thinner

Results will vary by color, thinning and other additives.
*Product data calculated on full formula.

Drying Time:

To Touch:	20 minutes
To Handle:	2 hours
To Recoat:	16 hours

Dry Time @77°F (25°C); 50% relative humidity

In Service Temperature:
Dry Heat (F): 850° Dry Heat (C): 454°

Flash Point: 62°F, (16.7°C)

Features / Benefits

High heat and thermal stress resistance.
Protects stainless steel against chloride attack and stress corrosion cracking.

Limitations of Use

For Professional Use Only; Not Intended for Household Use. Apply only when air, product and surface temperatures are 40°F (4.4°C) and when surface temperature is at least 5°F (3°C) above the dew point. Avoid exterior painting late in the day when dew or condensation are likely to form, or when rain is threatening. Special attention should be given to insure that this product is not contaminated by moisture during the application process. Drying times listed may vary depending on temperature, humidity, color and air movement.

I7

PITT-THERM® 97-724 Series

HPC/Industrial Maintenance PITT-THERM® High Heat & Stress Corrosion Coating

General Surface Preparation

Remove all loose paint, mill scale, and rust. The surface to be coated must be dimensionally stable, dry, clean, and free of oil, grease, and other foreign materials. Service life of coating is in direct proportion to surface preparation. WARNING! If you scrape, sand, or remove old paint, you may release lead dust or fumes. LEAD IS TOXIC. EXPOSURE TO LEAD DUST OR FUMES CAN CAUSE SERIOUS ILLNESS, SUCH AS BRAIN DAMAGE, ESPECIALLY IN CHILDREN. PREGNANT WOMEN SHOULD ALSO AVOID EXPOSURE. Wear a properly fitted NIOSH-approved respirator and prevent skin contact to control lead exposure. Clean up carefully with a HEPA vacuum and a wet mop. Before you start, find out how to protect yourself and your family by contacting the USEPA National Lead Information Hotline at 1-800-424-LEAD or log on to www.epa.gov/lead. In Canada contact a regional Health Canada office. Follow these instructions to control exposure to other hazardous substances that may be released during surface preparation.

For application to Austenitic Stainless Steel SSPC-SP1 Solvent Wash is the minimum surface preparation. For Carbon Steel applications, SSPC-SP10 Near White Metal Blast is required. Where appropriate bare areas should be primed with a suitable primer.

HPC Systems in Detail Brochure (H10788) COATING SYSTEMS: 225-HD, 226-HD, 227-HD

Recommended Primers

none	Refer to HD Coating Systems.
Steel	Self Priming, 97-673/674 or 675, 97-676 or 677

Directions for Use

Mix thoroughly to suspend all pigmentation before, and during use. Explosion-proof equipment must be used when coating with these materials in confined areas. Keep containers closed and away from heat, sparks, and flames when not in use. USE WITH ADEQUATE VENTILATION. KEEP OUT OF REACH OF CHILDREN. Read all label and Material Safety Data Sheet (MSDS) information prior to use. MSDS are available through our website or by calling 1-800-441-9695.

Permissible temperatures during application:

Material:	40 to 90°F	4 to 32°C
Ambient:	40 to 100°F	4 to 38°C
Substrate:	40 to 130°F	4 to 54°C

Application Information

Recommended Spread Rates:

Wet Mils :	4.3	minimum to	5.7	maximum
Wet Microns:	109.2	minimum to	144.8	maximum
Dry Mils :	1.5	minimum to	2.0	maximum
Dry Microns:	38.1	minimum to	50.8	maximum

Application Equipment: Changes in application equipment, pressures and/or tip sizes may be required depending on ambient temperatures and application conditions. Spray equipment must be handled with due care and in accordance with manufacturer's recommendation. High-pressure injection of coatings into the skin by airless equipment may cause serious injury.

Conventional Spray: Fluid Nozzle: DeVilbiss MBC gun, with 704 or 777 air cap with E or FF tip and needle, or comparable equipment. Atomization Pressure: 55 - 70 Fluid Pressure: Can not specify, dependent on numerous factors.

