 INER-F1018

出國報告（出國類別：其他）

赴加拿大 Candu 公司及美國 Sargent&Lundy 公司參訪

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派赴國家：加拿大、美國
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摘　要

2015 年 11 月 12 日至 11 月 25 日林永鵬與胡相宸二員奉派赴加拿大 Candu/SNC-Lavalin 公司及美國 Sargent&Lundy 公司參訪，考察核電廠圍阻體內再循環集水池濾網更新方案及討論濾網更換後續相關工作和評估計畫進度。核電廠圍阻體若發生破管等緊急事故，造成碎屑累積在圍阻體再循環集水池濾網上，阻礙冷卻水回流反應爐，因此圍阻體再循環集水池濾網更換視為重要的安全相關議題，為執行核三廠濾網更換計畫，確保核電廠圍阻體在發生破管碎屑後，爐心仍能安全營運，有必要實際參訪濾網設計公司及計畫技術服務顧問公司，進行實質交流，以便掌握最新技術和資訊及計畫進度和未來工作內容。核三廠新的濾網由加拿大 Candu 公司負責設計及安裝，核能研究所和美國的 Sargent&Lundy 公司則為核三廠的濾網更換計畫，提供技術服務工作，以確保新濾網能達到技術規範的要求。Sargent&Lundy 公司也是執行爐心下游效應分析的廠商，而目前核三廠兩部機組再循環集水池的新濾網已安裝完畢，各項分析工作也已順利完成，唯爐心內下游效應分析之纖維流量，並未能滿足原能會及美國核管會對每一燃料束纖維流量限值的要求，因而有必要參訪核三廠現有濾網設備廠商 Candu 公司，了解其所提出的改善方案是否能滿足法規要求，以及與 Sargent&Lundy 公司進行技術交流和討論後續未完成的工作，藉此蒐集最新訊息和技術資料，並深入了解旁通濾網(Bypass Strainer)之設計概念、濾網改善有關的分析方法和業界規範、及相關管制單位的法規要求，俾有助於順利執行台電委託計畫，有利於日後工作的推展。

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一、目　的

美國核能管制委員會(United States Nuclear Regulatory Commission, USNRC)於1996年9月發布191號一般安全議題(Generic Safety Issue 191) GSI-191，指出壓水式核能電廠(Pressurized Water Reactor, PWR)圍阻體再循環集水池濾網可能因重大失水事故發生阻塞；2004年9月再發出通函(General Letter, GL) GL 2004-02，要求美國所有PWR電廠，針對圍阻體內管路破裂之冷卻水流失(Loss of Coolant Accident, LOCA)事故，因高能流體破管而出，沖擊各種設施，造成大量碎屑隨水流下，最後累積在再循環集水池濾網處，導致安全系統相關泵，如餘熱移除(Residual Heat Removal, RHR)泵、圍阻體噴灑(Containment Spray, CS)泵，因取水不足功能喪失而影響緊急爐心冷卻系統(Emergency Core Cooling Systems, ECCS)正常運作，進行安全評估和濾網的改善工程。台灣電力公司核能三廠因而於2010及2013年進行二階段之圍阻體集水池濾網評估及更換之改善工程，核三廠二號機和一號機新濾網安裝工程已分別於2014年三月和2015年四月完成。

壓水式核能電廠之圍阻體再循環集水池濾網是一個與運轉安全有關的重要設備，核三廠一號機及二號機已更換由加拿大Candu公司設計的鰭狀(Fin Type)濾網，而GSI-191濾網更換第一階段和第二階段計畫相關的技術服務及報告審核工作由核能研究所和美國的Sargent&Lundy公司負責。因此有必要赴加拿大和美國分別聽取Candu公司對核三廠下一階段爐心堵塞議題的改善措施及Sargent&Lundy公司針對現階段計畫執行情況的簡報包括尚未完成事項和未來核三廠需要執行的改善工作，以符合NRC針對爐心議題所提出的規範要求。此次赴Candu和Sargent&Lundy公司除與其專家討論核電廠圍阻體再循環集水池濾網改善計畫相關等工作，同時蒐集技術資料包括核電廠安全度評估、爐心運轉安全、燃料堵塞問題及核電廠安全設備等，有助於未來工作的推展。 本次公差目的說明如下：

I.　藉由此次參訪Candu/SNC-Lavalin公司與其執行台電濾網計畫成員討論研究濾網

相關安全議題，聽取 Candu 公司提出核三廠下一階段濾網改善工作簡報和新設計的旁通濾網 (Bypass Strainer)，以減少爐心纖維流量並符合新法規的要求，同時蒐集技術資料，並與 Candu/SNC-Lavalin 專家，分享工作經驗，有助於本所技術能力的建立和作為日後工作推展之參考依據，對於台電委託計畫案的執行及核能電廠的安全分析，有莫大的助益，尤其是在電廠爐心堵塞下游效應方面之安全議題。

II. 藉由此次參訪 Sargent&Lundy 公司與其 GSI-191 濾網改善案的工作成員進行計畫工作討論，聽取整個核三廠濾網改善案目前計畫執行情況簡報包括已完成工作、未竟事項、審閱 Candu 的工作項目，其中有 29 項議題需要澄清、殘渣碎屑負荷(Debris Loads)計算程序說明、爐心內下游效應分析議題及相關計算說明、和 WCAP-17788 爐心內纖維流量 NRC 安全評估報告時程以及下一階段規劃事項討論等，與其台電 GSI-191 濾網計畫成員充分交換意見，達成參訪交流的目的。美國核能管制委員會(US NRC)對國內核電廠執行濾網改善情況也高度關注，過去幾次台美 AEC/NRC 雙邊核安管制技術交流會議上多有提及，與 Sarget&Lundy 的合作經驗分享，不僅在專業技術能有所提升，同時對最新資訊的取得更有助益，並有助於提升本所及我國核能安全之廣度與深度。

二、過　程

此次赴加拿大參訪 Candu/SNC-Lavalin 公司及赴美國參訪 Sargent&Lundy 公司進行交流及工作計畫討論，主要是針對核三廠圍阻體再循環集水池濾網改善案計畫執行相關事宜及目前核電廠圍阻體再循環集水池濾網更換現況和其他爐心堵塞影響運轉安全等相關議題。再循環集水池濾網為核電廠運轉安全的重要設備，電廠圍阻體若發生破管事故，造成碎屑累積在圍阻體再循環集水池濾網上，阻礙冷卻水回流反應爐，是非常嚴重的安全問題；若過多之碎屑因此進入反應爐內，造成燃料棒破損或堵塞，又是更為棘手之輻安議題，因此濾網之設計製造及相關的安全分析變得非常重要。核三廠集水池濾網改善方案已被原子能委員會（Atomic Energy Council, AEC）列入追蹤管制項目，而核三廠圍阻體內再循環集水池濾網設計製造的得標廠商為 Candu 公司，濾網規範、技術支援、報告審核及硬體檢查，則由核能研究所和 Sargent&Lundy 公司負責。因此參訪這兩家公司有其必要性，首先於 104 年 11 月 12 日搭機赴加拿大(多倫多) ，於 11 月 13 日參訪 Candu 公司與濾網相關負責人士座談，聽取工作簡報及介紹新設計的旁通濾網(Bypass Strainer)和安裝建議事項，然後於 11 月 16 日至 11 月 20 日到位於芝加哥的 Sargent&Lundy 公司進行計畫工作交流，期間與 Sargent&Lundy 公司相關主管、專案工程師進行討論、交換意見及經驗分享，參訪工作會議結束後，於 11 月 23 日則從芝加哥回多倫多，再經由多倫多轉機回台。行程簡列於表一：

表一：公差行程

日　期	行程	工　作　內　容
11 月 12 日	台北－多倫多	去程
11 月 13、14 日	多倫多	與加拿大 Candu/SNC-Lavalin 公司有關人士進行會議、討論濾網相關議題
11 月 15 日	多倫多－芝加哥	路程

11 月 16 日至 11 月 22 日	芝加哥	到 Sargent&Lundy 公司進行計畫工作討論
11 月 23 日至 11 月 25 日	芝加哥－多倫多－台北	回程
公差人員	林永鵬、胡相宸	

此次赴加拿大 Candu/SNC-Lavalin 公司及美國 Sargent&Lundy 公司參訪，考察核電廠圍阻體內再循環集水池濾網更新方案、評估計畫進度及討論濾網更換後續相關工作，分別與其專家討論核電廠圍阻體再循環集水池濾網設計、分析、實驗及製造等相關應用議題以及計畫執行現況，並蒐集技術資料包括爐心堵塞議題、爐心運轉安全、核電廠安全設備等，並深入了解濾網之設計概念、分析方法及試驗規範、及相關的最新法規要求和 GSI-191 結案選項等，俾便將來執行台電相關委託計畫，有助於日後工作推展，整個參訪過程詳細說明如下：

(一)、參訪 Candu/SNC-Lavalin 公司

首先是參訪 Candu/SNC-Lavalin 公司，與 Candu 濾網相關部門主管及工程師進行交流(圖一)，會議討論和說明事項(附錄附件一)包括：

1、 核三廠現已安裝之濾網尚未完成事項

核三廠二號機 Candu 濾網已先於 2014 年 3 月安裝完成，一號機濾網也已於 2015 年 4 月安裝完畢，濾網硬體部分相關工作已全部完成，然而與濾網設計分析有關的文件報告仍有些爭議性議題需要 Candu 公司再做澄清說明，用以回覆管制單位原子能委員會的詢問，尤其是回應原能會在 GSI-191 議題有關濾網改善案執行情況的回應報告 General Letter (GL) 2004-02，GL 2004-02 回應報告為電廠完成濾網更換後須提交核安管制主管機關進行審查的文件，其內容須依據美國核管會(US NRC)的規範和要求撰寫，主要項目

列於表二作為參考，其內容有多處需要 Candu 做更完整的說明和文字補強，部分內容及需要說明之處將整理完成後請 Candu 回覆。

表二：Specific Guidance for Review Areas

Section	Description	Responsible Organization
1	Overall Compliance	
2	General Description of and Schedule for Corrective Actions	
3	Specific Information Regarding Methodology for Demonstrating Compliance	
3a	Break Selection	
3b	Debris Generation/Zone of Influence (ZOI) (excluding coatings)	Candu
3c	Debris Characteristics	
3d	Latent Debris	
3e	Debris Transport	Candu
3f	Head Loss and Vortexing	Candu
3g	Net Positive Suction Head (NPSH)	Candu
3h	Coatings Evaluation	
3i	Debris Source Term (i.e. housekeeping)	
3j	Screen Modification Package	Candu
3k	Sump Structural Analysis	Candu
3l	Upstream Effects	Candu
3m	Downstream Effects – Components and Systems	Candu
3n	Downstream Effects – Fuel and Vessel	
3o	Chemical Effects	Candu
3p	Licensing Basis	

