INER-F0416 **INER-F0416**

出國報告（出國類別：實習）

赴美國橡樹嶺國家實驗室研習核電廠反應器壓力槽機率破裂力學安全評估技術-國外實習報告

服務機關：核能研究所
姓名職稱：周雄偉
派赴國家：美國
出國期間：99年8月28日~99年10月26日
報告日期：99年11月22日

摘 要

此次實習主要爲配合核研所目前執行的「高容量用過燃料乾式貯存系統設計開發計畫」研究計畫，前往美國橡樹嶺國家實驗室(Oak Ridge National Laboratory, ORNL)，研習機率破裂力學應用於核能電廠重要組件之安全評估技術，可應用於我國沸水式反應器壓力槽之安全評估，並配合未來可能延續之壓水式反應器壓力槽承受壓力熱衝擊事件作用之分析工作，加強相關技術之修習。本次實習期間，自 99 年 8 月 28 日起，至 99 年 10 月 26 日止，共爲期 60 天。主要研習方向爲破裂機率力學應用於反應器壓力槽分析之理論與技術，以應用相關分析程式評估核能電廠之安全性，並研讀探討美國反應器壓力槽完整性管制法規之發展與應用。透過與該實驗室專家學者之指導與交互討論，並蒐集有關的技術資料，以了解及增進電廠重要組件最新評估之技術及經驗。可應用於我國核電廠反應器壓力槽完整性分析，以較客觀之機率破裂力學理論，評估反應器壓力槽於遭遇各種溫壓暫態與環境衝擊下之失效機率，以作爲電廠遭遇各種假想情況之安全評估，達到輻射脆裂之預防與監控，並增進該設施的壽命與安全性。

關鍵字：橡樹嶺國家實驗室、機率破裂力學、壓力溫度衝擊

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一、 目的

此次實習主要爲配合核研所目前執行的「高容量用過燃料乾式貯存系統設計開發計畫」研究計畫，前往位於美國田納西州之橡樹嶺國家實驗室(Oak Ridge National Laboratory, ORNL)，研習機率破裂力學應用於核能電廠重要組件之安全評估技術。美國橡樹嶺國家實驗室，爲一著名國家級研究單位，隸屬於美國能源部(Department of Energy, DOE)，由田納西大學與貝泰紀念研究院(Battelle Memorial Institute)所管理。該實驗室之 Computational Sciences & Engineering Division，研發領域包含致力於整合設施壽命與失效評估於設計與運轉過程中，以有效地增進設施使用之安全性。其所發展之 FAVOR 程式，則係應用機率破裂力學理論評估核能電廠反應器壓力槽(Reactor Pressure Vessel, RPV)之可靠度分析程式，目前亦爲美國官方管制境內核能電廠安全性之主要分析工具。因其機率破裂力學理論與應用，於該實驗室已臻成熟，相關技術即可應用於目前我國核能電廠之反應器壓力槽，俾利於評估該設施之壽命與可能的失效因子。目前 FAVOR 程式於本所向該實驗室引進後，主要應用於我國沸水式(Boiling Water Reactor, BWR)反應器壓力槽之安全評估。而該程式之主要作者 Mr. Terry L Dickson，爲該實驗室之資深工程師，曾於 98 年受邀於本所訪問暨技術交流，實務經驗與研究成果發表豐碩，可爲本所學習典範，曾多次表達歡迎本所派員至該實驗室研究學習之意願。職本次於橡樹嶺國家實驗室之實習，主要便由 Mr. Terry Dickson 指導並分派研究任務，藉助其專精之機率破裂力學安全評估技術，應用於我國核能電廠之反應器壓力槽，以獲取如下之成效。

1. 獲得美國方面於管制核能電廠反應器壓力槽破裂機率之考量條件與相關作法，以作爲我國評估該設施安全性之重要參考。
2. 精進 FAVOR 程式之架構與操作程序，以適用我國核能電廠反應器壓力槽之破裂機率評估，並作爲我國未來於發展機率破裂力學評估技術之重要基礎。

本次實習期間，自 99 年 8 月 28 日起，至 99 年 10 月 26 日止，共爲期 60 天。主要研習方向爲破裂機率力學應用於反應器壓力槽分析之理論與技術，以應用相關分析程式評估核能電廠之安全性。透過 Mr. Terry Dickson 與其他重要學者專家之指導以及交互討論，並讓職參與其研究計畫，其工作內容包含 FAVOR 程式基本理論與應用之學習、電廠反應器壓力槽安全性分析之執行(包含沸水式反應器與壓水式反應器(Pressurized Water Reactor, PWR)之分析應用)、數據資料之整理應用與程式撰寫，並研讀探討美國反應器壓力槽完整性管制法規之相關研究報告，以了解美國管制法規理論基礎並增進電廠重要組件最新評估之技術及經驗。相關之學習經驗與技術可應用於我國核電廠反應器壓力槽之完整性分析，以較客觀之機率破裂力學理論，評估反應器壓力槽於遭遇各種溫壓暫態與環境衝擊下之失效機率，以作爲電廠遭遇各種假想情況之安全評估，達到輻射脆裂之預防與監控，並增進該設施的壽命與安全性。亦可配合未來可能延續之壓水式反應器壓力槽承受壓力溫度衝擊事件作用之分析工作，加強相關技術之修習與應用。

二、　過程

此次實習共計 60 天，由 99 年 8 月 28 日至 10 月 26 日。實習地點爲美國橡樹嶺國家實驗室，研習內容主要爲學習破裂機率力學應用於反應器壓力槽分析之理論與技術，透過其研究工作之參與、文獻之閱讀、分析程式之執行，與數據資料之整理，瞭解美國以風險告知(Risk-Informed)導則管制電廠組件使用限度之基本理論、背景與應用方法，以增進核能電廠安全評估等相關技術之發展。行程及工作日誌大要如下：

行程及工作日誌大要如下:

日期	行程	公差地點	工作內容
99.08.28(六)	台北→美國洛杉磯	洛杉磯	去程與轉機城市
99.08.29(日)	洛杉磯→芝加哥→諾克斯維爾(田納西州)	橡樹嶺	去程轉機，休息及準備、整理資料
99.08.30(一) | 99.10.22(五)		橡樹嶺	赴橡樹嶺國家實驗室修習核電廠反應爐壓力槽機率破裂力學安全評估技術
99.10.24 (日)	諾克斯維爾→達拉斯→洛杉磯	洛杉磯	返程與轉機城市
99.10.25 (一) | 99.10.26(二)	洛杉磯→台北		返程

8 月 28 日，星期六

自桃園機場搭乘長榮航空出發，約於當地時間晚上 21 時許到達美國洛杉磯國際機場，並於次日凌晨零時搭機飛往芝加哥再次轉機。

8 月 29 日，星期日

於當地時間 5:50 飛抵芝加哥奧海爾國際機場，在機場稍作等待後，再於 9:20 搭機飛往田納西州諾克斯維爾市，於當地時間 11:50 分到達諾克斯維爾機場，並由 Mr. Terry Dickson 爲職接機，送至職於橡樹嶺與其他 ORNL 研究人員合租之公寓住所。此公寓係由服務於 ORNL Environmental Science Division 之 Postdoc Research Fellow 鄭旺博士所承租，並同意職實習期間與其分租，同時亦願意提供其車輛共乘；此公寓另亦分租給來自新加坡之 Postdoc 研究員，同樣至 ORNL Chemical and Material Division 實習約 2 個月之徐波博士。因在異鄉能與同爲華人之室友相遇，使職倍感親切並相談甚歡，更能在生活上多所照應。然而因超過 24 小時之長途飛行與轉機等待，造成身心俱疲，加上尚須調適時差，本日下午職與室友至超市購買生活所需物品後，便回住所稍加休息，以儲備體力。

8 月 30、31 日，星期一、二

本日早上先由 Mr. Terry Dickson 至住所接職至 ORNL，並先辦理報到相關事宜。首先我們先至 ORNL 之 Visitor Center(如圖一)辦理登記與配發證件，訪客於 ORNL 服務期間，需配戴 2 張證件，如圖二所示。分別爲出入識別證(左)，以及各館舍門禁卡(右)。爾後每次進入 ORNL 大門，便須由門口警衛查驗識別證方可放行，大門管制哨照片如圖三，至於各館舍大樓之進入，則須利用門禁卡感應入口處之感應器，使門鎖做動才能進入。職本次實習服務單位爲 ORNL 之 Computational Sciences & Engineering Division，Modeling & Simulation Group。證件辦妥後，Mr. Terry Dickson 先帶職至其辦公室，並介紹其相關同事與職認識，包括其 Group Leader, Mr. David Hetrick、FAVOR 之計畫主持人 Dr. Richard Bass，資深研究員 Dr. Paul Williams，Division 秘書 Ms Angie Scott，以及於前次至 2010 ASME PVP Conference 認識之尹勝軍博士等。職與 Mr. Terry Dickson 之同事們稍作寒喧後，便先由 Mr. Terry Dickson 大概介紹工作環境，並領職參觀位於 ORNL 之 NCCS (National Center of Computational Science)之 JAGUAR 高速運算系統(如圖四)設備後，隨即開始安排工作位置與相關職前訓練事宜。