Airless Spray: Pressure 1500 psi, tip 0.011" - 0.015"

Brush: Not Recommended

Roller: Not Recommended

Thinning:
DO NOT THIN. Spray product as received.

Packaging: 1-Gallon (3.78L)

Not all products are available in all sizes. All containers are not full-filled.

PPG Industries, Inc.
Architectural Coatings
One PPG Place
Pittsburgh, PA 15272
www.ppghpc.com

Technical Services
1-800-441-9695
1-888-807-5123 fax

Architect/Specifier
1-888-PPG-IDEA

PPG Architectural Finishes
400 S. 13th Street
Louisville, KY 40203

PPG Canada, Inc.
Architectural Coatings
4 KenviewBlvd
Brampton, ON L6T 5E4

I7 10/2008

(4) Keeler & Long/PPG KLE

KLE

E.340

Product Data Sheet

Keeler & Long
PPG High Performance Coatings

Keeler & Long/PPG
856 Echo Lake Road
Watertown, CT 06795
1-800-238-8596

Epoxy Enamel
KLE Series

Product Information

Product Code:	KLE1XXXX Part A where XXXX is a color designation.
	KLE2XXXX Part A
	KLE1B Curing Agent Part B
Product:	Polyamide Epoxy
Suggested Use:	A two component, polyamide epoxy enamel formulated to provide excellent chemical, abrasion and direct impact resistance for interior exposures.
	Use as a topcoat for concrete and steel surfaces, subject to radiation, decontamination, and loss-of-coolant accidents in Coating Service Level I areas of nuclear power plants.
Not Recommended:	Areas other than above, as the KLJ Series can be utilized in Coating Service Level II and certain Level III areas, as well as balance of plant, of nuclear power plants.

Product Description

Colors:	Available in a wide range of colors.
Gloss 60°:	KLE1XXXX 85 minimum
	KLE2XXXX 35 - 65
VOC:	3.47 lbs./gal. (416 g/L) * mixed, unthinned
Method:	Calculated
Weight/Gallon:	10.2 ± 0.5 lbs./gal. *
In Service Heat Limitations:	250°F (121°C) **
Flash Point:	Part A 82°F (27.8°C)
	Part B 104°F (40°C)
Package:	Part A is available in one gallon containers at 0.80 gallon (3.03 liters) and five gallon containers filled at 4.00 gallons (15.1 liters).
	KLE1B Part B is available filled in quart containers at 25.6 fluid ounces (751 mL) and full filled gallon containers.
Percent Solids by Volume:	53.9 ± 3.0% *
Percent Solids by Weight:	66.1 ± 3.0% *

Drying Schedule

Air Dry @ 77°F (25°C) ASTM D5895

Dry to Touch:	4 hours
Dry to Handle:	8 hours

Drying Schedule (continued)

Dry to Recoat:	48 hours
	Drying times listed may vary depending on temperature, humidity and air movement.

Application Data

Substrate:	Metal or masonry
Substrate Preparation:	The service life of the coating is directly related to the surface preparation. The surface to be coated must be properly prepared and primed, dry, clean and free of contamination including oil, dirt, grease and rust.
Basecoats:	Epoxy Surfacer, Epoxy White Primer
Application Method:	Apply by spray, brush or roller application.
	Air Spray: DeVilbiss MBC gun, 704 or 777 air cap, "E" for "F" tip and needle or equivalent equipment. Atomization Pressure: 30-60 psi.
	Airless Spray: Equipment capable of maintaining a minimum of 2500 psi without surge at the tip. 0.011" (0.279 mm) to 0.017" (0.432 mm) orifice.
	Brush: Use a high quality natural bristle brush.
	Roller: Use a high quality roller cover with a solvent resistant core.
	Refer to Application Guide APG-2 for additional information.
Thinner Code & Percent:	Thin up to 5% by volume with KL4093 as needed for application.
Coverage Sq. Ft/Gal @ 2 mils:	362 sq. ft./gal.*
Mixing Instructions:	Thoroughly mix Part A before blending. Add KLE1B Part B to Part A. Mix until uniform. Allow to digest for 1 hour before use.
Wet Film Per Coat:	3.7 to 4.6 mils *
Dry Film Per Coat:	2.0 to 2.5 mils
Clean Up Solvent:	KL4093