2、 核三廠 GSI-191 濾網改善計畫結案建議選項和新旁通濾網設計(Bypass Strainer Design)議題 (附錄附件一)

由於核三廠目前爐心下游效應分析結果顯示纖維流經濾網進入反應爐內的纖維量遠大於 NRC Safety Evaluation for WCAP-16793 每燃料束 15g 的限值，因此核三廠目

前安裝的新濾網無法滿足現有法規的要求，美國大多數電廠也無法達到此一限值，因此針對爐心纖維流量限值新的規範 WCAP-17788 的安全分析報告，NRC 預計於 2016 年中公告，目前美國 NRC 針對 GSI-191 濾網改善如何結案，提出三項解決方案，此三項結案選項(Resolution Paths for GSI-191)說明於下：

Option 1: Compliance with 10 CFR 50.46 Based on Approved Models

依據現有的整體解決方案符合 10 CFR 50.46 的要求來處理濾網議題通常用於低纖維的電廠。

Option 2: Deterministic or Risk-Informed
Option 2a: Deterministic Resolution Path
Option 2b: Full Risk-Informed Resolution Path

根據電廠纖維量的多少逐次進行電廠的改善方案，包括用(2a)已經確認的 PWROG 方法或(2b)用資訊風險評估的方式進行濾網評估。

Option 3: Different Regulatory Treatment for Suction Strainer and In-Vessel Effects (Deterministic for Strainer Head Loss / Risk-Based for In-Vessel Effects Resolution Path)

第三個選項 Option 3 基本上是以選項 Option 2a 進行濾網改善，加以選項 2b 進行爐心內效應分析。

Candu 公司為核三廠提出五種可能減少爐心纖維量的方案，其方案分別說明於下：

i. Use of upstream “Pre-Screen”

在現有濾網外圍碎屑擋板(Trash-Rack)外，再加裝新濾網以減少碎屑流到集水池濾網。

ii. Use of different fin type with finer mesh

Candu 現在有更細網格的濾網(80-mesh per 1 inch^2)可供取代核三廠目前安裝的濾網(1/16 inch hole)以降低纖維流經濾網。

iii. Use of “secondary” strainer downstream of current strainer

Candu 設計新的旁通濾網(Bypass Strainer)可安裝在核三廠現有集水池內，再次將碎屑過濾以減少纖維流進爐心。

iv. Debris generation and transport re-analysis

用更精準的方法從新計算分析殘屑的產生和流到濾網的含量並適度放寬非必要的保守條件以降低殘屑量。

v. Insulation replacement

更換電廠現在具有纖維材質的保溫隔絕材料為反射式金屬材質的隔絕材料。

以上五種降低爐心內纖維量的提案，第三案加裝新的旁通濾網(Bypass Strainer)似較為可行，但核三廠最終要如何處理下游爐心議題，還需要等 NRC 有關 WCAP-17788 的安全評估報告於 2016 年公布後才能決定最後的結案方式，Candu 的提議僅作為核三廠濾網改善案結案選擇的參考。

圖一：參訪 Candu 會議照片

(二)、參訪 Sargent & Lundy 公司

Candu 會議結束後，飛往芝加哥參訪 Sargent&Lundy 公司，與其 GSI-191 團隊成員見面進行工作會議(圖二、三)，討論計畫工作事項、未完成工作項目、殘渣碎屑負荷(Debris Loads)計算程序說明、爐心內下游效應分析議題及相關計算說明、和 WCAP-17788 爐心內纖維流量 NRC 安全評估報告內容，以及下一階段規劃事項交換意見等事項，同時審閱 Candu 未回覆或未提供完整說明的工作項目，其中有 29 項議題需要再請 Candu 澄清，此次參訪工作能有機會與 Sargent&Lundy 工作夥伴充分交流工作經驗、分享心得，能更深入了解相關計算程序書的內容，有助於提升本所專業技術能力，並了解最新的法規要求和業界準則，此行收穫良多。此次參訪的工作內容，請參考附錄附件二，現說明主要討論事項和各項工作內容：

1、 核三廠 GSI-191 濾網改善案計畫進度

Sargent&Lundy 公司已協助完成核三廠濾網改善案第一階段所有工作，包括圍阻體勘查、殘渣碎屑負荷產生(Debris Generation)計算分析、正淨吸水頭分析(NPSH Analysis)、濾網招標規範、濾網製造生產檢驗、及濾網測試見證工作等事項。第二階段工作還在進行中包括濾網相關的分析報告皆已審閱完畢、爐心內下游效應分析也大致完成、GL 2004-02 回應報告初稿也已完成，並協助回覆原能會的詢問。

圖二：Sargent&Lundy 會議照片一

圖三：Sargent&Lundy 會議照片二

2、 爐心內下游效應分析結果 (In-Vessel Effects Analysis)

依據通函文件(Generic Letter) GL 2004-02 的要求事項，針對殘渣碎屑流經濾網進入爐心後，對爐心長期冷卻(Long-Term Core Cooling, LTCC)效果的影響評估至為重要。爐心內下游效應分析主要是評估在嚴重意外事故破管冷卻水大量流失 (Loss of Coolant Accident, LOCA)後，流經濾網的纖維殘屑及可能的化學沉澱物，對爐心冷卻效果的影響和衝擊，因此需要完成兩樣主要的分析包括爐心堵塞分析和計算沉澱物累積在燃料棒上對熱傳的影響。

首先是爐心堵塞議題的分析，所有分析工作是依照 PWR Owner Group (PWROG) 針對爐心效應所提出的工業導引：WCAP-16793-NP, Revision 2 進行，以確認新慮網是否滿足 10 CFR 50.46 章節中對長期爐心冷卻效果的要求，同時 WCAP-16793-NP 也明確指出每束燃料棒 (Fuel Assembly, FA) 所允許的最大纖維流量，目前每束燃料棒的流經纖維上限是 15g/FA，目前大多數美國電廠皆無法達成此項數值，因此新的工業導引 WCAP-17788 中很有可能會調整此數值。另一項具有挑戰性的工作是分析化學沉澱物對爐心燃料棒熱傳導的影響，這些可能的沉澱物的來源包括流經濾網的鋁、保溫材質、混凝土及漆類等殘屑，在高溫爐水中溶解和爐心冷卻水中的硼酸(Boric Acid)、氫氧化鋰(Lithium Hydroxide)，以及加入在再循環集水池中的硼酸(Boric Acid)、氫氧化鈉(Sodium Hydroxide)等物質，起化學反應產生各種化學沉澱物，進而附著累積在燃料套管上阻礙熱傳導，造成燃料套管溫度升高，因此對於化學沉澱物累積的厚度，需要做精確的計算，以維護爐心運轉的安全。計算過程也是依據 PWROG 工業導引：WCAP-16793-NP, Revision 2 進行，目前 WCAP-16793-NP 要求燃料套管最高溫度不可超過 800 F^o，以及沉澱物累積的厚度要小於 50 mils。

Sargent&Lundy 針對核三廠進行爐心內下游效應分析之結果如下：

i. 燃料套管最高溫度(Peak Cladding Temperature)是 411 F^{o}。

ii. 最大化學沉澱物累積厚度(Maximum Deposition Thickness)是 23.7 mils。

iii. 每束燃料束纖維流經數量(Quantity of Fiber at Core) 依據 Candu 測試結果計算為 29.5g。

3、 Candu 尚未回覆之議題

核三廠濾網改善案第一階段和第二階段與濾網設計基準有關的文件及分析報告皆已完成審閱，然而仍有部分議題，Candu 公司尚未完全回覆，需要 Candu 公司提出更完整的說明用，以回應原能會的詢問，現將 Candu 未回覆的議題整理成 29 個主要問題，詳列於表三。

表三：Issues Requiring Resolution Prior to GSI-191 Closure

Item	Major Remaining Issue	Candu Response	Note
1	Mineral wool ZOI		
2	Temp-Mat ZOI		
3	Temp-Mat size distribution		
4	Bounding break location		
5	Maximum qualified coating quantity		
6	Dynamic effects		
7	SBLOCA minimum water level		
8	System flow rate		
9	Circumscribed debris condition		
10	Tested debris load		
11	Maximum precipitate loading		
12	Strainer head loss scaling		
13	NPSH required		
14	NPSH scenarios		
15	NPSH calculations		
16	Strainer margin		
17	Air accumulation		
18	Vortex testing		
19	Fiber bypass test flow		
20	Fiber bypass measurement		
21	Test repeatability		
22	Chemical effects test pH		
23	Chemical precipitate debris load		
24	Downstream wear: seal leakage		
25	Downstream wear: pump performance		
26	Downstream wear: RVLIS & RG 1.97 components		
27	Downstream wear SI throttle valves		
28	ANASYS files for structural analysis		
29	Specification Conformance		

4、 GSI-191Closure Options 美國壓水式(PWR)核電廠結案情況

美國核管會(US NRC)對全美壓水式(PWR)核電廠發出 GSI-191 濾網安全評估議題結案的三種選項，三種選項內容如前節所述：Option 1: Allows use of approved models and test methods; Option 2: (2a) Requires implementation of additional mitigative measures until resolution is complete and (2b) Allows additional time to resolve issues through testing or risk informed approach; Option 3: Separates the regulatory treatment of the sump strainer and in-vessel effects，目前全美 PWR 有 18 個機組選擇 Option 1、31 個機組選擇 Option 2a、14 個機組選擇 Option 2b，以及 2 個機組選擇 Option 3 進行 GSI-191 的結案工作。此外 WCAP-17788 “Comprehensive Analysis and Test Program for GSI-191 Closure”針對 GSI-191 濾網改善議題最終結案導則，尤其是爐心纖維量是否放寬和限制條件等規範事項，現已經送進美國核管會進行審查，預計美國核管會將在 2016 年完成安全評估報告，以供各電廠遵行執行濾網改善案的結案工作。