於 ORNL 實習期間須進行之職前訓練皆爲線上學習課程，並於結束後進行測驗並紀錄成績，分別有以下 5 項：

1. Site Access Training：包含 ORNL 之介紹以及各項相關規定，包含研究領域、輻射防護、門禁、交通、人員識別、違禁物品、財產管理等...相關管制要求。此課程 ORNL 已要求職於台灣期間先行完成，以利報到手續之進行。

2. Cyber Security Training：爲 ORNL 之資訊安全課程、使職員了解電腦或其他資訊產品之使用安全與保密工作。

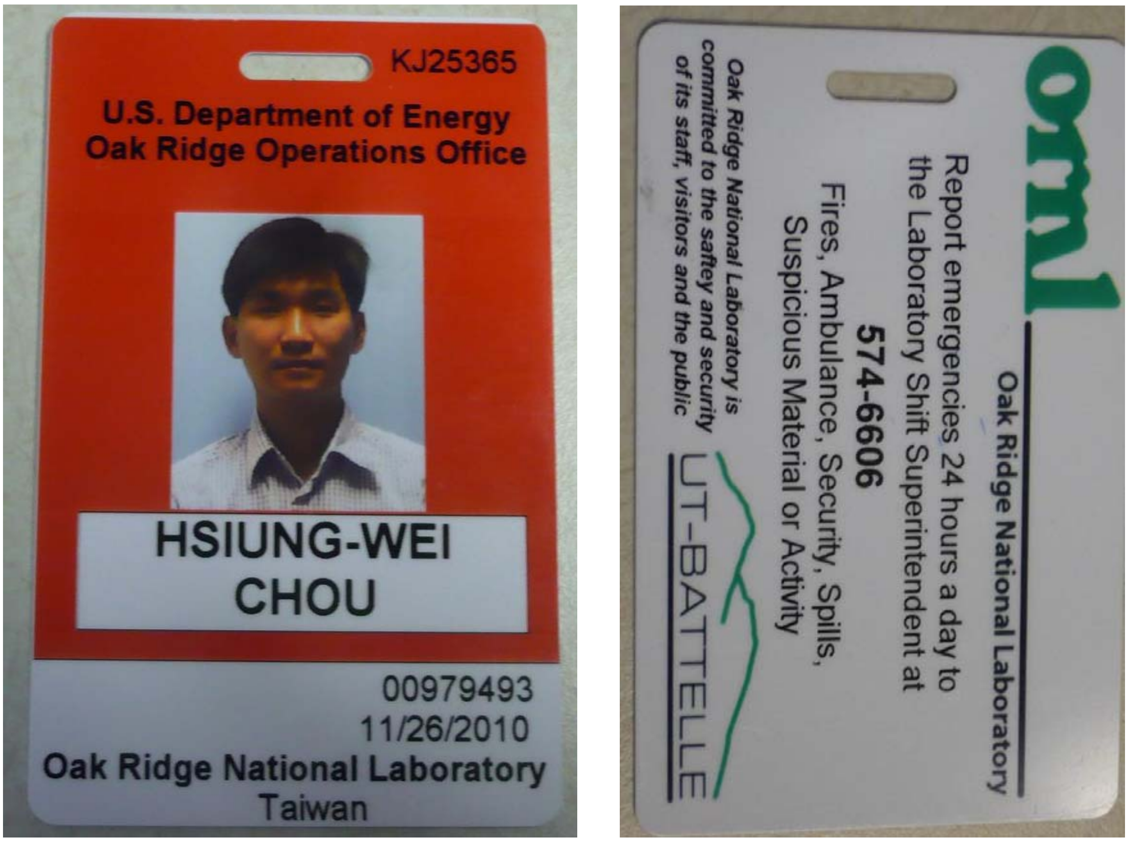
3. Environment Management Systems Awareness：指導員工相關環境保護要求，以減少因工作對環境之衝擊，避免對空氣、水、土壤之污染、廢棄物管理、環境永續經營，以及相關法規罰則等。

4. Export Control Awareness Training：主旨爲 ORNL 相關儀器、財產、研發成果、及其他資訊等應避免私自流通至美國以外地區，須經上級核准方可流通，但仍嚴格限制對象國家如中國、烏克蘭等...，並詳述其罰則，目的便在於保護研發成果之機密。

5. Research Safety Summaries：閱讀 ORNL 與職相關工作流程，主管單位與組織架構等。

完成各項職前訓練後，最後再由秘書 Ms. Angie Scott 面談並簽署相關文件，介紹 ORNL 之 Campus 配置與相關規定，介紹後便完成報到程序。圖五~圖七則爲職於 ORNL 實習期間較常進出之建築物外觀。實習期間除由 Mr. Terry Dickson 指導 FAVOR09.1 之相關技術外，接下來所參與執行之各項研究項目，則分週次，概略地加以說明。

圖一　ORNL 之 Main campus 立碑與 Visitor Center 外觀。



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圖二　ORNL 實習期間需配帶之(左)人員識別証，(右)館舍門禁通行卡。

圖三　ORNL 位於 Bethel Valley Road 上之進出管制哨(該管制哨距離內部 Main Campus 約還 5 英哩)。

圖四　NCCS 之 JAGUAR 高速運算系統設備

圖五　ORNL 之 Computational Sciences & Engineering Division 所在館舍，Mr. Terry Dickson 等人員之辦公室即位於此。

圖六　ORNL 之 National Institute for Computational Sciences，相關領域之實習訪客(包含職)之辦公室亦分配至此。

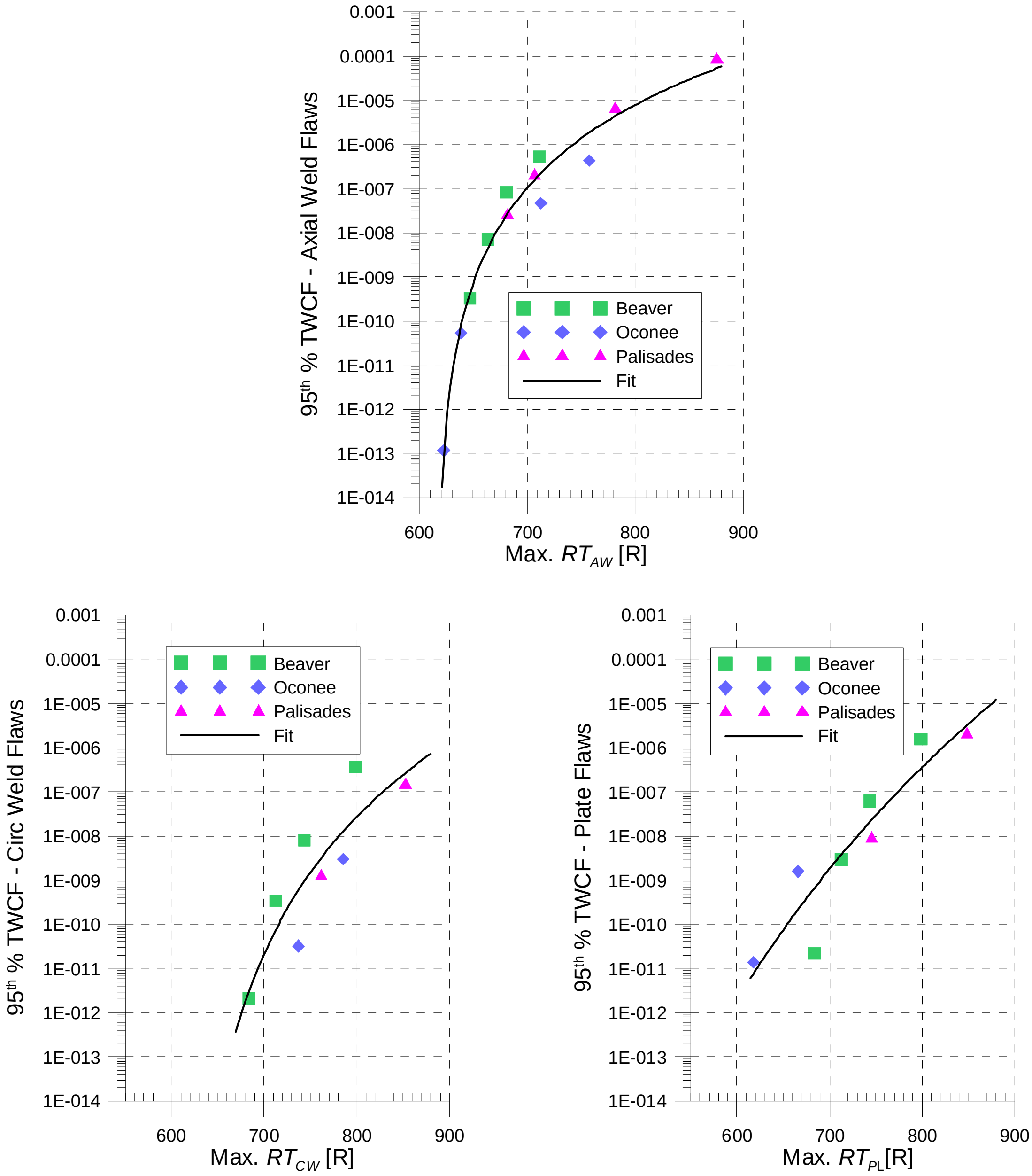
圖七　圖書館與 Chemical & Material Science Center。

8 月 29 日~9 月 4 日，第一週

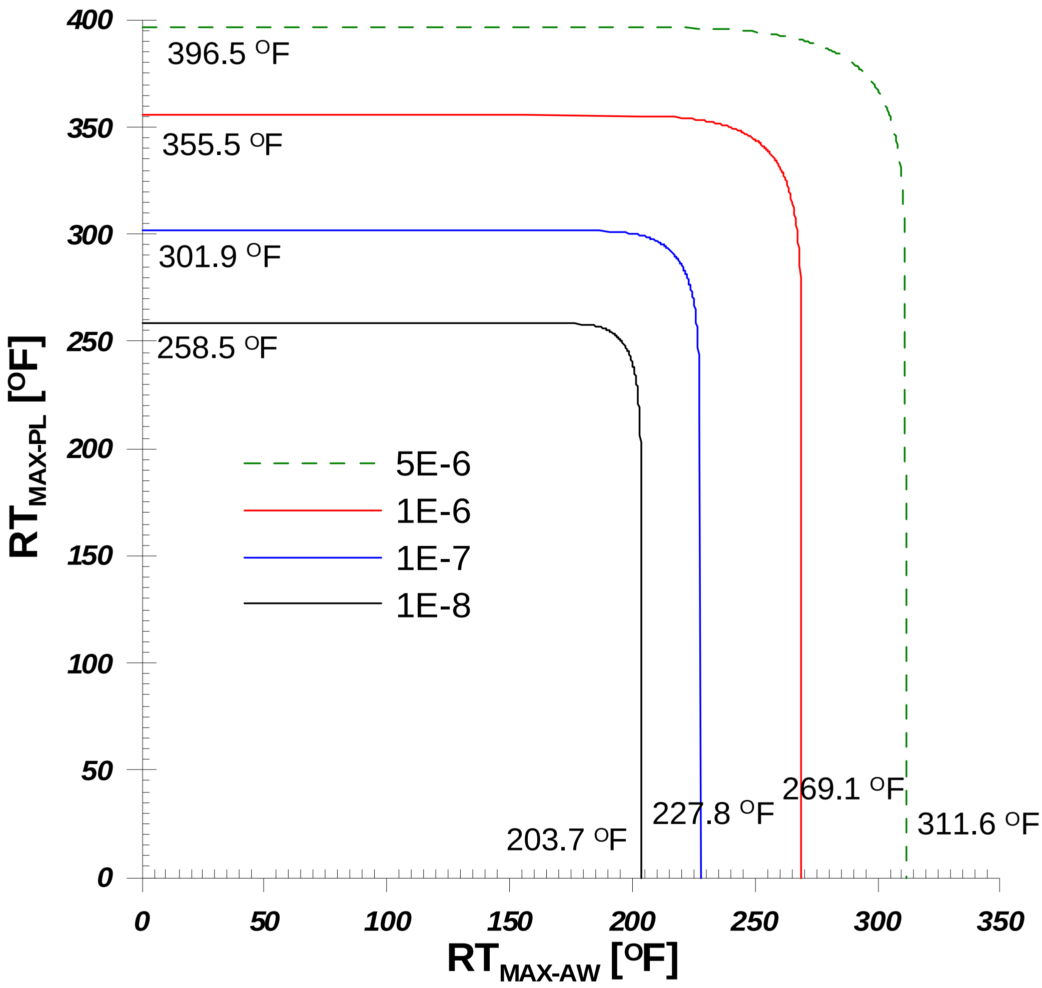
實習期間由 Mr. Terry Dickson 指導 FAVOR 程式之相關理論與使用，並包含研究任務之指派，且由尹勝軍博士從旁協助指導。除敎授 FAVOR 09.1 相關技術外，本週之工作主要爲建立美國管制規範 10CFR50.61a 之相關理論來源，依據 NUREG-1874 報告之內容，進行壓水式反應器壓力溫度衝擊(Pressurized Thermal Shock, PTS)規範之 Re-evaluation，以還原其分析模式。10CFR50.61a 爲美國 NRC 針對壓水式反應器遭受壓力溫度衝擊作用時，其安全評估之法規，爲修訂原規範 10CFR50.61 之版本。