E.340 March, 2005

Product Data Sheet

Keeler & Long/PPG
856 Echo Lake Road
Watertown, CT 06795
1-800-238-8596

PPG High Performance Coatings

Epoxy Enamel
KLE Series

Application Information (continued)

Parts Base by Volume:	4 part "A"
Parts Catalyst by Volume:	1 part KLE1B Part "B"
Digestion Time:	1 hour @ 77°F (25°C)
Potlife:	8 hours @ 77°F (25°C)

Additional Information

Apply only when air, product and surface temperatures are at least 55 °F (12.8°C) and surface temperature is at least 5°F (3°C) above the dew point. Curing is retarded below 60ºF (15.6ºC).

Store materials at temperatures between 45ºF (7.2ºC) and 95ºF (35º)

Permissible substrate temperatures during application is 55ºF (12.8ºC) and 120ºF (48.9ºC).

*Values are calculated using KLE16002 White mixed 4:1 by volume with KLE1B. Values will vary with color.

**KLE Series coating system was evaluated and passed the 7-Day 340ºF Design Basis Accident Test per ANSI N101.2 and ASTM D3911.

Read all label and Material Safety Data Sheet (MSDS) information prior to use. MSDS are available by calling 1-800-238-8596.

Not intended for residential use.

Spray equipment must be handled with due care and in accordance with manufacturer's recommendation.

High-pressure injection of coatings into the skin by airless equipment may cause serious injury, requiring immediate medical attention at a hospital.

WARNING! If you scrape, sand, or remove old paint, you may release lead dust or fumes. LEAD IS TOXIC. EXPOSURE TO LEAD DUST OR FUMES CAN CAUSE SERIOUS ILLNESS, SUCH AS BRAIN DAMAGE, ESPECIALLY IN CHILDREN. PREGNANT WOMEN SHOULD ALSO AVOID EXPOSURE. Wear a properly fitted NIOSH-approved respirator and prevent skin contact to control lead exposure. Clean up carefully with a HEPA vacuum and a wet mop. Before you start, find out how to protect yourself and your family by contacting the USEPA National Lead Information Hotline at 1-800-424-LEAD or log on to www.epa.gov/lead. In Canada contact a regional Health Canada office. Follow these instructions to control exposure to other hazardous substances that may be released during surface preparation.

E.340 March, 2005

(5) Carboline® 890N

product data carboline® Carboguard® 890N

Selection & Specification Data

Generic Type Cycloaliphatic Amine Epoxy

Description Nuclear grade, DBA tested, self priming epoxy. Tested and certified for use in Nuclear Level 1 areas in a variety of systems.

Features
- Can be applied direct to steel without a primer
- Single coat, high build capabilities
- Can be applied to minimally prepared surfaces
- Compatible to many existing, aged epoxies and inorganic zinc coatings
- Easily decontaminated
- DBA tested and qualified for Nuclear Service Level 1
- Resistant to high levels of radiation
- High solids and low VOC help reduce effects on charcoal filters
- Application-friendly characteristics minimize man-rem exposure
- Suitable for use under insulation on hot surfaces operating up to 250°F (121°C) outside Level 1 areas

Color Refer to Carboline Color Guide. Certain colors may require multiple coats for hiding.

Finish Gloss

Primers Self-priming. Qualified over Carbozinc 11SG and Carboguard 893 for fabrication applications. May be applied over existing inorganic zinc primers and epoxy based systems. A mist coat may be required to minimize bubbling over inorganic zinc primers. Consult Carboline for system recommendations and test data for use in nuclear applications.

Dry Film Thickness 4.0-6.0 mils (100-150 microns) per coat
6.0-8.0 mils (150-200 microns) over light rust and for uniform gloss over inorganic zincs.
Don't exceed 10 mils (250 microns) in a single coat. Excessive film thickness over inorganic zincs may increase damage during shipping or erection.
Note: Acceptable DFT ranges are based on plant specific DBA test data. Carboguard 890 has been tested in multi-coat and wide DFT range scenarios. Consult Carboline for applicable DBA test data.