5、 GSI-191 濾網改善下一階段(Phase III)工作和未來發展

核三廠濾網改善計畫第二階段(Phase II)工作，雖還有部分正在進行中，但主要工作已大致完成，因此核三廠現在就需要規劃下一階段(Phase III)的濾網改善措施，以符合原能會及美國核管會(US NRC)針對壓水式(PWR)核電廠 GSI-191 濾網議題所提出的結案要求和 WCAP-17788 中規範的事項。Sargent&Lundy 公司可協助核三廠及核研所完成下列第三階段的濾網改善工作包括：

i. 更新殘渣碎屑負荷產生分析報告 Debris Generation Analysis
ii. 管路動態評估 Dynamic Effects Assessment
iii. SBLOCA 最低水位計算 SBLOCA Minimum Water Level
iv. 依據最新 RHR、CS Pump 及濾網設計基準資料從新計算 NPSH 數值
v. 依據新的設計基準文件評估下游磨耗效應 Downstream Wear
vi. NRC 公告 WCAP-17788 的安全評估報告(Safety Evaluation Report)後將會從新分析

爐心內下游效應 In-Vessel Effects

vii. 依據所有新的設計基準文件從新改寫 GSI-191 的回應報告 GL 2004-02

壓水式(PWR)核電廠 GSI-191 濾網議題，也將會應用到沸水式(BWR)核電廠，目前美國核管會(US NRC)針對沸水式(BWR)核電廠，依據 PWR 核電廠 GSI-191 的經驗提出 12 項 BWR 核電廠需要處理的議題，其中包括：

i. 下游效應元件設備分析 Downstream Effects – Components

ii. 下游效應爐心燃料分析 Downstream Effects – Fuel

iii. 殘屑累積層水頭損失分析 Debris Bed Head Loss

iv. 化學效應分析 Chemical Effects

v. 塗料評估 Assessment of Coatings

vi. 灰塵碎屑分析 Latent Debris

vii. 噴射氣流試驗中所影響區域範圍調整議題 ZOI Adjustment for Air Jet Testing

viii. 核能等級保護塗料影響區域範圍議題 ZOI for Qualified Protective Coatings

ix. 殘渣碎屑流動針對腐蝕議題 Debris Transport – Erosion

x. 殘屑特性鈣有關議題 Debris Characteristics – Cal

xi. 濾網測試四周環境議題 Near Field Effect

xii. 應用假設球型影響區域範圍議題 Spherical ZOI Approach

三、心　得

此次公差參訪核三廠現有濾網設備廠商 Candu，對其所提出的改善方案是否能滿足新規範的要求、是否能解決目前流入爐心纖維量過多的問題等進行討論，以及與 Sargent&Lundy 公司進行技術交流，討論現有計畫後續未完成的工作和下一階段核三廠濾網進一步改善事項，參訪過程中有機會更深入了解兩家公司的技術實力和工作態度，同時藉此蒐集技術資料，並深入了解濾網之設計概念、分析方法及檢測規範、及相關的法規要求，俾有助於順利執行台電委託計畫，有助於日後工作推展。

Candu/SNC-Lavalin 是核三廠現有濾網的設計、測試、製造監督及安裝廠商，對核三廠現況和整廠設計，也非常熟悉，其所提出的旁通濾網(Bypass Strainer)有著更細密的網格，可過濾掉絕大多數的殘渣碎屑，為核三廠解決目前流入爐心纖維量過多問題的可能選項，Candu 提出的處理步驟如下：

I. 定義旁通濾網效能的技術規範 Define Technical Specifications for Bypass Strainer Performance
II. Candu 公司已進行完全的試驗計畫以決定最佳化和最小可能網格的濾網測試提供最適合的旁通濾網 Align Bypass Strainer Requirements against ‘high efficiency’ Strainer Screen Options
III. 執行完整的前期觀察測試(Scoping)和最終的品質認證(Qualification)試驗 Test/Qualify Strainer design
IV. Candu 公司負責詳細設計製造和安裝確保品質 Detail Design, Manufacture and Installation

但核三廠最後要選擇何種方案處理下游爐心議題，還需要等 NRC 有關 WCAP-17788 的安全評估報告於 2016 年公布後，才能決定最後的結案方式，Candu 的

提議目前僅作為核三廠濾網改善案結案選項的參考之一。

參訪 Sargent&Lundy 公司與其 GSI-191 濾網改善案的工作成員對計畫執行情況，進行廣泛而深入的交流，討論目前計畫工作事項和第三階段濾網改善案的內容，期間聽取整個核三廠濾網改善案目前計畫執行情況簡報，包括已完成工作、未竟事項、審閱 Candu 的工作項目，其中有 29 項議題需要澄清、詳細說明殘渣碎屑負荷(Debris Loads)計算的程序，以及爐心內下游效應分析議題及相關計算說明等，至於核三廠如何對現有濾網做進一步的改善措施，以符合 NRC 對爐心內纖維流量的要求，我們也進行了深入討論，會議結論是無論何種結案選項都應等到 2016 年，NRC 對 WCAP-17788 的安全評估報告出來後再做決定，整個會議中所提出需要進一步處理的事項整理於表四中，此次參訪工作能有機會與 Sargent&Lundy 工作夥伴充分交流工作經驗、分享心得，能更深入了解相關計算程序書的內容，有助於提升本所專業技術能力，同時了解最新的法規要求和業界準則，並為核三廠未來濾網再次需要改善工作預作準備，此次參訪達成所有的預先規劃的工作目標，請參閱附錄附件三，此行的收穫遠超過原先的預期，獲益良多。

表四：Action Items Summary

Item	Action Item
1.	Provide NDE procedure for S&L review.
2.	Provide strainer technical specification compliance matrix for S&L review.
3.	Provide electronic files for GSI-191 meeting presentations
4.	Complete in-vessel effects calculation. • INER and S&L reviewed comments and responses during meeting. • S&L to provide revised paragraphs/sections for INER review. • INER to provide concurrence with responses. • S&L to provide final, approved calculation.
5.	Provide GSI-191 Response Executive Summary. • Open items to be discussed in general terms.
6.	Provide GSI-191 Response Sections 3g (NPSH), 3m (downstream wear), and 3o (chemical effects) with outstanding comments inserted.
7.	Provide GSI-191 Phase 2 project summary report.
8.	Provide reference for MNPP power level (2915 MWt).
9.	Provide reference for containment spray (CS) pump recirculation flow rate (~80 gpm).
10.	Obtain MNPP procedures that ensure strainer submergence prior to recirculation. • Procedure revisions were planned per November 13, 2014, email from MNPP to INER/S&L. • Also obtain supporting calculations if possible (e.g. that demonstrate submergence can be achieved even with SBLOCA).
11.	Determine David Chen's (MNPP) availability to support a 2 day GSI-191 meeting in Taiwan away from the plant. The purpose of the meeting will be to allow S&L/INER to present the significant open items (approximately 29) and allow TPC to determine a path forward.
12.	Establish agenda and appropriate dates for GSI-191 meetings in Taiwan.
13.	Extend contract end date (if possible)

四、建　議　事　項

(一)、參訪 Candu/SNC Lavalin 討論核三廠濾網改善措施：

i. 此次參訪 Candu 公司其濾網改善團隊，針對核三廠現在面對爐心纖維流量過大的議題，所提出的解決方案值得我們參考，作為諸多考量的選項之一。Candu/SNC-Lavalin 為加拿大最重要的核能工業公司，不僅提供重水反應爐興建核能電廠外，更提供核能發電相關設備支援核能產業，同時與加拿大政府的核能研究中心 AECL 密切合作，AECL 相當於我國的核能研究所，但 AECL 不僅是對核能作基礎、理論的研究，更將其研究成果交由 Candu 開發應用推廣到核能工業界，其針對核電工業界的需求，所設計開發的相關產品，很多已成為業界中的翹楚，其中廣泛應用的產品除集水池濾網外，還有高精密度金屬封環，用於關鍵閥門和管路中，以及被動式自行催化氫氣重新組合器(PAR)和其他相關的工業產品。Candu/SNC-Lavalin 不僅能從事開發業界需求的產品，又能設計生產製造核電工業所需的元件和設備，其所採取的方法和步驟，以及投入的資源和專業人才的養成，都值得我們效法。

ii. 定期與 Candu/SNC-Lavalin 進行技術交流會議，交換工作心得與經驗，藉由參訪交流可有效提升本所在核能應用和產品開發以及研究方面的廣度與深度。Candu/SNC-Lavalin 的專業架構及研發成果、產品設計製造，都有助於我們規劃未來的核能研究方向及對未來業界應用的項目進行開發。

(二)、參訪 Sargent&Lundy 討論計畫工作關事宜：

i. Sargent&Lundy 公司為美國最著名的核能業界和大型能源設施的工程顧問服務公司，也是核能研究所重要的計畫合作夥伴，此次參訪 Sargent&Lundy 公司，與其核三廠 GSI-191 濾網改善案的團隊成員見面，討論現有計畫工作事項和未來合作執行核三廠濾網改善案第三階段爐心議題工作等事宜，參訪前所訂的目標和討論主題的內容，在與其專業工程師、專案經理座談討論過程中皆已達成，主要項目包括濾網

工作、技術及經驗交流、未完成工作項目說明、介紹殘渣碎屑負荷(Debris Loads)計算程序、討論爐心內下游效應分析議題及相關計算說明、分享 NRC 針對 WCAP-17788 爐心內纖維流量安全評估報告的內容以及對下一階段規劃事項交換意見和對 BWR 電廠可能產生的衝擊等，同時完成審閱 Candu 未回覆或未提供完整說明的工作項目，共有 29 項議題需要再請 Candu 澄清，以上參訪規劃事項在會議中都圓滿完成。此次參訪工作能有機會與 Sargent&Lundy 工作夥伴充分交流工作經驗、分享心得，能更深入了解相關分析計算工作，有助於提升本所專業技術能力，並了解最新的法規要求和業界準則，此行收穫良多，是一次非常成功的參訪公差。藉由此次機會與 Sargent&Lundy 專家充分溝通與資訊之交換，可有效提升本所在面對國內核電廠有關濾網安全議題上的自主性，因此建議應與 Sargent&Lundy 公司維持良好的合作關係。

ii. Sargent&Lundy 專家在會議中對 BWR 議題也多有著墨，因為 GSI-191 所引發的 PWR 濾網安全議題，現對 BWR 電廠也產生衝擊，是未來台電和核研所需要關注的核安管制議題，目前 BWR Owner Group (BWROG)業主集團已援引 PWR 濾網改善所遇到的問題、所發展的方法以及所學到的經驗，試圖應用到 BWR 電廠以改進電廠的安全性和濾網效能，我國應充分掌握相關議題之後續發展並妥為因應。藉由此次與 Sargent&Lundy 公司的互動，有助於我們掌握目前業界動態，累積業界經驗，為未來台電 BWR 電廠可能會進行的濾網改善案預作準備，因此也建議與 Sargent&Lundy 公司保持密切聯繫和人員交流。