10CFR50.61a 理論基礎之一部份，係由 FAVOR06.1 針對美國 Palisades、Beaver Valley，以及 Oconee 三座電廠之 RPV 進行 PTS 衝擊下之 PFM 分析結果所整理，而相關 PFM 分析，當初便爲 Mr. Terry Dickson 等人所執行。NRC 認爲此三座電廠特性可代表所有美國境內之 PWR，所有可能之 PTS 事件亦可歸類成 Primary Pipe Break (LOCA)、Primary Stuck-Open Valves (SO-1)、Main Steam-Line Breaks (MSLB)，以及 Secondary Stuck-Open Valves(SO-2)等四類。因此可以利用其分析結果，獲得其第 95 百分比穿壁裂縫貫穿機率(95th %ile Through Wall Crack Frequency, $TWCF_{95}$)隨 RPV 各部位最大無延性脆化參考溫度(Reference Temperature of Nil-Ductility Transition, RT_{MAX-XX})之關係，如圖八所示。便可推導出垂直焊道(Axial Welds)，水平焊道(Circumferential Welds)，與板材(Plates)之 $TWCF_{95}$ 與最大 RT_{NDT} 之關係。利用其相關公式，便可推求出 RPV 整體穿壁裂縫貫穿機率 $TWCF_{95\text{-}Total}$，作爲 PTS 之 Screening Criterion，但由於公式推導複雜，職與 Mr. Terry Dickson 以及尹博士耗時約一週方解出，故便不於此報告

中詳述。職本週與次週之研究項目，便係利用相關公式，撰寫 10CFR50.61a 管制 PTS 之 Screen Criterion 之 Matlab 程式，以供 Mr. Terry Dickson 等使用。經計算執行後之相關曲線如圖九所示，其中 1E-6(美國 NRC 制定之最大容許 TWCF 爲 1×10^{-6}/yr)之曲線便爲美國 NRC 目前管制境內 PWR RPV 之 Screening Criterion 曲線，並可得知 PWR RPV 垂直焊道之最大容許無延性脆化參考溫度 $RT_{MAX\text{-}AW}$ 爲 269°F，板材之最大容許無延性脆化參考溫度 $RT_{MAX\text{-}PL}$ 則爲 356°F；至於水平焊道之 $RT_{MAX\text{-}CW}$ 則以 $TWCF_{95\text{-}CW}=1\times10^{-8}$/yr 計算爲 312°F(以上適用大部份壁厚小於 9.5”之 RPV)。此程式適用於各式美式 PWR 電廠，亦可任意指定欲規範電廠之 $TWCF_{95\text{-}Total}$，故同樣可應用於我國 PWR 管制基準之制定，相關之程式內容則可詳見附件一。



圖八 PWR RPV 各部位 TWCF95 與最大無延性脆化參考溫度 $RT_{MAX\text{-}XX}$ 之關係。



圖九 PWR 垂直焊道與板材之 PTS-Limit 曲線，其中 1E-6 即爲 10CFR50.61a 之 Screening Criterion 管制基準。

9 月 5 日~9 月 11 日，第二週

除延續上週 PTS Screening Criterion 曲線之推導與程式撰寫外，本週主要研討 NUREG-1874 與 10CFR50.61a 關於 RPV 輻射脆化之議題，亦對 FAVOR 程式進行一驗證工作。針對此項目，職撰寫一 Matlab 程式，利用 10CFR50.61a 相關公式，計算 RPV 材質因輻射脆化 RT$_{NDT}$，其與 FAVOR 程式計算驗證之結果可參考表一與表二。可發現此程式可準確地計算 RPV 各部位之輻射脆化程度，故亦可應用於國內電廠 RPV 之輻射脆化評估，此程式後續亦提供與尹勝軍博士參考使用。至於相關之 Matlab 程式內容，則可參閱附件二。

表一 RPV 輻射脆化評估驗證比較(Palisades 垂直焊道)。

RT$_{NDT}$ Calculation from FAVOR 06.1 for Axial Welds of Palisades Applying 10CFR 50.61a (RG 1.99 Rev. 3) Correlation by Terry Dickson									
EFPY	**RT$_{NDT}$ @ ID**	**RT$_{NDT}$ @ t/4**	**RT$_{NDT}$ @ 3t/4**	**ID fluence**	**Copper (%)**	**Nickel (%)**	**Phos (%)**	**Mn (%)**	**RT$_{NDT (u)}$ (°F)**
32	226.36	208.4	168.9	**1.9699**	**0.213**	**1.010**	**0.019**	**1.315**	**-56**
60	252.24	232.8	196.5	**3.2129**	**0.213**	**1.010**	**0.019**	**1.315**	**-56**
200	326.22	296.3	249.4	**9.4604**	**0.213**	**1.010**	**0.019**	**1.315**	**-56**

500	421.05	374.6	304.5	22.8479	0.213	1.010	0.019	1.315	-56

RT_{NDT} Calculation from RTNDT.m for Axial Welds of Palisades Applying 10CFR 50.61a (RG 1.99 Rev. 3) Correlation by Hsiung-Wei Chou

EFPY	RT_{NDT} @ ID	RT_{NDT} @ t/4	RT_{NDT} @ 3t/4	ID fluence	Copper (%)	Nickel (%)	Phos (%)	Mn (%)	$RT_{NDT\ (u)}$ (°F)
32	226.31	208.39	168.90	1.9699	0.213	1.010	0.019	1.315	-56
60	252.19	232.75	196.53	3.2129	0.213	1.010	0.019	1.315	-56
200	326.45	296.33	249.35	9.4604	0.213	1.010	0.019	1.315	-56
500	421.13	374.64	304.53	22.8479	0.213	1.010	0.019	1.315	-56

RT_{NDT} Calculation for Axial Welds of Palisades Applying RG 1.99 Rev. 2 Correlation by Hsiung-Wei Chou

($\sigma_I=21\ ^oF$, $\sigma_\Delta=17\ ^oF$, Margin=54 ^oF)

EFPY	RT_{NDT} @ ID	RT_{NDT} @ t/4	RT_{NDT} @ 3t/4	ID fluence	Copper (%)	Nickel (%)	Phos (%)	Mn (%)	$RT_{NDT\ (u)}$ (°F)
32	282.99	250.11	182.84	1.9699	0.213	1.010	0.019	1.315	-56
60	311.08	280.81	213.88	3.2129	0.213	1.010	0.019	1.315	-56
200	357.18	338.08	282.63	9.4604	0.213	1.010	0.019	1.315	-56
500	371.74	365.88	330.55	22.8479	0.213	1.010	0.019	1.315	-56

表二 RPV 輻射脆化評估驗證比較(Beaver Valley 板材)。

RT_{NDT} Calculation from FAVOR 06.1 for Plates of Beaver Valley 10CFR 50.61a (RG 1.99 Rev. 3) Correlation by Terry Dickson

EFPY	RT_{NDT} @ ID	RT_{NDT} @ t/4	RT_{NDT} @ 3t/4	ID fluence	Copper (%)	Nickel (%)	Phos (%)	Mn (%)	$RT_{NDT\ (u)}$ (°F)
32	223.6	210.9	189.8	4.2678	0.14	0.62	0.015	1.400	73
60	252.4	235.3	208.5	8.1339	0.14	0.62	0.015	1.400	73
100	282.9	261.0	227.0	13.6569	0.14	0.62	0.015	1.400	73
200	338.7	307.7	260.1	27.4643	0.14	0.62	0.015	1.400	73

RT_{NDT} Calculation from RTNDT.m for Axial Welds of Beaver Valley Applying 10CFR 50.61a (RG 1.99 Rev. 3) Correlation by Hsiung-Wei Chou

EFPY	RT_{NDT} @ ID	RT_{NDT} @ t/4	RT_{NDT} @ 3t/4	ID fluence	Copper (%)	Nickel (%)	Phos (%)	Mn (%)	$RT_{NDT\ (u)}$ (°F)
32	223.65	210.87	189.76	4.2678	0.14	0.62	0.015	1.400	73
60	252.42	235.34	208.46	8.1339	0.14	0.62	0.015	1.400	73
100	282.95	261.03	227.03	13.6569	0.14	0.62	0.015	1.400	73
200	338.69	307.75	260.09	27.4643	0.14	0.62	0.015	1.400	73

RT_{NDT} Calculation for Axial Welds of Beaver Valley Applying RG 1.99 Rev. 2 Correlation by Hsiung-Wei Chou