Solids Content By Volume:75% ± 2%

Theoretical Coverage Rate 1203 mil ft^2 (30.0 m^2/l at 25 microns)
241 ft^2 at 5 mils (6.0 m^2/l at 125 microns)
Allow for loss in mixing and application

VOC Values

As supplied	1.80 lbs/gal (216 g/l)
Thinned w/#2:	7oz/gal: 2.03 lbs/gal (244 g/l)
	13oz/gal: 2.26 lbs/gal (271 g/l)
Thinned w/#33:	7oz/gal: 2.05 lbs/gal (246 g/l)
	16oz/gal: 2.40 lbs/gal (288 g/l)

Dry Temp. Resistance Continuous: 250°F (121°C)
Non-Continuous: 300°F (149°C)
Carboguard 890 N has been successfully tested under DBA / LOCA temperatures up to 340°F (171°C). Please contact Carboline for specific variables.
Discoloration and loss of gloss is observed above 200°F (93°C).

Temp. Resistance (Under Insulation) Under Insulation: 250°F (121°C)
(Normally dry)
Not for use under insulation in Level 1 areas.

Limitations Qualification of Carboguard 890N for Level 1 applications is plant specific and must be supported with relevant DBA test data.

Substrates & Surface Preparation

General Surfaces must be clean and dry. Employ adequate methods to remove dirt, dust, oil and all other contaminants that could interfere with adhesion of the coating. Follow approved specification for specific project.

Steel (General) For shop painting :SSPC-SP6
1.5-3.0 mils (38-75 microns)
For plant maintenance: SSPC-SP2 or SP3
Refer to applicable DBA testing specific to plant postulated LOCA conditions.

Concrete (General) Concrete must be cured 28 days at 75°F (24°C) and 50% relative humidity or equivalent. Prepare surfaces in accordance with ASTM D4258 Surface Cleaning of Concrete and ASTM D4259 Abrading Concrete. Voids in concrete may require surfacing. Prime with approved primer.

Previously Painted Surfaces Follow approved specification for specific project. Consult Carboline for available compatibility test data.

Performance Data

Test Method	System*	Results	Report #
ASTM D3911 DBA	890 / 890 Steel, SP3, SP11	Pass	02658, 02732, 02927
ASTM D3911 DBA	2011S / 890 Concrete	Pass	02658, 02732, 02927
ASTM D3911 DBA	893 / 890	Pass	02689
ASTM D3911 DBA	CZ11SG / 890	Pass	02927
ASTM D4082 Radiation Tolerance	890 / 890 893 / 890	No Defects	02658, 02689
ASTM D4256 Decontamination	890	99.96%	02411
ASTM D4541 Elcometer Adhesion	890	980 PSI	02411
ASTM D3912 Chemical Resistance	890	Pass all chemicals except Potassium Permanganate, Nitric Acid and MIBK	02411
ASTM E84 Flame Spread	890/890	Flame Spread 5 Smoke Generation 20	02919
ASTM E1461 Thermal Conductivity	890	4.79 btu-in/hr-ft^2-°F	03683
ASTM D4060 Taber Abrasion	890	85 mg lost	02411

Test reports and additional data available upon written request.
** Carboguard 890 received a name change in June 2004 to Carboguard 890N for nuclear service projects.*

January 2012 replaces July 2011 0986

Application Equipment

Listed below are general equipment guidelines for the application of this product. Job site conditions may require modifications to these guidelines to achieve the desired results. **General Guidelines**:

Spray Application (General) This is a high solids coating and may require adjustments in spray techniques. Wet film thickness is easily and quickly achieved. The following spray equipment has been found suitable and is available from manufacturers such as Binks, DeVilbiss and Graco.

Conventional Spray Pressure pot equipped with dual regulators, 3/8" I.D. minimum material hose, .070" I.D. fluid tip and appropriate air cap.