總結此次參訪結果和以上建議事項，有三個主要方向可作為本所未來努力的目標，不僅能增進本所在核能專業的實力，同時也能強化本所對核能應用工業產品開發和製造，提升本所的實力，為未來可能的轉型預作準備，進而達成本所的使命與職責，因此對本所需要的努力方向和採行方案，提出以下建議：

I. 增進與國際主要核能設備廠商或工程顧問公司的交流與聯繫，即時掌握最新的業

界動態與需求，有機會共同參與產品的開發，累積產品開發製造經驗。

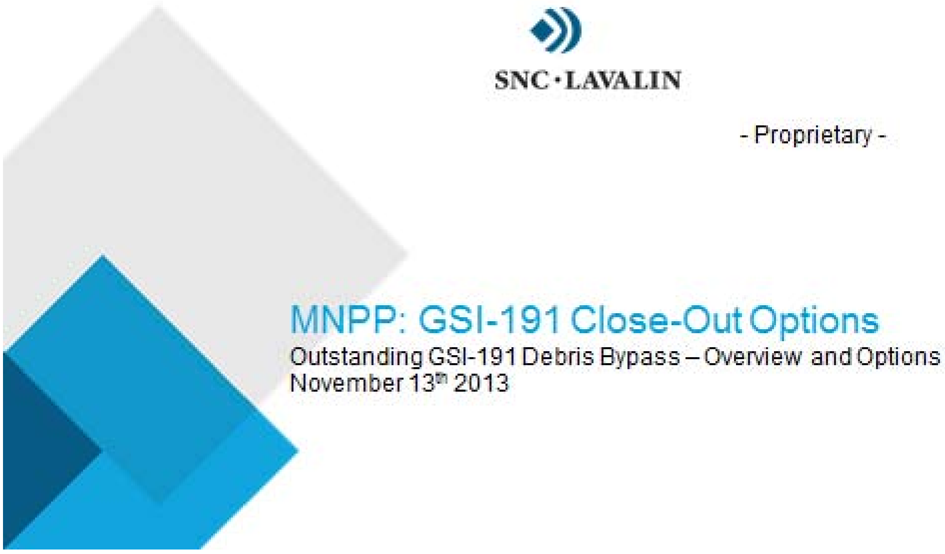
II. 加強與國外學術及科研單位的交流，參與相關的研究計畫，提升研發實力與投入人才培育、確保國內核能安全與研究的品質。

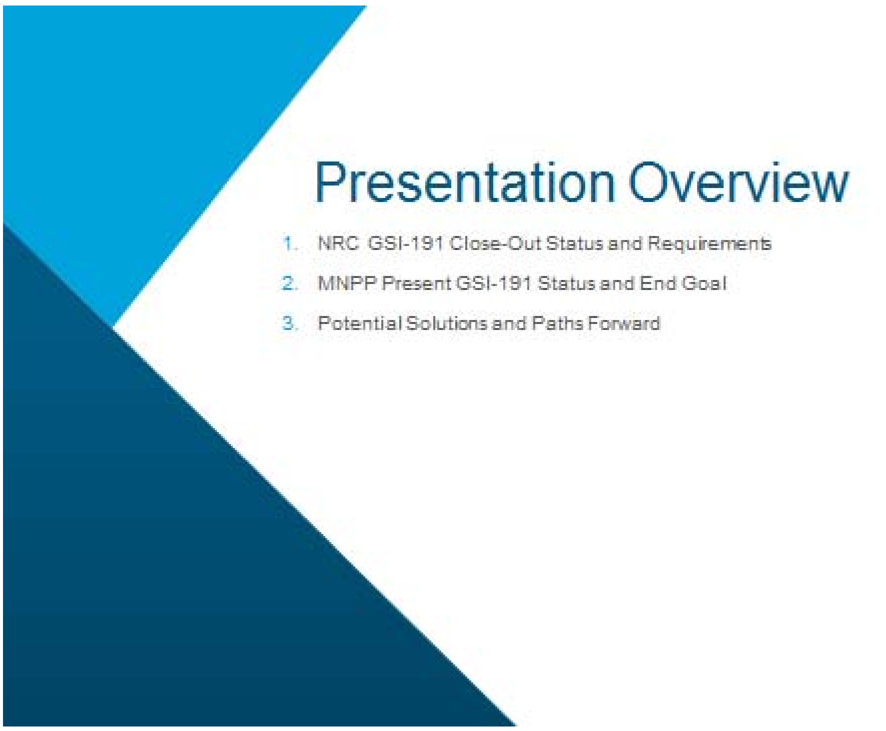
III. 同時加強與國外電廠的經驗交流，無論是安全改善議題、技術開發或效率提昇等，都值得借鏡，有助於台電委託案的執行。

五、附　錄

附件一

Candu/SNC-Lavalin 簡報內容





NRC GSI-191 Close-Out Status and Requirements

Presently, Strainer By-Pass and In-Core effects are the only outstanding item for PWROG on GSI-191.

Three (3) Resolution Paths have been developed by PWROG:

Option 1: Compliance with 10 CFR 50.46 Based on Approved Models

Option 2: Deterministic or Risk-Informed

- *Option 2a: Deterministic Resolution Path*
- *Option 2b: Full Risk-Informed Resolution Path*

Option 3 Different Regulatory Treatment for Suction Strainer and In-Vessel Effects

MNPP - Bypass Options

Candu has reviewed MNPP's bypass issues and provided input on potential options to reduce MNPP strainer bypass value:

1. *Use of upstream "pre-screen"*
2. *Use of different fin type with finer mesh*
3. *Use of "secondary" strainer downstream of the current strainer*
4. *Debris generation and transport re-analysis*
5. *Insulation replacement*

Option 3 is INER and TPC's Preferred Option

Option 1 Use of upstream “pre-screen”

Install a “pre-screen” around the existing trash-rack to reduce debris transported to the existing sump strainer.

Such a “pre-screen” and the change in debris loading would effect the current strainer design/qualification. The reduction in debris reaching the strainer would reduce the load on the strainer, resulting in lower pressure drop.

However, without reducing the existing strainer size, the reduced debris loads and resulting reduced bed thickness; there would be an increased proportion of bypass of the reduced debris load.

Solution involves crediting the reduced pressure drop to reduce the current strainer size; the reduced size would reduce bypass further.

Pros:

1. Reduced bypass
2. Easy strainer size reduction by removing fins

Cons:

1. Risk of flow blockage before the current strainer because of the location of the current strainer inside the sump area, covered on the top and blocked on one side
2. Location of pre-screens needs to be defined
3. Effectiveness of pre-screens is unknown
4. New testing and analysis (including seismic) required for pre-screens, or a combination of pre-screens and reduced size strainer

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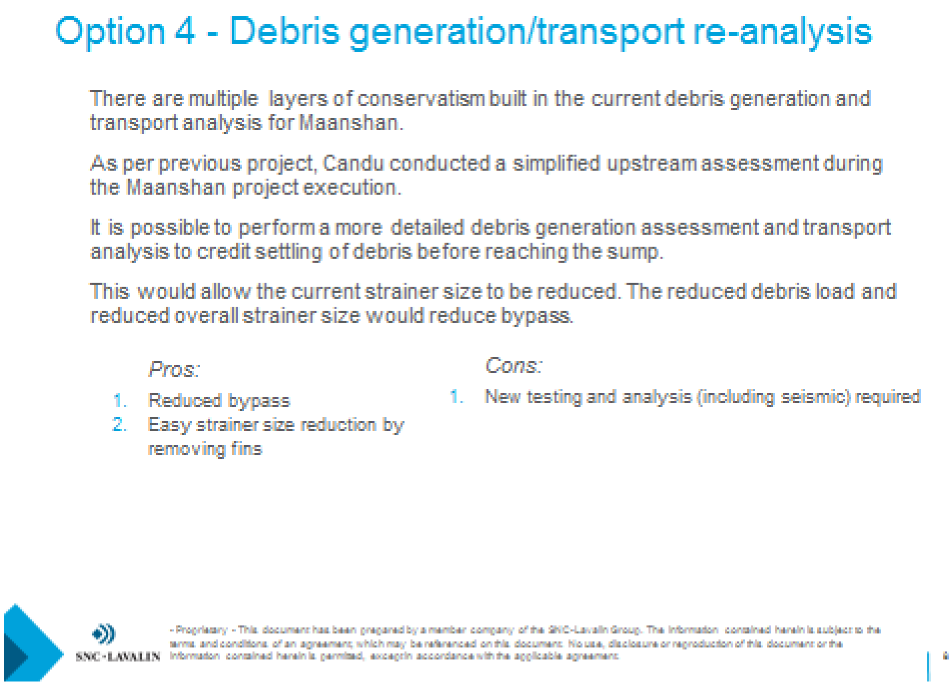
Option 4 - Debris generation/transport re-analysis
There are multiple layers of conservatism built in the current debris generation and transport analysis for Maanshan.
As per previous project, Candu conducted a simplified upstream assessment during the Maanshan project execution.
It is possible to perform a more detailed debris generation assessment and transport analysis to credit settling of debris before reaching the sump.
This would allow the current strainer size to be reduced. The reduced debris load and reduced overall strainer size would reduce bypass.
Pros:
1. Reduced bypass
2. Easy strainer size reduction by removing fins
Cons:
1. New testing and analysis (including seismic) required
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6

Option 5 - Insulation replacement

A final option would consider replacement of all fibrous insulation within the ENTIRE containment building by RMI or other stronger type of insulation leading to lower fibrous debris.

This would allow the current strainer size to be reduced.

The reduced fibre quantity would reduce bypass.

Pros:

1. Reduced bypass
2. Easy strainer size reduction by removing fins

Cons:

1. New testing and analysis required due to change in debris loading conditions
2. Complexity and Cost of insulation replacement
3. Increased dose to workers

Preferred Option – Path Forward

Based on preliminary discussions between INER and TPC, the preferred option for achieving the targeted 15g/FA acceptance criteria is:

- *"Option 3 – A Secondary "Bypass" Debris Strainer".*

<u>Candu is ideally positioned to provide services for this option because:</u>

1. Fully familiar with the current plant design and debris conditions.
2. Has conducted a comprehensive test program and provided an 80 mesh low bypass strainer type to stations in the past.