($\sigma_I=17\ ^oF$, $\sigma_\Delta=28\ ^oF$, Margin=65.5 ^oF)

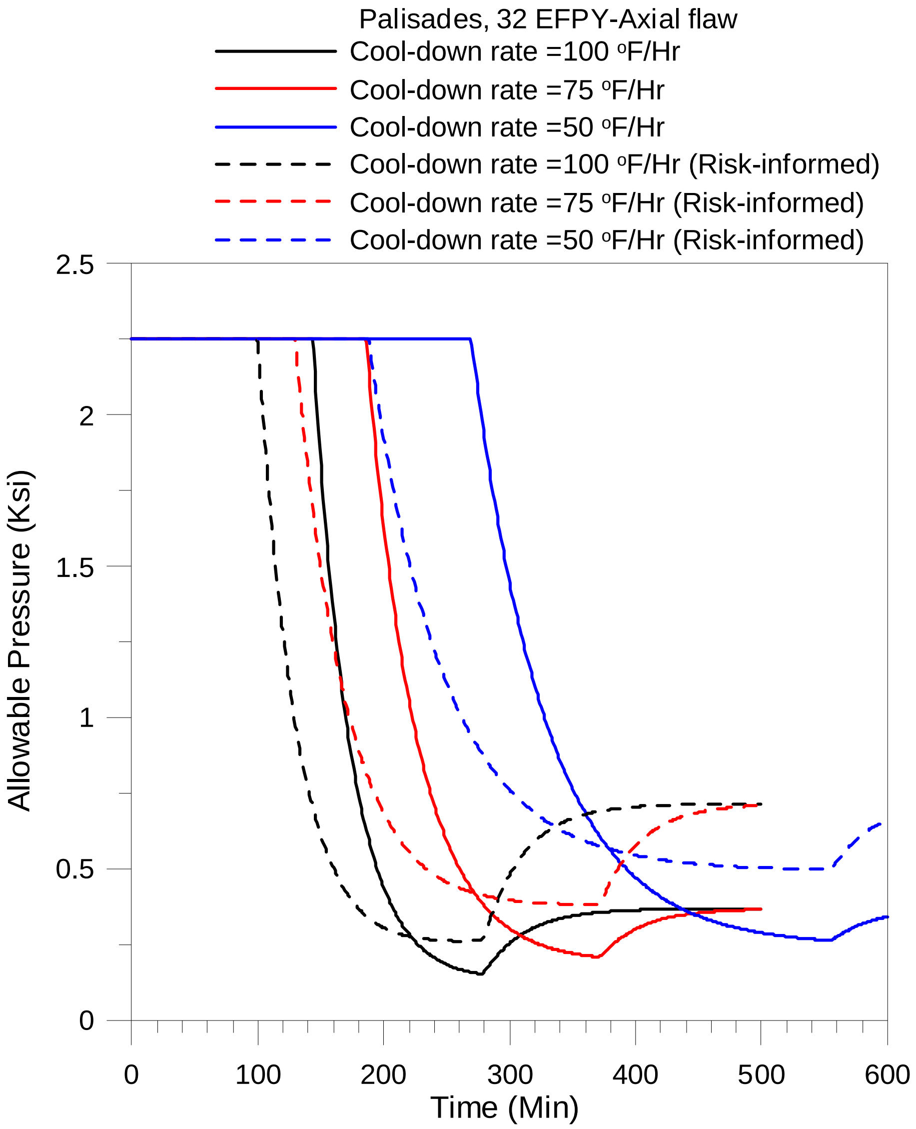
EFPY	RT_{NDT} @ ID	RT_{NDT} @ t/4	RT_{NDT} @ 3t/4	ID fluence	Copper (%)	Nickel (%)	Phos (%)	Mn (%)	$RT_{NDT\,(u)}$ (°F)
32	264.69	253.56	227.63	4.2678	0.14	0.62	0.015	1.400	73
60	276.34	268.02	245.36	8.1339	0.14	0.62	0.015	1.400	73
100	282.30	276.86	258.36	13.6569	0.14	0.62	0.015	1.400	73
200	284.77	283.77	272.69	27.4643	0.14	0.62	0.015	1.400	73

本週參與之另一項工作項目則執行 FAVOR 06.1 與 FAVOR 09.1 於 FAVLoad 部份之 V&V 工作。由於 FAVOR 09.1 在裂縫位置之讀取與 RPV 半徑-壁厚比計算應力集中因子之嵌合係數有大幅之修正，故須進行驗證分析工作，並教授有關 FAVOR 程式中 LDQA 功能之用法，以作爲 FAVOR Deterministic 參數分析之應用。

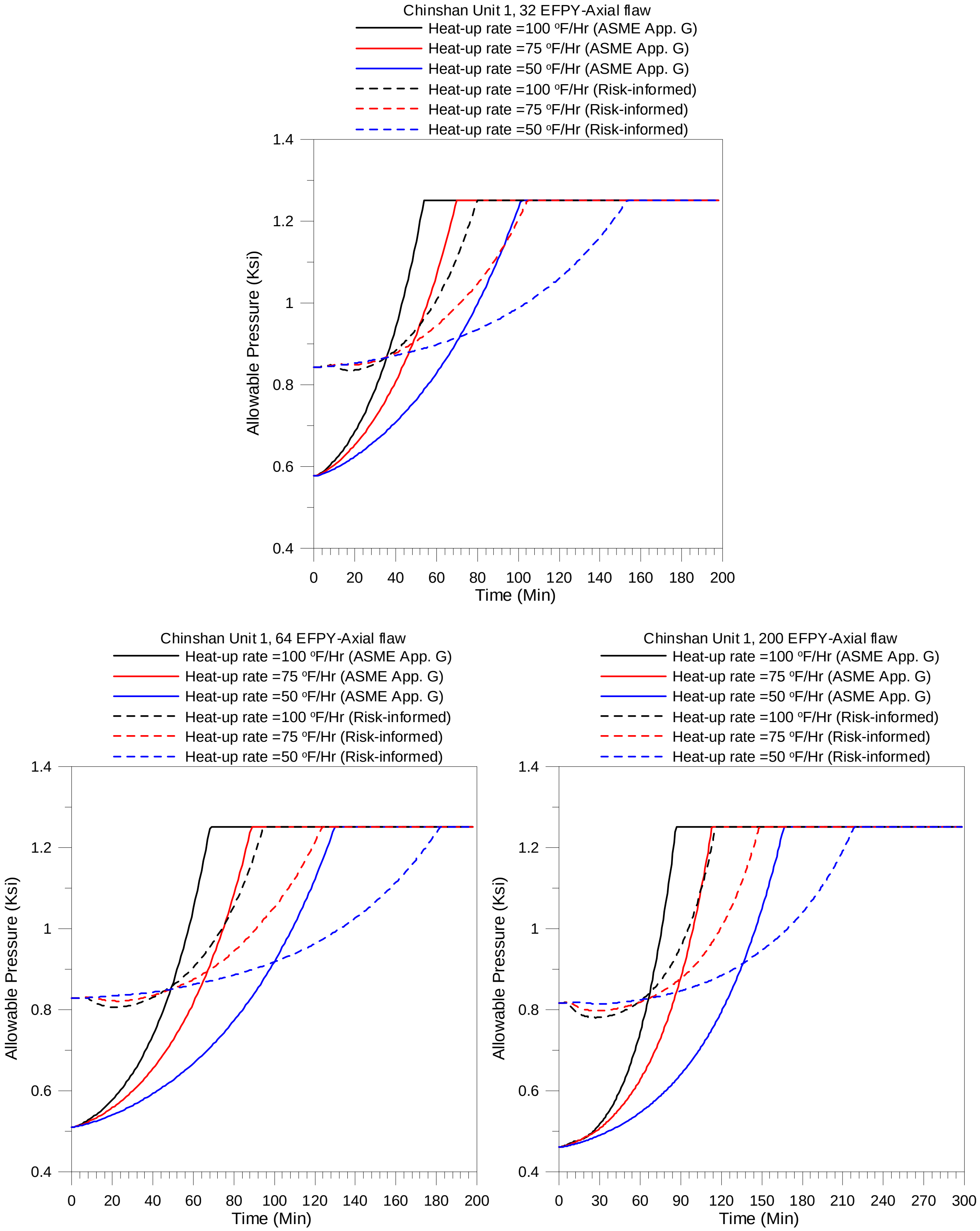
9 月 12 日~9 月 18 日，第三週

本週 Mr. Terry Dickson 指導職如何建立較真實之 RPV 腹帶區 FAVOR 分析模型。有別於先前本所採用較保守之分析模型，此模型依據我國核一廠之 RPV，分別包含所有垂直焊道，水平焊道，以及板材等，合併建立單一較詳細之 FAVPFM 輸入檔。並利用較新之裂縫分布檔，同樣採用低溫過壓(Low Temperature Over Pressure, LTOP)暫態，執行核一廠 RPV 完整性分析，相關之更新 FAVPFM 輸入檔，則可參閱附件三。至於核一廠 1 號機 RPV 完整性之 FAVOR 分析，則歷經約 3 週之電腦運算，才可獲得足夠收斂之結果提供參考。