Airless Spray

Pump Ratio: 30:1 (min.)*	Tip Size: .017"-.021"
GPM Output: 3.0 (min.)	Output PSI: 2100-2300
Material Hose: 3/8" I.D. (min)	Filter Size: 60 mesh

*Teflon packings are recommended and available from the pump manufacturer.

HVLP 3M Accuspray Spray Gun Model HG09

Brush & Roller (General) Multiple coats may be required to obtain desired appearance, recommended dry film thickness and adequate hiding. Avoid excessive re-brushing or re-rolling. For best results, tie-in within 10 minutes at 75°F (24°C).

Brush Use a medium bristle brush.

Roller Use a short-nap synthetic roller cover with phenolic core.

Mixing & Thinning

Mixing Power mix separately, then combine and power mix. Partial mixing of kits is not recommended without specific approval and written procedures from plant engineering and QA.

Ratio 1:1 Ratio (A to B)

Thinning*
Spray: Up to 13 oz/gal (10%) w/ #2
Brush: Up to 16 oz/gal (12%) w/ #33
Roller: Up to 16 oz/gal (12%) w/ #33
Thinner #33 can be used for spray in hot/windy conditions. Use of thinners other than those supplied or recommended by Carboline may adversely affect product performance and void product warranty, whether expressed or implied.
*See VOC values for thinning limits.

Pot Life 3 Hours at 75°F (24°C)
Pot life ends when coating loses body and begins to sag. Pot life times will be less at higher temperatures.

Cleanup & Safety

Cleanup Use Thinner #2 or Acetone. In case of spillage, absorb and dispose of in accordance with local applicable regulations.

Safety Read and follow all caution statements on this product data sheet and on the MSDS for this product. Employ normal workmanlike safety precautions. Hypersensitive persons should wear protective clothing, gloves and use protective cream on face, hands and all exposed areas.

Ventilation When used as a tank lining or in enclosed areas, thorough air circulation must be used during and after application until the coating is cured. The ventilation system should be capable of preventing the solvent vapor concentration from reaching the lower explosion limit for the solvents used. User should test and monitor exposure levels to insure all personnel are below guidelines. If not sure or if not able to monitor levels, use MSHA/NIOSH approved supplied air respirator.

Caution This product contains flammable solvents. Keep away from sparks and open flames. All electrical equipment and installations should be made and grounded in accordance with the National Electric Code. In areas where explosion hazards exist, workmen should be required to use non-ferrous tools and wear conductive and non-sparking shoes.

Application Conditions

Condition	Material	Surface	Ambient	Humidity
Normal	60°-85°F (16°-29°C)	60°-85°F (16°-29°C)	60°-90°F (16°-32°C)	0-85%
Minimum	50°F (10°C)	50°F (10°C)	50°F (10°C)	0%
Maximum	90°F (32°C)	125°F (52°C)	110°F (43°C)	85%

This product simply requires the substrate temperature to be above the dew point. Condensation due to substrate temperatures below the dew point can cause flash rusting on prepared steel and interfere with proper adhesion to the substrate. Special application techniques may be required above or below normal application conditions.

Curing Schedule

890N (Based on 4–8 mils, 100-200 microns dry film thickness.)

Surface Temp. & 50% Relative Humidity	Dry to Recoat	Dry to Topcoat w/ Other Finishes	Final Cure	
			General	Immersion
50°F (10°C)	12 Hours	24 Hours	3 Days	N/R
60°F (16°C)	8 Hours	16 Hours	2 Days	10 Days
75°F (24°C)	4 Hours	8 Hours	1 Day	5 Days
90°F (32°C)	2 Hours	4 Hours	16 Hours	3 Days

Higher film thickness, insufficient ventilation or cooler temperatures will require longer cure times and could result in solvent entrapment and premature failure. Excessive humidity or condensation on the surface during curing can interfere with the cure, can cause discoloration and may result in a surface haze. Any haze or blush must be removed by water washing before recoating. During high humidity conditions, it is recommended that the application be done while temperatures are increasing. **Maximum recoat/topcoat times are 30 days for epoxies and 90 days for polyurethanes at 75°F (24°C)**. If the maximum recoat times have been exceeded, the surface must be abraded by sweep blasting or sanding prior to the application of additional coats.