Details of Candu experience with low bypass strainer designs will be provided in the next presentation.

附件二

Sargent&Lundy 會議討論內容

Agenda

- Status of S&L GSI-191 work for MNPP
- ROCAEC Meeting in Taiwan
- MNPP GSI-191 Closure Issues
- Status of GSI-191 in U.S.
- Possible Project Extension (Phase 3)
- WCAP-17788 (In-Vessel)
- WCAP-16793 (LOCADM)
- Debris Generation Spreadsheet
- Future Opportunities

2

S&L GSI-191 Work for Maanshan

- Walkdowns - Complete
  - Unit 1 and 2 walkdowns
    - GSI-191, Latent, Foreign Material, and Designer
- Preliminary Engineering - Complete
  - Debris generation analysis
  - NPSH margin analysis
  - Draft strainer technical specification

3

S&L GSI-191 Work for Maanshan

- Phase 1 – Complete
  - Technical Overviews
  - Strainer manufacturing audit at TSM
  - Strainer test witnessing at AECL

4

S&L GSI-191 Work for Maanshan

- Phase 2 – In Progress
  - Technical Overviews
    - Complete
  - In-Vessel Effects Analysis
  - GL 2004-02 Close-out Report
  - ROCAEC RAI support
  - Meeting with ROCAEC

5

Phase 2 Scope

Task	% Complete (Total)
Project Work Plan (PWP)	100%
MNPP Analyses	
Downstream component blockage	100%
Downstream component wear	100%
HELB review	100%
NPSH	100%
Strainer Testing and Analysis	
Gap evaluations / EQ assessment	100%
Chemical effects HL test report	100%
Strainer hydraulic performance analysis	100%
Seismic / load analysis	100%
Strainer Manufacturing	
Welding procedures	100%
Non-Destructive Examination (NDE) proc's	
Torquing procedure	100%
Cleaning procedure	100%
Equipment calibration procedure	100%

6

Phase 2 Scope

Task	% Complete (Total)
Strainer Modification	
Spec Conformance	
DCR (strainer installation) - 1st Unit	100%
DCR (strainer installation) - 2nd Unit	100%
Drawing review - Unit 1	100%
Drawing review - Unit 2	100%
Strainer mock-up procedure - Common	
Strainer installation & maintenance procedure	100%
Certificate of Compliance	100%
In-Vessel Effects Analysis	95%
GL 2004-02 Close-out Report	90%
RAIs from AEC	55%
Meeting(s) w/ AEC in Taiwan	Planned

7

Technical Overviews

- One round of comments per document
- One round of comment response review
- S&L has provided more than one round of comments on several documents

8

Phase 1 GSI-191 Technical Overviews

- MNPP Analysis Topics - Complete
  - Debris generation
  - Debris transport
  - Chemical effects
- Strainer Testing Topics - Complete
  - Head loss test procedures
    - Thin bed, full load, chemical effects, vortexing
  - Fiber bypass test procedures
  - Head loss (non-chemical) test report
  - Fiber bypass test report

9

Phase 2 GSI-191 Technical Overviews

- MNPP Analysis Topics - Complete
  - Downstream component blockage
  - Downstream component wear
  - HELB review
  - NPSH assessment

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Phase 2 GSI-191 Technical Overviews

- Strainer Testing and Analysis Topics - Complete
  - EQ assessment
  - Chemical effects head loss test report
  - Strainer hydraulic analysis
  - Strainer structural analysis

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Phase 2 GSI-191 Technical Overviews

- Strainer Manufacturing Topics – Complete
  - Welding procedures
  - Torqueing procedure
  - Cleaning procedure
  - Equipment calibration procedure
  - Non-Destructive Examination (NDE) procedures
    - Never received, ∴ no overview
  - Inspection & test plans
  - Packing procedure

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Phase 2 GSI-191 Technical Overviews

- Strainer Modification Topics – Complete
  - Technical specification conformance
    - Never received, ∴ no overview
  - DCRs – Units 1 & 2
  - Drawing review – Units 1 & 2
  - Strainer mock-up procedure
    - Never received, ∴ no overview
  - Strainer installation & maintenance procedure
  - Certificate of Compliance (C of C)

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Technical Overview Summary

- No significant open items pertaining to strainer manufacturing or modification
- Although Phase 1 and Phase 2 overviews are "complete," significant open items remain in the design basis documentation
  - Specific items addressed later in presentation

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Status of S&L Phase 2 GSI-191 In-Vessel Effects

- In-Progress
- In-Vessel Effects Analysis
  - Sent for Owner's Acceptance Review 6-Aug-2014
  - TPC comments received 11-Nov-2014
  - Comment responses sent 4-Feb-2015
  - Awaiting TPC concurrence with comment responses
- LOCADM results acceptable

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Status of S&L Phase 2 GSI-191 In-Vessel Effects

- In-vessel fiber loading > 15 g/FA
- Recommend completing calculation as is
  - Consistent with U.S. plants
- Many U.S. plants plan to use WCAP-17788 to increase acceptable fiber limit once NRC SE is complete (expected mid 2016)

16

Status of S&L Phase 2 GSI-191 GL 2004-02 Close-Out Report

- In-Progress
- Co-prepared by TPC/INER/S&L/Candu
- Incomplete S&L tasks:
  - Executive Summary
  - Inserting comments regarding open items into Sections 3g (NPSH), 3m (downstream wear), and 3o (chemical effects)
- What is overall status?

17

Status of S&L Phase 2 GSI-191 ROCAEC RAI Support

- ROCAEC RAI Support
  - Ongoing
- Responses to several rounds of comments have been provided
  - August 2014
  - October/November 2014
  - February 2015

18

Status of S&L Phase 2 GSI-191: ROCAEC Meeting

- What is TPC expectation for meeting?
  - Review MNPP resolution of GL 2004-02?
    - What is TPC plan for addressing open items?
  - Discuss additional ROCAEC RAIs?
  - Update on U.S. status of GSI-191?
  - Remaining work?

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Issues Requiring Resolution Prior to GSI-191 Closure

- Significant issues and concerns discussed with TPC, INER, and Candu on August 19, 2014
  - Most issues remain open
- 29 significant issues to be discussed in more detail
- How is TPC planning on addressing open items?
- Is Candu still engaged in MNPP GSI-191 project?

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#1: Mineral Wool ZOI

- Upstream Assessment Open Item
  - MNPP-34325-ASD-002
- NRC SE for NEI 04-07 does not contain a ZOI for encapsulated mineral wool
- ZOI of 5.5D + 10% used
- Insufficient justification
  - Based on force (jet pressure*area) computation and assumption that all Transco cassettes have similar L/D
- Impacts design debris load

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#1: Mineral Wool ZOI

- Assumes that jet pressure of 4 psig is exerted over 20D diameter circle at L=100D
  - Pressure actually exerted over 1D circle per Table D-1 of NEI 04-07 » much less force at L=100D
- Assumes that mineral wool cassettes cannot be longer than 25” at MNPP

22

#1: Mineral Wool ZOI

Cassettes Appear > 25”

23

#2: Temp-Mat ZOI

- Upstream Assessment Open Item
  - MNPP-34325-ASD-002
- NRC SE for NEI 04-07 provides a ZOI of 11.7D for Temp-Mat with SS wire retainer
- ZOI of 5.5D + 10% used
- Insufficient justification
  - Based on force (jet pressure*area) computation and assumption that all Transco cassettes have similar L/D
- Impacts design debris load

24

#2: Temp-Mat ZOI

- Similar argument to mineral wool
- Assumes that Temp-Mat cassettes cannot be longer than 6” at MNPP

25

#2: Temp-Mat ZOI

Cassettes Appear > 6”

26

#3: Temp-Mat Size Distribution

- Upstream Assessment Open Item
  - MNPP-34325-ASD-002
- Temp-Mat size distribution
  - 60% small fines
  - 40% large pieces
- Size distribution intended to be used with NRC SE Temp-Mat ZOI of 11.7D
- Not appropriate when using a reduced ZOI

27

#3: Temp-Mat Size Distribution

- Excerpt from NRC guidance (ML100900172) for use of Sure-Hold bands with Nukon (which reduce the ZOI):
  - *Appendix II documents that the staff’s acceptance of the* ***baseline size distribution of 60% small pieces and 40% large pieces for Nukon fiber blankets was based on a ZOI size of 17D****. As demonstrated in Figure II-2 from this appendix, the* ***degree of insulation fragmentation is not constant with jet pressure****, but increases as the jet pressure impacting the target is increased, approaching 100% fragmentation into small fines at impingement pressures of approximately 20 psig.*
- Same concept applies to Temp-Mat

28

#3: Temp-Mat Size Distribution

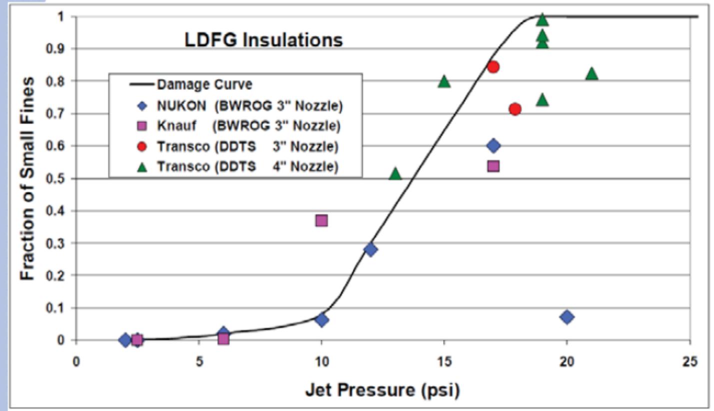


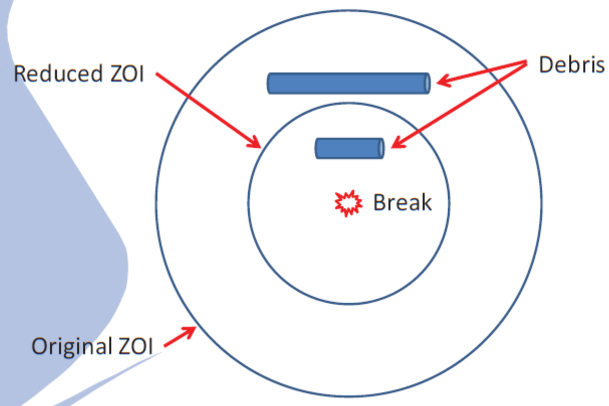
Figure II-2. LDFG Damage Curve for Small Fine Debris