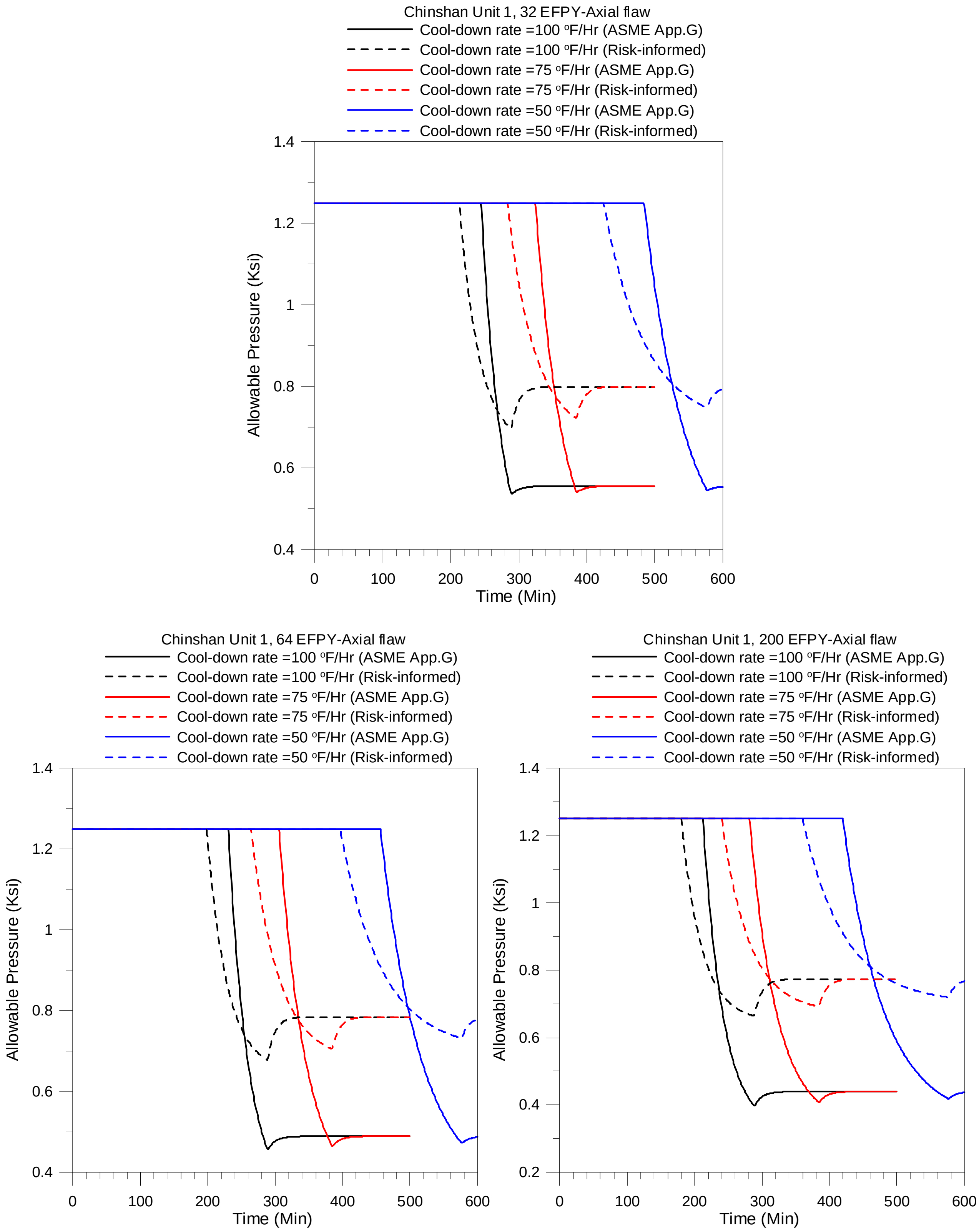
此外，Mr. Terry Dickson 亦指導如何應用 FAVOR 程式執行 Deterministic 分析。首先便是應用其 LDQA 功能，建立核能電廠之 Heat-up 與 Cool-down 之容許 P-T limit 曲線(依據 ASME B&PV Sec.XI App. G)。FAVOR 之 LDQA 可計算 RPV 中某一裂縫之應力集中因子 K_I 隨時間之歷時，或某一暫態時間點某一形狀裂縫之 K_I 隨位置之分布。此報告不詳述 P-T limit 曲線之分析公式與建立過程，僅介紹相關之工作成果。首先先以美國之 Palisades 電廠(爲 PWR 型式)之 RPV 特性參數作練習，求出不同 Cool-down 速率下之 P-T limit 曲線，並包含美國核電業界所提出有別於 ASME B&PV Sec.XI App. G 之曲線(Risk-informed)，如圖十所示。其次利用我國 BWR 電廠特性做分析，代入核一廠 RPV 之各項參數，以獲得其 P-T limit 曲線作參考。圖十一與圖十二爲應用核一廠 1 號機 RPV 參數建立之容許 Heat-up 與 Cool-down 之 P-T limit 曲線，分別包含 32 EFPY、64 EFPY、200 EFPY 之假設條件，以及不同昇降溫速率之條件所得結果。同樣地，核一廠 2 號機 RPV 之 P-T limit 曲線，則如圖十三與圖十四所示。



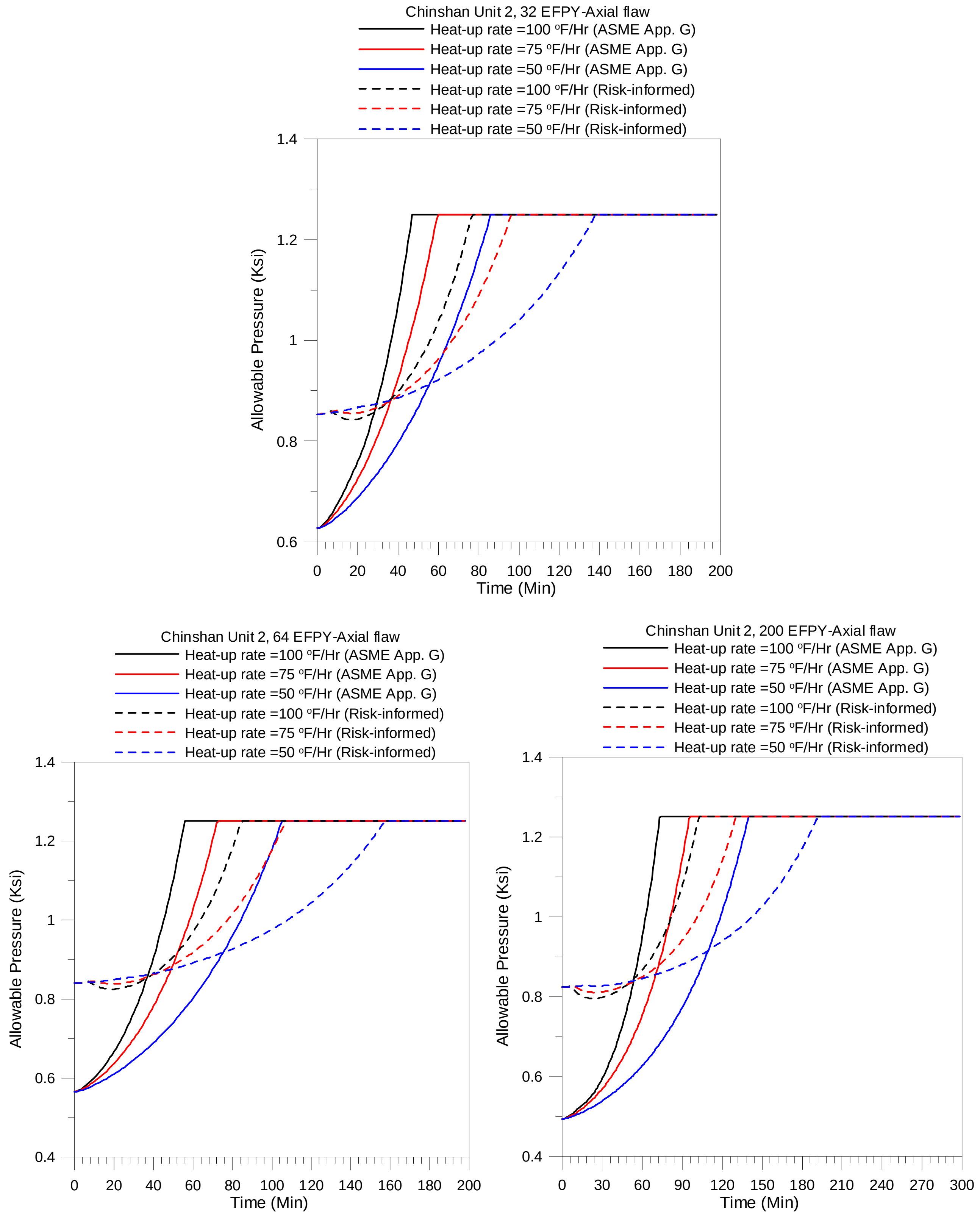
圖十 美國 Palisades 電廠 RPV 之容許 Cool-down P-T limit 曲線，分別考慮 100°F/hr、75°F/hr 與 50°F/hr 之降溫速率。



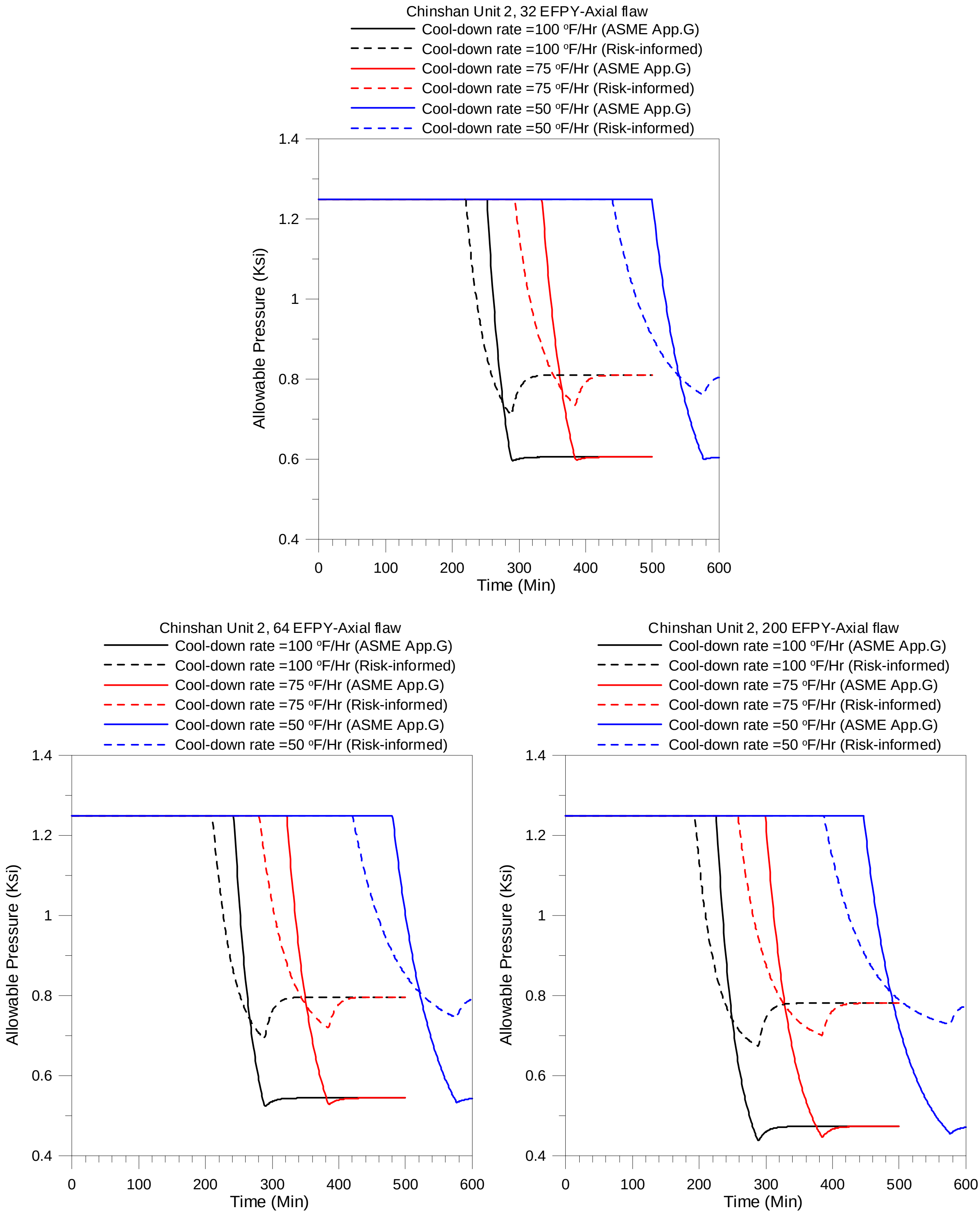
圖十一　核一廠 1 號機 RPV 之容許 Heat-up P-T limit 曲線，分別考慮 32 EFPY、64 EFPY、200 EFPY，以及 100°F/hr、75°F/hr 與 50°F/hr 之昇溫速率。