Packaging, Handling & Storage

Shipping Weight (Approximate) 2 Gallon Kit: 29 lbs (13 kg); 10 Gallon Kit: 145 lbs (66 kg)

Flash Point (Setaflash) 89°F (32°C) for Part A
73°F (23°C) for Part B

Storage Temperature & Humidity 40° -120°F (4°-49°C) Store indoors.
0-100% Relative Humidity

Shelf Life Part A: 36 months at 75°F (24°C)
Part B: 15 months at 75°F (24°C)

***Shelf Life: (actual stated shelf life) when kept at recommended storage conditions and in original unopened containers.**

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January 2012 replaces July 2011

(6) ASTM B29 – 鉛的標準規格

Designation: B 29 – 03

Standard Specification for Refined Lead[1]

This standard is issued under the fixed designation B 29; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers refined lead in pig, block, or hog form.

1.2 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to become familiar with all hazards including those identified in the appropriate Material Safety Data Sheet for this product/material as provided by the manufacturer, to establish appropriate safety and health practices, and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 The following documents of the issue in effect on the date of material purchase form a part of this specification to the extent referenced herein.

2.2 *ASTM Standards:*

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[2]

E 37 Test Methods for Chemical Analysis of Pig Lead[3]

E 88 Practice for Sampling Nonferrous Metals and Alloys in Cast Form for Determination of Chemical Composition[3]

3. Ordering Information

3.1 Orders for refined lead under this specification shall include the following information:

3.1.1 ASTM designation and year of issue,

3.1.2 Quantity (weight),

3.1.3 Name of material (for example, pure lead),

3.1.4 Size and shape (see Section 6),

3.1.5 Grade (see Table 1 and accompanying notes), and

3.1.6 Certification or test report if specified (Section 13).

TABLE 1 Chemical Requirements[A,B]

Grade	Composition (Weight Percent)			
	Low Bismuth Low Silver Pure Lead, max[C]	Refined Pure Lead, max[D]	Pure Lead, max	Chemical-Copper Lead[E]
Sb	0.0005	0.0005	0.001	0.001 max
As	0.0005	0.0005	0.001	0.001 max
Sn	0.0005	0.0005	0.001	0.001 max
Sb As and Sn	...	...	0.002	0.002 max
Cu	0.0010	0.0010	0.0015	0.040–0.080
Ag	0.0010	0.0075	0.010	0.020 max
Bi	0.0015	0.025	0.05	0.025 max
Zn	0.0005	0.001	0.001	0.001 max
Te	0.0001	0.0001	...	...
Ni	0.0002	0.0002	0.0005	0.002 max
Fe	0.0002	0.001	0.001	0.002 max
Lead (min) by difference	99.995	99.97	99.94	99.90
UNS Number	L50006	L50021	L50049	L51121

[A] The following applies to all specified limits in Table 1: For the purpose of determining conformance with this specification, an observed value obtained from the analysis shall be rounded off "to the nearest unit" in the last right hand place of figures used in expressing the limiting value, in accordance with the rounding method of Practice E 29.

[B] By agreement between the purchaser and the supplier, analyses may be required and limits established for elements or compounds not specified in Table 1.

[C] This grade is intended for chemical applications where low silver and low bismuth contents are required.

[D] This grade is intended for lead acid battery applications.

[E] This grade is intended for applications requiring corrosion protection and formability.

4. Materials and Manufacture

4.1 Lead shall be supplied in commercial standard forms or shapes requested by the purchaser in the following grades:

4.1.1 Low bismuth low silver pure lead,

4.1.2 Refined pure lead,

4.1.3 Pure lead, and

4.1.4 Chemical copper lead.

4.2 The grades of lead listed in 4.1.1-4.1.4 shall be produced by any smelting and refining process from ore or recycled materials to meet the chemical requirements of this specification.