#4: Bounding Break Location

- Upstream Assessment Open Item
  - MNPP-34325-ASD-002
- Bounding break locations determined with:
  - Mineral Wool ZOI = 17.0D
  - Temp-Mat ZOI = 11.7D
- Bounding break locations may be different if reduced ZOIs are used
  - Use of same locations may be non-conservative
- Impacts design debris load

30

#4: Bounding Break Location



31

#5: Maximum Qualified Coating Quantity

- Upstream Assessment Open Item
  - MNPP-34325-ASD-002
- Qualified epoxy coatings based on 4D ZOI
- Currently based on break that impacts a wall adjacent to RCS
- More conservative break location would be at bottom of intermediate leg
  - Wall and floor impacted by break
- Impacts design debris load

32

#5: Maximum Qualified Coating Quantity

- Embedded conservatism in existing particulate debris load
- Latent particulate modeled with density of 100 pcf
- NRC SE for NEI 04-07 specifies 2.7 g/cm^3 (168 pcf)
- Tested particulate volume has margin

33

#6: Dynamic Effects

- Upstream Assessment Open Item
  - MNPP-34325-ASD-002
- No design basis documentation of the impact of dynamic effects on strainer
  - Jet impingement
  - Pipe whip
  - Missiles

34

#6: Dynamic Effects

- Upstream assessment states the following based on walkdowns:
  - *"no high energy SIS piping was found on the containment floor near the ECCS sump and strainer area."*
- Walkdowns performed by S&L do not support this statement

35

#6: Dynamic Effects

- Unit 1 Walkdown Report
  - *p. 13: To the northwest, west and east of the sumps are potential high energy lines of the ECCS. Valves near the sump include BH-V010, BH-V011, BH-HV039, BHHV106 and BC-HV206.*
- Unit 2 Walkdown Report
  - *p. 11: To the west side of the pit, the nearest high energy line is the SIS Cold Leg Injection line. To the east side of the pit, the nearest high energy lines are the SIS Cold Leg Injection line and the Loop 1 RHR B Suction line.*

36

#6: Dynamic Effects

- Per §205 of the strainer specification:
  - *Among the **required analyses is a review of high energy line breaks**. The contractor is responsible to **determine the jet loads** that their strainer will withstand and review the plant to determine which line breaks could affect the strainer. As a minimum, the evaluation shall consider the potential impact of the SIS Cold Leg Injection line to the west of the sump pit, the SIS Cold Leg Injection line to the east of the sump pit and the Loop 1 RHR B Suction line is also to the east of the sump enclosure.*

37

#7: SBLOCA Minimum Water Level

- Hydraulic Analysis Open Item
  - MNPP-34325-ASD-001
- Section 3f.2 of the GSI-191 response requests minimum strainer submergence under both small and large break LOCA scenarios
- SBLOCA minimum water level is not available in current design basis documentation

38

#8: System Flow Rate

- Current 2-train operation
  - 12,870 gpm
    - Q_{RHR} = 6300 gpm
    - Q_{CS} = 2 * (3650 – 365) = 6570 gpm
- Current 1-train operation
  - 8150 gpm
    - Q_{RHR} = 4500 gpm
    - Q_{CS} = 3650 gpm

39

#8: System Flow Rate

- ROCAEC RAI questioned CS recirculation flow
  - Actually 80 gpm, not 365 gpm
  - Q_{CS} = 2 * (3650 – 80) = 7140 gpm
- Q_{system} = 6300 + 7140 = 13,440 gpm
- Analyses based on 12,870 gpm 2-train flow may be non-conservative
  - Hydraulic analysis, Test Report, etc.
  - Revision to account for higher flow required

40

#9: Circumscribed Debris Condition

- Hydraulic Analysis Open Item
  - MNPP-34325-ASD-001
- MNPP strainer design susceptible to circumscribed debris condition
  - Debris accumulation around the perimeter instead of between fins

41

#9: Circumscribed Debris Condition

- From March 2008 NRC head loss test guidance
  - *Figure 3.2 schematically shows modules connected into a common plenum with the modules arranged in an array. In this type of arrangement, the center modules may only have one outer surface contributing to the circumscribed area. During prototype testing of a single module, it is unlikely that the similitude for both the screen and the circumscribed velocities can be simulated simultaneously. For these strainers, the test matrix may have to include tests where the respective similitude is achieved piecemeal. A simple area-ratio scaled head loss test may not be conservative.*

42

#9: Circumscribed Debris Condition

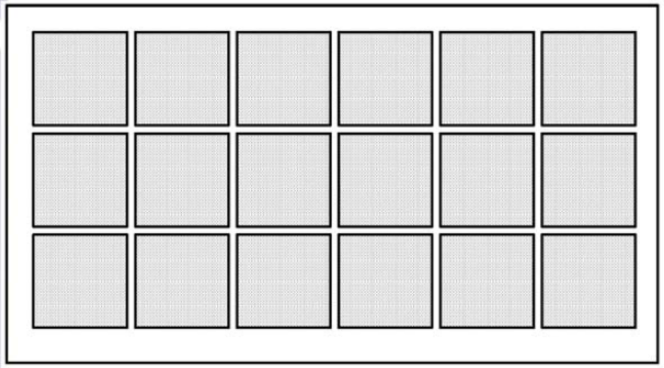


Figure 3.2 - Schematic of Array of Modules Connected to Common in-Floor Plenum

43

#9: Circumscribed Debris Condition

- Condition not fully dispositioned in current documentation
  - Need to explain how testing demonstrates that plant will not experience circumscribed debris condition
  - Perimeter fins in the plant will be exposed to ~4 times the tested debris load
- Some justification was provided in comment responses, but not in design documents

44

#10: Tested Debris Load

- Test Report Open Item
  - MNPP-34325-TR-001
- Design basis tests performed with debris load from “Pipe Break 2”
- Tested debris load may be non-bounding/non-conservative based on other outstanding comments on debris load
- Non-conservative debris load could lead to non-conservative strainer head loss

45

#11: Maximum Precipitate Loading

- Chemical Effects Analysis Open Item
  - MNPP-34325-ASD-004
- Intermediate leg break used to determine precipitate load
  - Maximum fiber load
- Reactor vessel nozzle break not addressed with respect to chemical effects
  - Maximum amount of soluble debris due to large Foamglas inventory
- Most likely not a major issue, but requires disposition

46

#12: Strainer Head Loss Scaling

- Test Report Open Item
  - MNPP-34325-TR-001
- Bore holes formed prior to peak head loss in design basis chemical effects head loss test
- Scaling based on flow sweeps may not be appropriate

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#12: Strainer Head Loss Scaling

Figure C-8 MNPP-CET01 Debris Bed after Fin Removal

48

#12: Strainer Head Loss Scaling

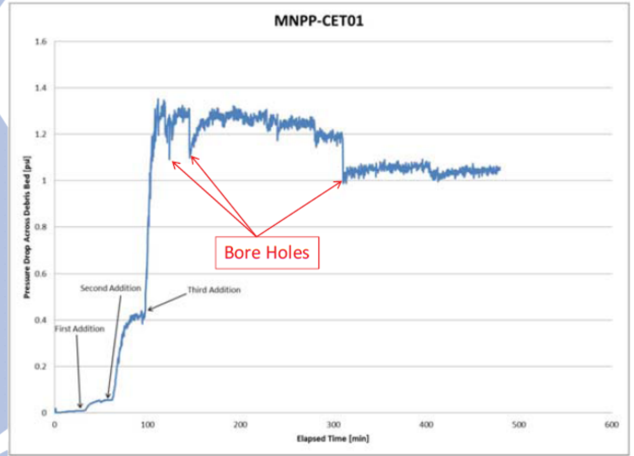


Figure 6-16 Pressure Drop during MNPP-CET01 Debris Additions

49

#12: Strainer Head Loss Scaling

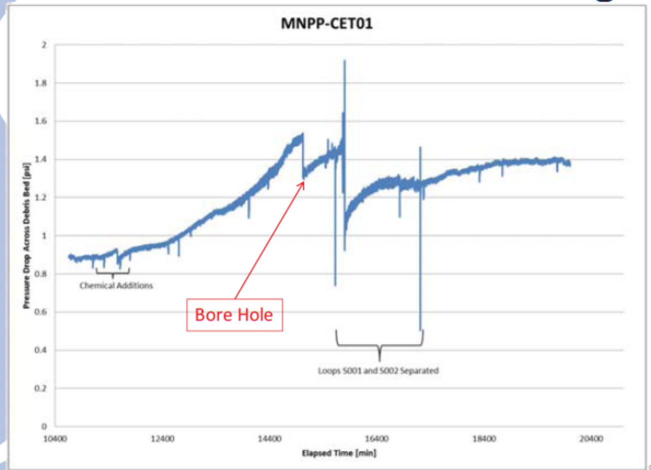


Figure 6-18 Pressure Drop during MNPP-CET01 Chemical Additions

50

#12: Strainer Head Loss Scaling

- Per March 2008 NRC head loss guidance:
  - *If indications of channeling were observed during testing, any correction for temperature should be justified from both the perspective of laminar and turbulent flow regimes,* ***and from the perspective that the head loss could have been higher if debris bed morphology changes due to differential pressure had not occurred.***
- Further justification for scaling of design basis tests required

51

#13: NPSH Required

- Hydraulic Analysis Open Item
  - MNPP-34325-ASD-001
- Deaeration occurs due to ΔP through strainer
- Void fraction impacts NPSH required per Regulatory Guide 1.82
  - $NPSH_{R,adjusted} = NPSH_R * \beta$
  - $\beta = 1 + \alpha_p$
  - α_p = volumetric % air in fluid at pump inlet

52

#13: NPSH Required

- Void fraction increases NPSH
- Not currently accounted for in hydraulic analysis
- Impacts strainer margin

53

#14: NPSH Scenarios

- NPSH assessment based on 2-train operation
- 2-train operation may not be conservative for NPSH margin
- More flow through strainer maximizes head loss and deaeration (conservative)
- RHR flow during 2-train operation is less than for 1-train operation
  - Lower NPSH required during 2-train operation
- Both 1- and 2-train operation should be assessed

54

#15: NPSH Calculations

- Strainer Technical Specification Open Item
- Strainer Test Report Open Item
  - MNPP-34325-TR-001
- Impact of strainer head loss on RHR and CS pump NPSH addressed in strainer test report
- RWST water level change due to DCR M1-2033 to be included in NPSH calculations per strainer tech spec

55

#15: NPSH Calculations

- Design basis NPSH calculations
  - RHR: M-BK-116.06, “RHR Pump NPSH During Containment Sump Suction”
  - CS: M-BK-116.05, “Spray Pump NPSH During Recirculation”

56

#15: NPSH Calculations

- Per §205 of Strainer Specification:
  - *"…the contractor shall **revise the existing NPSH calculations** for the ECCS and CS pumps to verify that the new screens ensure that the required NPSH to the ECCS and CS pumps under the worst postulated conditions post-DBA is available."*

57

#15: NPSH Calculations

- Other Design Basis NPSH Documents
  - M-VBH-215.01, "Verification of Available NPSH for Emergency Core Cooling (ECCS) Pumps"
  - M-VBK-216.02, "NPSHA for the RHR and Containment Spray Pumps as a Function of Percent Containment Sump Screen Blockage."