圖十二　核一廠 1 號機 RPV 之容許 Cool-down P-T limit 曲線，分別考慮 32 EFPY、64 EFPY、200 EFPY，以及 100°F/hr、75°F/hr 與 50°F/hr 之降溫速率。



圖十三　核一廠 2 號機 RPV 之容許 Heat-up P-T limit 曲線，分別考慮 32 EFPY、64 EFPY、200 EFPY，以及 100°F/hr、75°F/hr 與 50°F/hr 之昇溫速率。



圖十四　核一廠 2 號機 RPV 之容許 Cool-down P-T limit 曲線，分別考慮 32 EFPY、64 EFPY、200 EFPY，以及 100°F/hr、75°F/hr 與 50°F/hr 之降溫速率。

9 月 19 日~9 月 25 日，第四週

本週依 Mr. Terry Dickson 之指派，將 FAVOR 程式之 LDQA 功能更進一步之應用。Mr. Terry Dickson 將上週所建立核一廠 1 號機 RPV 之 FAVPFM 輸入檔所

試跑結果產生之 SCATTER 輸出檔，包含會產生 CPI(Conditional Crack Initiation)之裂縫型態、裂縫大小形狀、裂縫尖端材料性質、Applied K_I，以及對應之 CPI 值等，交予職應用 LDQA 先求出此型態裂縫之 $K_I(t)$，再以 FAVOR 09.1 之 Theory Manual 中之理論解加以驗算，以達到驗證分析之目的。惟此工作計算數量龐大，且需撰寫計算程式與資料整理，故耗費將近一週方完成此工作，並於計算過程發現問題之機會，和 Mr. Terry Dickson 持續討論，使職對 FAVOR 之 Deterministic 分析有更深入之了解。相關驗證分析之結果則列於表三與表四中。

本週後段亦開始進行上週完成之 Cool-down 與 Heat-up 容許暫態之 PFM 分析。分析之條件採用我國核一廠 1 號機之電廠特性，並考量 32 EFPY 與 60 EFPY 之輻射劣化條件，但由於分析之計算量頗大，故約需 4 周方有結果。此外，職亦協助 Mr. Terry Dickson 審核美國一 APWR 電廠之安全評估報告，對其進行重新驗證分析之工作，同樣地先驗算其輻射脆化程度，並重新建立其 Cool-down 與 Heat-up 之 P-T limit 曲線，爲下周欲對該電廠進行之 PFM 分析之重要前置作業。

9 月 26 日~10 月 2 日，第五週

本週主要延續上週工作，持續進行核一廠 1 號機 RPV 之 Cool-down 與 Heat-up 容許暫態之 PFM 分析，並已獲得部份 Surface breaking flaw 之分析結果。同時，Mr. Terry Dickson 則開始教授 RPV 之 Deterministic Minimization 概念，主要利用 FAVOR 09.1 之 LDQA(IQA=2)功能，計算特定裂縫下，能產生裂縫初始(CPI)之最小 RT_{NDT}，以估算最佳容許之輻射脆化程度，並同樣以核一廠 1 號機 RPV 之 Cool-down 與 Heat-up 容許暫態爲計算對象，相關結果則列於附件四中。

此外，職亦協助 Mr. Terry Dickson 審核美國一 APWR 電廠之安全評估報告(爲 Mitsubishi 所建構之電廠)，對其進行重新驗證分析之工作。首先先驗算其輻射脆化程度，並利用 FAVOR 之 Deterministic 分析，求得相關暫態之熱應力集中因子歷時，以求得其 P-T limit 曲線，並進行驗證之工作。惟此結果與其相關報告因尚未同意公開之故，因此職所獲得之驗證分析結果亦未能摘錄於此報告中。

表三　以 FAVOR 09.1 LDQA 分析模擬核一廠 1 號機 RPV 產生 CPI 之裂縫破裂性質與機率驗證分析。

(假設垂直焊道寬 1.375 in，水平焊道寬 1.25 in)

No. of flaw of initiation	Flaw type	Location of inner crack tip (in)	Crack depth (in)	Aspect ratio	RT_{NDT} (°F)	K_I by PFM analysis (Ksi $\sqrt{in}$)	CPI by PFM analysis	K_I by LDQA (Ksi $\sqrt{in}$)	CPI by Eq.(11) of FAVOR 09.1 theory manual
1	Inner embedded, axial flaw	0.330	0.615	3.273	113.09	**25.95**	**0.1177E-05**	**25.97**	**0.1229E-05**
2		0.242	0.716	1.457	127.72	**23.71**	**0.1149E-06**	**23.69**	**0.1039E-06**
3		0.281	0.512	3.772	112.77	**24.30**	**0.9242E-10**	**24.30**	**1.0350E-10**
4		0.132	1.127	1.416	77.52	**31.43**	**0.2239E-06**	**31.45**	**0.2351E-06**
5		0.350	0.973	1.302	120.28	**25.75**	**0.3660E-05**	**25.76**	**0.3704E-05**
6		1.322	1.433	3.767	72.42	**31.48**	**0.2722E-09**	**31.47**	**0.2180E-09**
7		0.305	0.563	2.330	139.14	**23.47**	**0.8654E-06**	**23.47**	**0.8566E-06**
8		0.236	0.461	5.465	129.01	**24.03**	**0.5032E-06**	**24.04**	**0.5110E-06**
9		0.336	1.075	1.445	105.41	**28.32**	**0.1010E-04**	**28.32**	**0.1012E-04**
10		0.205	1.639	1.265	126.79	**35.64**	**0.3580E-02**	**35.66**	**0.3600E-02**
11		0.162	0.666	2.534	104.97	**27.26**	**0.1985E-05**	**27.28**	**0.2041E-05**
12		0.336	1.229	1.050	110.29	**26.51**	**0.1841E-05**	**26.52**	**0.1865E-05**
13		0.226	0.819	2.122	97.00	**28.68**	**0.2720E-05**	**28.67**	**0.2664E-05**
14		0.455	0.512	3.803	134.53	**23.14**	**0.9099E-07**	**23.14**	**0.9038E-07**
15		0.420	0.973	2.475	79.68	**30.33**	**0.3214E-07**	**30.33**	**0.3204E-07**
16		0.535	1.024	2.530	108.32	**29.72**	**0.5891E-04**	**29.72**	**0.5878E-04**
17		0.204	0.614	2.558	125.05	**25.75**	**0.7718E-05**	**25.74**	**0.7572E-05**
18		0.258	1.741	1.069	80.94	**33.61**	**0.1824E-04**	**33.61**	**0.1825E-04**
19		0.492	1.075	1.959	143.07	**29.22**	**0.5880E-03**	**29.21**	**0.5864E-03**
20		0.183	1.383	1.138	87.94	**31.09**	**0.7117E-05**	**31.11**	**0.7259E-05**
21		0.358	0.665	2.201	120.91	**25.00**	**0.9259E-06**	**24.99**	**0.9063E-06**
22		0.236	0.512	3.657	134.99	**24.48**	**0.3997E-05**	**24.47**	**0.3945E-05**

表四 以 FAVOR 09.1 LDQA 分析模擬核一廠 1 號機 RPV 產生 CPI 之裂縫破裂性質與機率驗證分析。

(假設垂直焊道寬 1.8 in，水平焊道寬 2 in)