[1] This specification is under the jurisdiction of ASTM Committee B02 on Nonferrous Metals and Alloys and is the direct responsibility of Subcommittee B02.02 on Refined Lead, Tin, Antimony, and Their Alloys.

Current edition approved June 10, 2003. Published July 2003. Originally approved in 1919. Last previous edition approved in 1997 as B 29 - 92 (1997).

[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 03.05.

5. Composition

5.1 The lead shall conform to the requirements prescribed in Table 1 and accompanying notes.

6. Sizes and Shapes

6.1 Pigs shall weigh up to a nominal 110 lb (50 kg).

6.2 Blocks or hogs shall be square or oblong and weigh up to 2530 lb (1150 kg).

7. Appearance

7.1 The lead shall be reasonably free from surface corrosion and adhering foreign material.

8. Lot

8.1 All lead of the same type produced and cast at one time shall constitute a lot for chemical analysis. Each pig or block of the lot shall bear a single identifying number that can be related to the manufacturing lot.

9. Sampling for Chemical Analysis

9.1 The sample for chemical analysis shall be selected by one of the following methods:

9.1.1 Test samples taken from the lot during casting, or

9.1.2 Test samples taken from the final solidified cast product.

9.2 *Sampling for Lot Analysis*—The supplier may obtain samples from the lot of molten metal during casting. All or part of these samples may be cast into shapes suitable for use in spectrographic analytical methods.

9.3 *Sampling of Cast Product*:

9.3.1 If the lead is in the form of standard pigs (Fig. 1), the sample for chemical analysis shall be taken in accordance with 9.3.3.1, 9.3.3.2, or 9.3.3.3.

9.3.1.1 If the pigs differ in shape from those shown in Fig. 1 or the product is cast into blocks or hogs, the supplier and the purchaser shall agree mutually as to the method to be followed in sampling such shapes.

9.3.2 *Sampling Pig Lead*—A portion representative of the total shipment shall be selected at random for the final sample. For lots containing at least 100 000 lb (45 400 kg) of pig lead, one pig shall be taken from every 20 000 lb (9080 kg). For smaller lots, a total of five pigs shall be taken.

9.3.3 *Sample Preparation*—Each pig shall be cleaned thoroughly to rid the surface of dirt or adhering foreign material prior to sampling by one of the following methods: sawing, drilling, or melting.

9.3.3.1 *Sawing*—The pigs selected shall be sawed completely through as illustrated in Fig. 1. The sawings from the pigs shall be mixed thoroughly and quartered, and the samples for analysis taken from the mixed material. The sawings must be free of extraneous material introduced from the saw blade. All sawings shall be treated with a strong magnet in order to remove iron introduced by sawing.

9.3.3.2 *Drilling*—The pigs shall be drilled at least halfway through from two opposite sides as illustrated in Fig. 2. A drill of about ½ in. (12.7 mm) in diameter shall be used. In drilling, the holes shall be spaced along a diagonal line from one corner of the pig to the other. Holes may be made in a single pig or in each of several pigs placed as illustrated in Fig. 2. The drillings shall be clipped into pieces not over ½ in. (12.7 mm) in length, mixed thoroughly, and treated with a strong magnet to remove iron introduced by drilling.

9.3.3.3 *Melting*—Whole pigs, portions of pigs produced by sawing, drillings, or sawings shall be melted in a clean vessel.

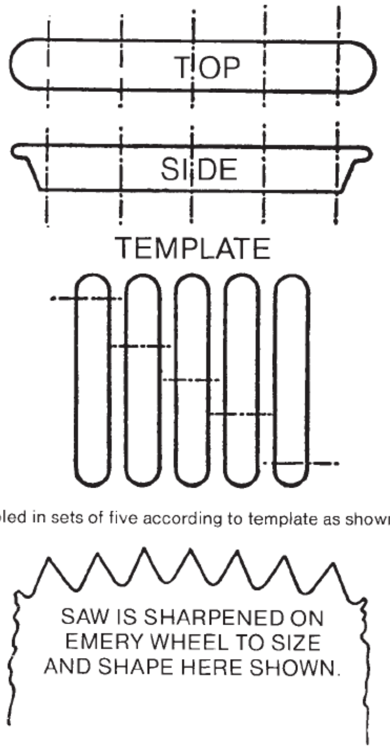
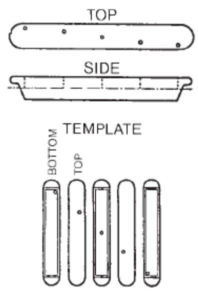