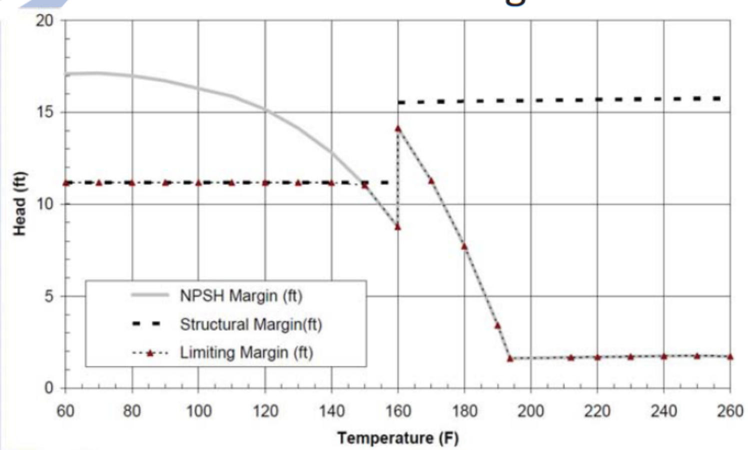
58

#16: Strainer Margin

- Test Report Open Item
  - MNPP-34325-TR-001
- Test report only documents hydraulic (i.e. NPSH margin)
- Structural margin not addressed
- Both NPSH and structural margin should be addressed

59

#16: Strainer Margin



Example Strainer Margin

60

#18: Vortex Testing

- Test Report Open Item
  - MNPP-34325-TR-001
- Vortex testing at 200% of nominal flow
  - Justification that this is bounding is needed
- Flow through modules near sump can be much greater than nominal
  - Validate that flow in modules over pit not > 200% of nominal flow

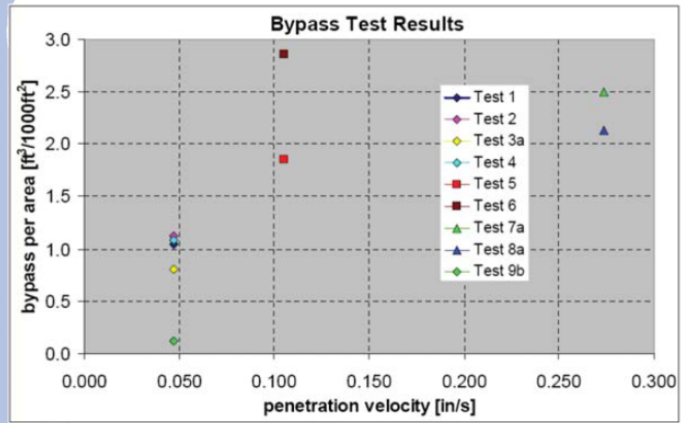
63

#17: Air Accumulation

- Hydraulic Analysis Open Item
  - MNPP-34325-ASD-001
- Deaeration occurs due to ΔP through strainer
- For 1-train operation, water flows through connecting duct
- Air could accumulate in connecting duct
  - Depends on bubble size, ascension velocity, and flow velocity
  - Could eventually block flow between sumps

61

#19: Fiber Bypass Test Flow



Example Bypass vs. Penetration Velocity

65

#20: Fiber Bypass Measurement

- Test Report Open Item
  - MNPP-34325-TR-001
- Fiber bypass measurement does not account for time when there was no capture filter in the test loop
  - Non-conservative
- Fiber bypass measurement should be adjusted to account for potentially missed bypass
- Impacts in-vessel effects fiber load

66

#20: Fiber Bypass Measurement

Date [YYYY MMM DD]	Time [hh:mm]	Elapsed Time from Start of Test [min]	Event
2014 Jan 22	11:30	0	Start of test (sacrificial Cuno filter already in)
	13:08	98	Removed sacrificial Cuno filter
	13:08	98	Installed MNPP-FBT02-CF01
	14:14	164	Sample MNPP-FBT02-GS-001
	14:16	166	Valved in first addition
	14:18	168	Sample MNPP-FBT02-GS-002
	14:20	170	Sample MNPP-FBT02-GS-003
	14:22	172	Sample MNPP-FBT02-GS-004
	14:24	174	Sample MNPP-FBT02-GS-005
	14:26	176	Sample MNPP-FBT02-GS-006
	14:31	181	Removed MNPP-FBT02-CF01
	14:35	185	Installed MNPP-FBT02-CF02

67

#20: Fiber Bypass Measurement

- Example
  - 1st filter in loop for 15 minutes after first fiber addition
  - Loop is then without filter for 4 minutes
  - No filter for ~20% of the time following 1st fiber addition
- Similar trend for other filter swaps

68

#21: Test Repeatability

- Test Report Open Item
  - MNPP-34325-TR-001
- Design basis includes only 1 of each
  - Fiber bypass test
  - Chemical effects head loss test
- Repeatability and should be accounted for

69

#21: Test Repeatability

- Repeatability is important issue as discussed in §17(c) of the March 2008 NRC guidance
  - *Staff Expectations: Licensees should consider items such as debris / precipitate settlement, the presence of debris bed bore holes,* ***test repeatability****, and pressure drop across the bed as a function of time, when evaluating head loss test results.*

70

#22: Chemical Effects Test pH

- Test Report Open Item
  - MNPP-34325-TR-001
- Lowest tested pH ~8.1
- Test acceptance criterion was pH 8.0±0.2
  - Comment made prior to test suggested pH acceptance criterion of 8.0 +0/-0.2
- Higher pH values are non-conservative
- TPC was to look into actual minimum pH
  - Believed minimum pH ~8.5

71

#22: Chemical Effects Test pH

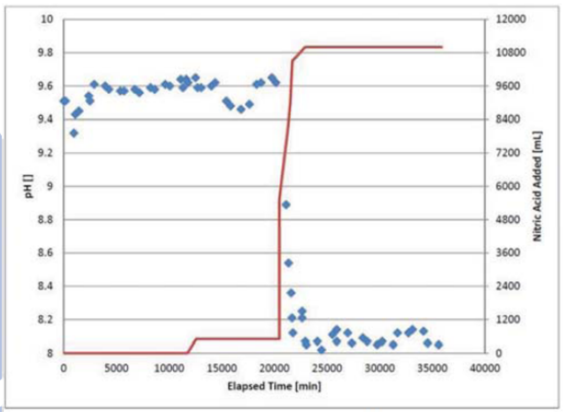
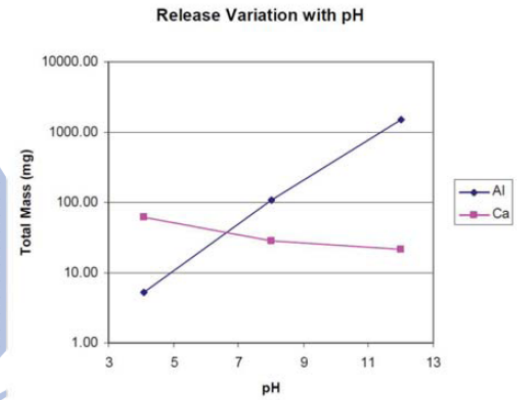


Figure 6-21 MNPP-CET01 Total Nitric Acid Added and Measured pH Upstream of the Strainer Box

72

#22: Chemical Effects Test pH



Taken from WCAP-16530

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#23: Chemical Precipitate Debris Load

- Test Report Open Item
  - MNPP-34325-TR-001
- Test report only provides precipitate contributions of Al, Si, and Ca
- Per WCAP-16530 guidance
  - 1 lbm Al per 9.7 lbm $NaAlSi_3O_8$
  - 1 lbm Al per 2.2 lbm AlOOH
- Type and identity of precipitates not provided

74

#23: Chemical Precipitate Debris Load

- Insufficient information to respond to Item 6 of March 2008 NRC guidance
  - *"Licensees should provide the chemical identities and amounts of predicted plant-specific precipitates"*

75

#24: Downstream Wear: Seal Leakage

- Downstream Wear Analysis Open Item
  - MNPP-34325-ASD-003
- Seal leakage due to wear outside containment can impact:
  - Room habitability
  - Off-site dose
  - Flooding
- Not addressed in downstream wear analysis

76

#25: Downstream Wear: Pump Performance

- Downstream Wear Analysis Open Item
  - MNPP-34325-ASD-003
- Wear can impact pump performance
  - RHR & CS pumps
- Impact of wear on pump performance not addressed
  - Minimum system flow rates should be assessed to ensure sufficient flow is provided
- Degraded pump performance can be offset by lower system resistance

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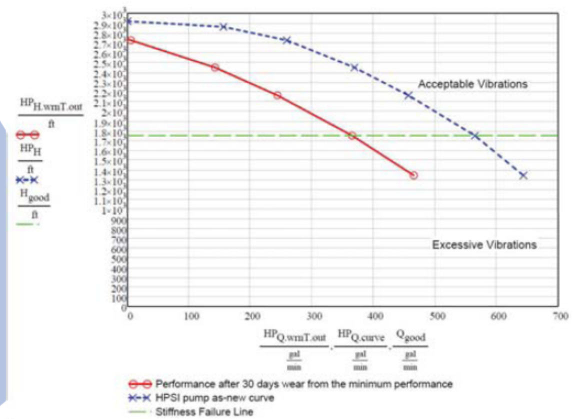
#25: Downstream Wear: Pump Performance