FIG. 1 Method of Sampling Lead by Sawing



NOTE 1—Pigs selected for sampling shall be placed side by side, every other pig bottom side up, and sampled according to template in sets of five pigs each as indicated above. The pigs shall be drilled at least halfway through: when a larger sample is desired, the pigs shall be turned over and sampled on the other diagonal.

FIG. 2 Method of Sampling Lead by Drilling

The melting temperature must not exceed 685°F (363°C) to prevent excessive drossing. The lead must be stirred immediately prior to sampling. The molten lead shall be cast into shapes suitable for use in spectrographic analysis, cast into thin sample bars not to exceed ⅜ in. (9.5 mm) thick for sawing, or granulated by pouring into distilled water and drying the material thoroughly. For sample bars, saw cuts shall be made halfway across the bar from each side and staggered so that they are about ½ in. (12.7 mm) apart. The sawings so produced are treated in accordance with 9.3.3.1.

9.3.4 *Sample Size*:

9.3.4.1 For spectrographic analysis, three samples shall be prepared of a size and shape satisfactory for use by the laboratory at which the analysis is to be made.

9.3.4.2 For wet chemical analysis, each prepared sample (sawings, drillings, or granules) shall weigh at least 600 g.[4]

9.3.5 Aspects of sampling and sample preparation not specifically covered in this specification shall be carried out in accordance with Practice E 88.

10. Methods of Chemical Analyses

10.1 The chemical compositions enumerated in Table 1 of this specification shall, in case of disagreement, be determined by wet chemical or spectrographic methods mutually agreed upon by the supplier and the purchaser.

10.2 By agreement between the purchaser and the supplier, analyses may be required and limits established for elements or compounds not specified in Table 1.

11. Inspection

11.1 Inspection of the material shall be agreed upon between the purchaser and the supplier as part of the purchase contract.

12. Rejection and Rehearing

12.1 Material that fails to conform to the requirements of this specification may be rejected. Rejection should be reported to the supplier promptly and in writing. In case of dissatisfaction with the results of the test, the supplier may make claim for a rehearing.

12.2 Rejection shall be considered as follows:

12.2.1 Variation of weight, quantity, dimensions, or workmanship.

12.2.2 Chemical composition.

12.2.2.1 In case of dispute, the material shall be sampled in the presence of both parties in accordance with 9.3.

12.2.2.2 The resulting sample (at least 1800 g) shall be mixed and separated into three equal parts, each of which shall be placed in a sealed package, one for the supplier, one for the purchaser, and one for the umpire if necessary, and analyzed in accordance with Test Methods E 37.

12.3 When the lead metal satisfies the chemical and physical requirements of this specification, it shall not be condemned for defects in manufacturing or for defects of alloys or products in which it is used.

13. Certification

13.1 When specified in the purchase order or contract, the purchaser shall be furnished certification that samples representing each lot have been tested as directed in this specification and the requirements have been met. When specified in the purchase order or contract, a certified report of the test results shall be furnished.

14. Marking and Special Requirements

14.1 A brand, by which the supplier can be identified, shall be cast or marked legibly upon each pig, block, or hog. In addition, other markings shall identify the material by type and lot number.

14.2 (Any) special marking, color code, and other quality requirements not covered by this specification shall be agreed upon between the supplier and the purchaser.

15. Keywords

15.1 chemical-copper lead; lead; lead metal; pure lead; refined pure lead

[4] "Determination of As, Sb, and Te in Lead and Lead Alloys Using Hydride Generation Atomic Absorption Spectrometry," G.J. Fox, *Atomic Spectroscopy*, Vol 11, No.1, January 1990, p. 13.