Example Pump Performance Assessment

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#26: Downstream Wear: RVLIS & RG 1.97 Components

- Downstream Wear Analysis Open Items
  - MNPP-34325-ASD-003
- Wear impact on RVLIS (Reactor Vessel Level Instrumentation System) not assessed
- Wear impact on Regulatory Guide 1.97 components not addressed
  - Instruments for monitoring plant variables and systems during and after an accident

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#27: Downstream Wear: SI Throttle Valves

- Downstream Wear Analysis Open Item
  - MNPP-34325-ASD-003
- Impact of wear on SI throttle valves not addressed
- TPC needs to obtain required input from Dragon Valves
  - Turns vs. Minimum Dimension / Gap Size
  - Turns vs. Area Open

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#28: ANSYS Files for Structural Analysis

- Structural Analysis Open Item
  - MNPP-34325-AR-002
- ANSYS files have not been provided
- Complete review not possible without files

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#28: ANSYS Files for Structural Analysis

- Section 203.10.6 of strainer specification:
  - *The Contractor shall notify TPC upfront as to any computer codes, calculations, or software to be used (e.g. CFD Transport Modeling) and* ***any/all calculation input disks or hydraulic modeling shall be given to TPC.*** *Where possible, Contractor shall use commercial available computer programs. Arrangements shall be made to ensure any proprietary software is retrievable (e.g. escrow arrangements).*

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#29: Specification Conformance

- Section 205 of the strainer specification:
  - *The Contractor shall submit for approval by the Purchaser a complete Design Report. The Contractor shall certify that the equipment furnished conforms to the specification requirements.*
- Section 207 of the strainer specification:
  - *The Contractor shall submit a compliance matrix that identifies how each paragraph/requirement defined in this specification will be satisfied. This matrix will mutually be agreed upon between the Contractor and Purchaser upon award.*
- A specification conformance matrix/document has not yet been provided

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In-Vessel Effects

- MNPP in-vessel fiber loading ≈ 30 g/FA
  - Greater than 15 g/FA acceptance criteria
  - Similar to many U.S. plants (> half)
- Existing in-vessel fiber loading may be acceptable following SE for WCAP-17788
- Further discussion later in presentation

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GSI-191 Status in U.S. - Accepted Closure Options

- Three closure options approved by NRC in 2012
- Option 1: Allows use of approved (deterministic) models and test methods
  - Typically used by relatively low fiber plants
- Option 2: Requires implementation of additional mitigative measures until resolution is complete and allows additional time to resolve issues through testing or risk informed approach
  - Typically used by plants with more problematic insulation

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GSI-191 Status in U.S. - Accepted Closure Options

- Option 2 (cont.)
  - Option 2A Deterministic: dependent upon more testing and analysis, specifically WCAP-17788 for in-vessel debris limits
  - Option 2B Risk Informed: Approach to quantify the risk associated with GSI-191
- Option 3: Separates the regulatory treatment of the sump strainer and in-vessel effects
  - Sump strainers assessed using current deterministic models
  - In-vessel effects assessed using risk informed approach

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Overall GSI-191 Status in U.S.

- 18 Option 1 units
  - GL 2004-02 closure letters issued to 13 units
- 31 Option 2A Deterministic units
  - Closure requires NRC review of WCAP-17788, expected in 2016
- 14 Option 2B Risk Informed units
  - South Texas Project (STP) is pilot plant
  - NRC review of STP application expected in 2016
  - Other plants to follow once STP approved
- 2 Option 3 units

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Risk Informed Approach Summary

- Determine ΔCDF (Core Damage Frequency) and ΔLERF (Large Early Release Frequency) between current plant and hypothetically perfect plant with respect to GSI-191
- Current configuration acceptable provided:
  - $\Delta CDF < 10^{-6}$ per reactor year
  - $\Delta LERF < 10^{-7}$ per reactor year
- Based on current plant PRA (Probabilistic Risk Assessment) and computation of LOCA frequencies

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Risk Informed Guidance

- Draft Regulatory Guide DG-1322 (April 2015)
  - “Risk Informed Approach for Addressing the Effects of Debris on Post-Accident Long-Term Cooling”
- Regulatory Guide 1.174
  - “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis”
- Regulatory Guide 1.200
  - “An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities”

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Risk Informed Guidance

- Draft NUREG-1855, Rev. 1
  - “Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making”
- NUREG-1829
  - “Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process”

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Possible Project Extension (Phase 3)

- S&L Phase 2 nearly complete
- S&L can assist in resolving some of the open items, e.g.
  - Select debris generation issues (#3-5)
    - Revise S&L debris generation analysis
  - Dynamic effects assessment (#6)
    - Perform new design basis evaluation
  - SBLOCA minimum water level (#7)
    - Perform new design basis evaluation

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Possible Project Extension (Phase 3)

- Revising or performing new design basis NPSH calculations for RHR and CS pumps (#13-16)
- Addressing downstream wear open items
  - Perform new design basis evaluation (#24-27)
- Incorporating WCAP-17788 once NRC SE issued
  - Revise S&L In-Vessel analysis
- Revision to GSI-191 response once design basis documents revised as appropriate

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Possible Project Extension (Phase 3)

- Many items require Candu work to be performed in parallel
  - Reduced insulation ZOIs (#1-2)
  - Incorporation of higher max system flow (#8)
  - Head loss test issues (#9-12, 21, 22)
  - Input to NPSH (e.g. VF at pump, 1- & 2-train HL)
  - Air accumulation (#17)
  - Vortex test issues (#18)

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Possible Project Extension (Phase 3)

- Fiber bypass test issues (#19-21)
- Precipitate load (#23)
- ANSYS files (#28)
- Strainer specification conformance (#29)

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WCAP-17788 Status

- "Comprehensive Analysis and Test Program for GSI-191 Closure"
  - Significant increases in allowable in-vessel fiber loading expected
- Submitted to NRC in July 2015
  - Safety Evaluation expected 2016
- Volumes 1-6
  - Volumes 1, 4, 5, and 6 contain proprietary information

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WCAP-17788 Status

- TPC should obtain WCAP from PWROG
  - Probably at no cost since TPC was a participant in PA-SEE-1090
- WCAP may be able to resolve in-vessel issue for MNPP without hardware modification
- MNPP PWROG representative (Frank Lin - u853681@taipower.com.tw) must send a request to PWROG to allow a utility agent (e.g. INER/S&L) to use the proprietary content

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WCAP-16793-NP, Revision 2

- "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in Recirculating Fluid"
- WCAP and associated NRC Safety Evaluation constitute current in-vessel guidance
- Acceptance Criteria
  - Maximum clad temperature < 800°F
  - Maximum thickness of cladding oxide and fuel deposits < 50 mils
  - In-vessel fiber quantity < 15 grams/fuel assembly

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WCAP-16793-NP, Revision 2

- Maximum clad temperature and fuel deposition evaluated with PWROG LOCADM Excel spreadsheet
- NRC SE provides 14 limitations and conditions

- Discussion of MNPP In-Vessel Analysis following presentation

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BWR ECCS Suction Strainer Issues

- Differences exist in the treatment of PWR sump strainers and BWR ECCS strainers
  - Issues not previously addressed by BWRs
  - Lessons learned from PWR response to GSI-191
- 12 outstanding issues that require resolution

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USNRC BWR Strainer Issues 1-2

- #1: Downstream Effects – Components
  - Limited evaluation for BWRs
- #2: Downstream Effects – Fuel
  - Limited evaluation for BWRs
  - Potential concern due to channeled fuel assemblies that inhibit crossflow

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USNRC BWR Strainer Issue 3

- #3: Debris Bed Head Loss
  - How were strainers sized (use of NUREG/CR-6224, vendor correlations, testing, etc.)?
  - Ensure appropriate/conservative treatment of microporous (e.g. Min-K) and calcium silicate insulations and thin fiber/particulate beds in head loss test programs

USNRC BWR Strainer Issues 4-6

- #4: Chemical Effects
  - Not addressed for BWRs
  - May impact head loss and downstream effects
- #5: Assessment of Coatings
  - Coating assessment programs may not adequately monitor degradation of qualified coatings or address changes to unqualified coatings quantities
- #6: Latent Debris
  - Form of latent debris (i.e. fiber or particulate) potentially non-conservative

USNRC BWR Strainer Issues 7-9

- #7: ZOI Adjustment for Air Jet Testing
  - BWRs utilized air jet test data, but steam may be more destructive than air
  - PWRs used reduced damage pressures to account for two-phase jets
- #8: ZOI for Qualified Protective Coatings
  - Evaluated differently for BWRs & PWRs
  - BWRs used generic coating mass total
- #9: Debris Transport – Erosion
  - Evaluated differently for BWRs & PWRs

USNRC BWR Strainer Issues 10-11

- #10: Debris Characteristics – Cal Sil/Microporous Insulation
  - Treatment for head loss testing/correlations potentially non-conservative
- #11: Near Field Effect
  - Not addressed for BWRs
  - Settling during testing takes credit for lack of transport already included in analyses
  - Non-prototypical test facility conditions
  - Potentially non-conservative head loss

USNRC BWR Strainer Issue 12

- #12: Spherical ZOI Approach
  - Potentially non-conservative if it results in exclusion of problematic debris which would be hit by jet but is outside of spherical ZOI
  - Common to both PWRs & BWRs

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BWR Strainer Issue Resolution Status

- 8 issues (#3 and 6-12) have been addressed using a combination of deterministic inputs and probabilistic evaluations within a risk informed framework
  - Submitted to NRC in October 2015
- 4 issues not yet addressed
  - Issues 2 (in-vessel) and 4 (chemical effects) to be addressed deterministically
  - Issues 1 (downstream effects – components) and 5 (coatings assessment) to be addressed via risk informed approach

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附件三

核研所規劃的主要討論事項

INER/S&L GSI-191 Project for Maanshan Nuclear Power Plant

S&L – INER Maanshan GSI-191 Project

Pon Lin, Steve Hu
Institute of Nuclear Energy Research, AEC

Chicago, November 16, 2015

INER

Topics

Prepared for Visiting S&L

- GSI-191 Closure Issues
- AEC RAI Response / Trip to Taiwan
- Maanshan Plant Modifications & Actions
- Possible Project Extension
- WCAP-17788 and WCAP-16793 Learnings
- Spread sheets / Scheme / Program used in Analysis
- GL 2004-02 Response Report Finalized
- Outstanding Comments Resolutions
- In-vessel Analysis Issues
- Project Summary Report
- Future Work