No. of flaw of initiation	Flaw type	Location of inner crack tip (in)	Crack depth (in)	Aspect ratio	RT_{NDT} (°F)	K_I by PFM analysis (Ksi $\sqrt{in}$)	CPI by PFM analysis	K_I by LDQA (Ksi $\sqrt{in}$)	CPI by Eq.(11) of FAVOR 09.1 theory manual
1	Inner embedded, axial flaw Inner embedded, axial flaw	0.396	0.819	2.455	135.49	**28.10**	**0.1947E-03**	**28.10**	**0.1945E-03**
2		0.200	0.972	1.111	106.02	**25.35**	**0.3441E-08**	**25.34**	**0.3014E-08**
3		0.590	1.331	1.126	112.35	**26.09**	**0.1308E-05**	**26.08**	**0.1287E-05**
4		0.683	0.871	1.828	119.91	**24.20**	**0.4468E-07**	**24.21**	**0.4658E-07**
5		0.543	1.229	2.162	74.67	**31.64**	**0.4463E-07**	**31.65**	**0.4571E-07**
6		0.389	1.024	1.565	98.27	**27.96**	**0.1094E-05**	**27.96**	**0.1092E-05**
7		0.230	1.382	1.194	91.41	**31.14**	**0.1604E-04**	**31.13**	**0.1583E-04**
8		0.285	1.076	1.464	87.64	**28.92**	**0.9965E-07**	**28.94**	**1.0538E-07**
9		0.217	0.922	1.585	106.07	**28.16**	**0.9391E-05**	**28.17**	**0.9480E-05**
10		0.442	1.024	1.844	98.58	**28.67**	**0.3974E-05**	**28.67**	**0.3973E-05**
11		0.951	0.973	1.938	116.28	**24.32**	**0.1047E-07**	**24.32**	**0.1057E-07**
12		0.171	0.615	2.668	126.33	**26.26**	**0.1753E-04**	**26.28**	**0.1794E-04**
13		0.321	0.922	1.243	89.83	**28.09**	**0.1694E-07**	**28.10**	**0.1788E-07**
14		0.727	1.178	1.009	135.37	**22.26**	**0.4837E-12**	**22.26**	**0.6308E-12**
15		0.665	1.536	1.017	102.25	**26.67**	**0.1997E-06**	**26.68**	**0.2055E-06**
16		0.273	0.563	3.970	152.75	**25.74**	**0.9154E-04**	**25.73**	**0.9115E-04**
17		1.134	1.433	1.256	108.43	**25.30**	**0.2029E-07**	**25.30**	**0.1988E-07**
18		0.152	0.768	2.647	102.60	**29.91**	**0.3283E-04**	**29.90**	**0.3266E-04**
19		0.551	1.076	2.947	87.80	**31.21**	**0.7873E-05**	**31.23**	**0.8062E-05**
20		0.163	1.024	1.909	80.86	**32.30**	**0.4478E-05**	**32.30**	**0.4477E-05**
21		0.234	1.69	1.582	82.69	**39.00**	**0.5194E-03**	**39.01**	**0.5217E-03**
22		0.495	0.563	2.967	145.15	**23.09**	**0.8678E-06**	**23.09**	**0.8590E-06**
23		1.159	1.332	1.750	95.81	**26.99**	**0.1142E-07**	**27.00**	**0.1230E-07**
24		0.424	1.485	1.249	94.79	**30.98**	**0.2540E-04**	**30.98**	**0.2537E-04**
26		0.260	0.563	2.444	117.79	**23.97**	**0.1860E-08**	**23.97**	**0.1844E-08**
27		0.134	0.768	2.172	87.05	**28.94**	**0.6918E-07**	**28.94**	**0.6975E-07**

28		0.258	0.717	1.987	105.29	**25.98**	**0.7713E-07**	**25.99**	**0.7949E-07**
29		0.203	1.587	1.279	67.58	**35.17**	**0.1506E-05**	**35.17**	**0.1503E-05**
30		0.321	1.127	1.388	99.47	**28.69**	**0.5051E-05**	**28.71**	**0.5160E-05**
31		0.178	1.024	1.657	145.38	**30.74**	**0.1374E-02**	**30.74**	**0.1372E-02**
32		0.442	1.689	1.498	70.64	**35.82**	**0.1023E-04**	**35.81**	**0.1016E-04**
33		0.442	0.87	1.879	103.26	**26.59**	**0.2414E-06**	**26.58**	**0.2352E-06**
34		0.170	1.127	1.469	85.15	**31.16**	**0.3631E-05**	**31.17**	**0.3690E-05**
35		1.273	1.075	1.970	122.18	**23.79**	**0.1364E-07**	**23.79**	**0.1379E-07**
36		1.141	1.331	1.586	99.71	**26.29**	**0.5771E-08**	**26.28**	**0.5543E-08**
37		1.103	1.638	1.660	84.48	**30.82**	**0.1761E-05**	**30.81**	**0.1732E-05**

10 月 3 日~10 月 9 日，第六週

本週除繼續協助 Mr. Terry Dickson 審核 US-APWR 電廠之安全評估報告，並亦與其同步進行驗證分析之工作外，Mr. Terry Dickson 亦利用工作執行之機會，教職閱讀 FAVOR 程式其它之輸出檔，例如 RTNDT.out、TRACE.out，以及 ARREST.out 等。RTNDT.out 記載了 FAVOR 程式運算時 RPV 材質參考溫度之取樣邏輯與分布。TRACE.out 則可紀錄特定模擬次數，以及特定暫態條件下，某一裂縫之各項受力情形與 cpi、cpf 值。ARREST.out 則詳述了與 TRACE.out 設定條件相同之裂縫下，FAVOR 程式之 IGA 模式運算結果，以了解裂縫成長與擴展之模擬情形。以上輸出檔皆對 FAVOR 分析結果之驗算與應用有很大之幫助。

此外，本週 Mr. Terry Dickson 與職亦開始學習裂縫模擬程式 VFLAW 之使用。VFLAW 爲美國 Pacific Northwest National Laboratory (PNNL)所發展之程式，由 F. A. Simonen 博士等人所撰寫。VFLAW 針對 FAVOR 程式之使用報告爲 NUREG/CR-6817，由於報告內容巨細靡遺，且並非 Mr. Terry Dickson 之專業領域，故其與職皆一同從同頭開始閱讀 VFLAW 之使用報告 NUREG/CR-6817。惟因涉及電廠之營運前、營運中之 NDE 技術，以及焊接材料科學等專業領域，故職與 Mr. Terry Dickson 皆無法完全了解其精髓，但已可了解各項輸入參數之定義，有助於自行建立所需之 FAVOR 裂縫資料檔。有關 VFLAW 程式所需輸入影響 RPV 壁體裂縫分布之變因，經了解大至與焊接方式與其比例、Weld bead 大小、材料部位、RPV 幾何條件等相關。因此，若可或獲得欲分析對象之相關參數後，便可模擬其焊道、不鏽鋼覆焊層，以及板材之裂縫分布，以供 FAVOR 分析所用。

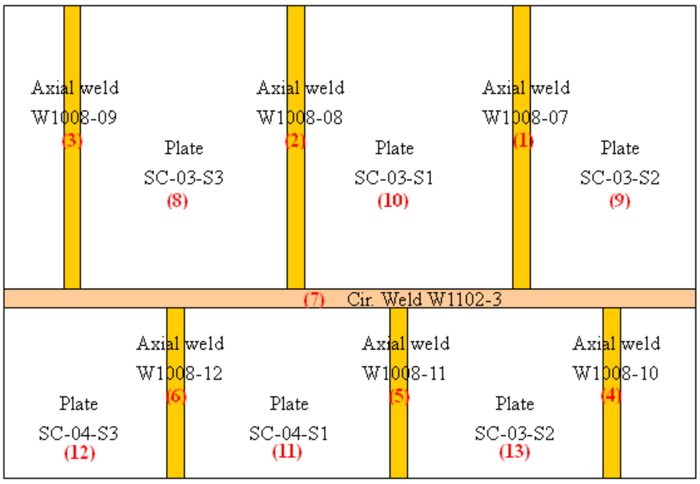
10 月 10 日~10 月 16 日，第七週

本週 Mr. Terry Dickson 交付職之任務爲將第一週與第二週針對 PWR 電廠之 PTS limit re-evaluation 工作 (主要依據爲 NUREG-1874 與 10CFR50.61a)，針對職撰寫之程式流程與資料圖形等結果整理部份，加以彙整成一篇概述之論文，以投稿 2011 年度之 ASME PVP Conference。此工作歷時約一週，完成後再交由 Mr. Terry Dickson 與尹勝軍博士修改，附件五則爲此篇論文之摘要初稿。

10 月 17 日~10 月 23 日，第八週

本週爲職赴 ORNL 實習之最後一週，除前段完成上週 Mr. Terry Dickson 交付之任務外，先前所執行之 FAVOR 分析，分別包含以新建立之核一廠 1 號機 PFM 輸入檔進行之遭遇 LTOP 事件，以及 ASME B&PV Sec. XI App.G 之 Cool-down 與 Heat-up 暫態下之 PFM 分析。分析結果分別列於表五及附件六中，亦再請 Mr. Terry Dickson 進行最後之指導與確認。最後幾天則開始辦理 ORNL 之離職手續，由秘書 Ms Angie Scott 與 Mr. Terry Dickson 協助，包含証件與物品之歸還、帳號清除，與辦公室之整理等。最後並再與 Mr. Terry Dickson 與尹勝軍博士拍照合影留念，如圖十五與圖十六。爲此次實習工作劃下完美的句點。

表五 以新建之核一廠 1 號機 FAVOR 分析模型執行之 PFM 分析結果。



Total CPI = 1.211×10^{-7}

Total CPF = 1.198×10^{-7}

Occurrence of LTOP event is 1×10^{-3}/yr

Flaw Population	**Major Region**	**Max. RT_{NDT} (°F)**	**% of total CPI**	**CPI**	**% of total CPF**	**CPF**
Axial weld	1	-7.0	0.18	2.180×10^{-10}	0.18	2.156×10^{-10}
	2	12.0	31.52	3.817×10^{-8}	30.85	3.696×10^{-8}
	3	1.7	65.27	7.904×10^{-8}	65.92	7.897×10^{-8}
	4	-6.7	0.08	9.688×10^{-11}	0.08	9.584×10^{-11}
	5	-17.0	2.10	2.543×10^{-9}	2.12	2.540×10^{-9}
	6	0.1	0.85	1.029×10^{-9}	0.85	1.018×10^{-9}
Circumferential weld	7	4.0	0	0	0	0
Plate	8	54.8	0	0	0	0
	9	78.2	0	0	0	0
	10	75.3	0	0	0	0
	11	93.4	0	0	0	0
	12	87.1	0	0	0	0
	13	69.2	0	0	0	0

圖十五　職與 Mr. Terry Dickson 之合影。

圖十六　職與尹勝軍博士合影。

10 月 24 日(星期日)至 10 月 26 日(星期二)

10 月 24 日由諾克斯維爾機場搭乘美國航空班機於下午六點二十分起飛，途中經德州達拉斯國際機場，再轉機飛往洛杉磯國際機場，最後飛返桃園機場，因國際換日及長途飛行，於 10 月 26 日抵達。

三、心得

本次實習受益良多，不僅有關專業技術之學習，亦包括對新事物之見識，與人際關係之拓展等，可以下列數點加以敘述之:

1. 本次實習機會學習到許多解決問題之思考邏輯與應用方式，例如應用 Matlab 數值模擬程式之撰寫，解決許多複雜之計算，便爲一項重要之訓練。Mr. Terry Dickson 亦認爲由職所撰寫之二程式(附件一與附件二)，可應用於我國核能電廠，作爲安全評估之工具。

2. 本次實習最主要收穫便是對 FAVOR 09.1 之應用有了深入之了解。亦對核能電廠反應器壓力槽之各項安全評估有了更進一步之認識。相信對提昇我國核能電廠之安全分析技術有很大之幫助。

3. 因參與了 Mr. Terry Dickson 之相關工作，發現 FAVOR 程式之發展，係歷經了十多年各專業領域廣範的研究，方可有今日之成果，決非少數人或團隊可達成。整個以 PFM 評估核能電廠 RPV 遭受 PTS 衝擊之安全評估，便係由美國 NRC 所主導，整合各單位之研究成果，例如 PNNL 之裂縫相關研究、Argonne 國家實驗室與馬里蘭大學負責之 PRA 相關研究、NRC 向各電廠要求整理之 PTS 相關暫態與事件描述整理，NRC 請 Eason 顧問公司所進行之 RPV 材料輻射脆化計算過程，以及 ORNL 之 FAVOR 分析程式等，爲一相當龐大之研究計畫。更可顯現美國管制單位對核能安全之重視。

4. 實習期間每日工作與交付之任務繁多，學習內容緊湊，Mr. Terry Dickson 亦毫無保留地指導職相關之專業知識。因此，雖然辛苦但也習得很多新的概念，並徹底地了解與使用 FAVOR 程式之應用。

5. ORNL 內發現華人數量不少，但幾乎皆來自於中國，諸如 Staff、Postdoc、Post master，或參訪學者等，但尚未遇到其他來自臺灣的學者。可發現中國對科技發展之重視，並已急起直追，值得我國警惕與借鏡。

6. 利用此次實習機會，體驗了美國的生活與風土民情。並利用在 ORNL 上班之機會，與亦師亦友的 Mr. Terry Dickson 與尹勝軍博士成爲摯友，並結識了坐職隔壁，來自美國 DOE，同樣來實習的 Shane Boone 博士。此外，於生活上，亦與室友鄭旺、徐波，以及鄰居宋亮、葉楚玉等(皆爲 ORNL 之研究人員)建立深厚友誼。對於個人之人際關係拓展，不啻爲另一重要收穫。

四、建議事項

本次實習之建議事項主要有下列幾點：

1. ORNL 內中國學者數量頗多，具有野心且競爭力強，顯見中國對科技發展之重視。反之臺灣學者數量稀少，若長此以往，我國在科技上之優勢，將逐漸爲中、韓所超前。故國內學者應多爭取出國學習之機會，以拓展視野，學習更新穎之技術。

2. 美國 NRC 所主導的整個 PTS-limit 計畫相當龐大，非少數人或團隊可達成，亦不可能一蹴可幾。故建議國內對於相關議題，除須參考學習美國法規與技術外，尚須循序漸進，整合多方專業領域，不可好高騖遠，以建立完整與扎實嚴謹之理論分析基礎。

3. ORNL 設備新穎，管理方式自由，每位職員(不論是秘書或研究人員)皆有自己之辦公室，且職員上下班時間不須刷卡管制，時間自主，研究人員對所屬工作負責完成後即可，於時間運用上有較大彈性，更易培養對工作任務之歸屬感與負責任之態度。然國情不同，此方式是否適合國內，則還須更進一步之研究與探討。

附件一 TWCF.m 程式內容
(推導 10CFR50.61a 之 PTS limit)

Twcf.m

```
clear
R=459.69; % Absolute temperature in F
limiting=input('Set allowable total TWCF95:  '); % Allowable total TWCF95
TWCF_maxcw=input('Set TWCF95_cw (Usually use 1e-8):  ');  % The maximum TWCF
of circumferential weld is usually assumed as 1e-8/yr
% alpha(RT) is determined by calalp.m
% definie the coefficient of axial weld
m_aw=5.5198; b_aw=-40.542; RT_thaw=616;
% definie the coefficient of plate
m_pl=23.737; b_pl=-162.36; RT_thpl=300;

% Step-1:determine the maximum value of RT_maxaw in absolute temperature
(assume maximum RT_maxaw>625(165.3F))
RT_aw_try=RT_thaw:.1:875;
check_aw1=limiting-TWCF_maxcw-calalp(RT_aw_try).*exp(m_aw.*log(RT_aw_tr
y-RT_thaw)+b_aw);
for n1=1:length(check_aw1)
  s1(n1)=check_aw1(n1);
if s1(n1)-min(abs(check_aw1))<=1e-15
break
end
end
max_RT_maxaw=RT_aw_try(n1);
Limit_RT_maxaw=max_RT_maxaw-R

% Step-2 determine the maximum vaule of RT_maxpl in absolute temperature
(assume maximum RT_maxpl>625(165.3F))
RT_pl_try=RT_thpl:.1:875;
check_pl=limiting-TWCF_maxcw-calalp(RT_pl_try).*exp(m_pl.*log(RT_pl_try
-RT_thpl)+b_pl);
for n2=1:length(check_pl)
  s2(n2)=check_pl(n2);
if s2(n2)-min(abs(check_pl))<=1e-15
break
end
end
max_RT_maxpl=RT_pl_try(n2);
Limit_RT_maxpl=max_RT_maxpl-R

% Step-3 Find the 1st and 2nd points of the locus
RT_maxaw(1)=R;
RT_maxaw(2)=RT_thaw;
RT_maxpl(1)=max_RT_maxpl;
RT_maxpl(2)=max_RT_maxpl;

% Step-4 Assume the TWCF_aw to calculate RT_maxaw
d=input('Number of points to plot the locus of screen criterion:   '); % the
point to plot the locus, more points will spent more tome!
for n3=1:d-1
    TWCF_aw(n3)=(limiting-TWCF_maxcw)/d*n3;

check_aw2=TWCF_aw(n3)-calalp(RT_aw_try).*exp(m_aw.*log(RT_aw_try-RT_tha
w)+b_aw);
    for n4=1:length(check_aw2)
```

```
        s4(n4)=check_aw2(n4);
       if s4(n4)-min(abs(check_aw2))<=1e-15
       break
       end
    end
    RT_maxaw(n3+2)=RT_aw_try(n4);
end
RT_maxaw(d+2)=max_RT_maxaw;

% Step-5 Use the assumed TWCF_aw to calculate RT_maxpl
for n6=1:d-1
    TWCF_pl(n6)=limiting-TWCF_maxcw-TWCF_aw(n6);

check_pl2=TWCF_pl(n6)-calalp(RT_pl_try).*exp(m_pl.*log(RT_pl_try-RT_thp
l)+b_pl);
    for n7=1:length(check_pl2)
        s7(n7)=check_pl2(n7);
       if s7(n7)-min(abs(check_pl2))<=1e-15
       break
       end
    end
    RT_maxpl(n6+2)=RT_pl_try(n7);
end
RT_maxpl(d+2)=R;
plot(RT_maxaw-R,RT_maxpl-R)
```

calaph.m

```
function [alpha]=calalp(RT)
if RT<=625
   alpha=2.5;
elseif RT>=875
   alpha=1;
else
   alpha=2.5-1.5/250*(RT-625);
end
end
```

附件二 RDNDT.m 程式內容

(依據 10CFR50.61a 計算 RPV 材料之 RT_{NDT})

RTNDT.m

```
clear
% Input the EFPY
EFPY=input('Input the EFPY of the plant (year):   ');
t=60*60*24*365.25*EFPY;
% Input the cold-leg temperature
Tc=input('Input the cold-leg temperature (F):   ');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Calculate the shift RTNDT of axial welds (DRTNDT)
% Input the parameters of axial welds
RTNDTu_aw=input('Input the unirradiated RTNDT of axial welds (F):   ');
flux_aw=input('Input the fast neutron flux on axial welds [n/cm2/sec]:   ');
Cu_aw=input('Input the Copper content of axial welds (%):   ');
Ni_aw=input('Input the Nickel content of axial welds (%):   ');
P_aw=input('Input the Phosphorus content of axial welds (%):   ');
Mn_aw=input('Input the Manganese content of axial welds (%):   ');
if flux_aw>=4.3925e10
   fluence_e_aw=flux_aw.*t;
else
   fluence_e_aw=flux_aw.*t.*(4.3925e10./flux_aw).^.2595;
end
% Calculate MD of axial welds
A_aw=1.417e-7;
MD_aw=A_aw*(1-.001718*Tc)*(1+6.13*P_aw.*Mn_aw.^2.471).*sqrt(fluence_e_a
w);
B_aw=155;
% Calculate effective Cu content of axial welds
for n1=1:length(Ni_aw)
   if Ni_aw(n1)<0.5
      Max_Cue_aw(n1)=0.370;
   elseif Ni_aw(n1)>0.75
      Max_Cue_aw(n1)=0.301;
   else
      Max_Cue_aw(n1)=0.2435;
   end
   if Cu_aw(n1)<=.072
      Cue_aw(n1)=0;
   else
      Cue_aw(n1)=min(Cu_aw(n1),Max_Cue_aw(n1));
   end
   % Calculate function f of axial welds
   if Cu_aw(n1)<=.072
      f_aw(n1)=0;
   elseif Cu_aw(n1)>.072 & P_aw(n1)<=.008
      f_aw(n1)=(Cue_aw(n1)-.072)^.6679;
   else
      f_aw(n1)=(Cue_aw(n1)-.072+1.359*(P_aw(n1)-.008))^.6679;
   end
   % Calculate function g of axial welds

g_aw(n1)=0.5+0.5*tanh((log10(fluence_e_aw(n1))+1.139*Cue_aw(n1)-.4483*N
i_aw(n1)-18.12025)/0.6287);
   CRP_aw(n1)=B_aw*(1+3.769*Ni_aw(n1)^1.191)*f_aw(n1)*g_aw(n1);
   DRTNDT_aw(n1)=MD_aw(n1)+CRP_aw(n1);
end
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Calculate the shift RTNDT of circumferential welds (DRTNDT)
% Input the parameters of circumferential welds
RTNDTu_cw=input('Input the unirradiated RTNDT of circumferential welds (F):
');
flux_cw=input('Input the fast neutron flux on circumferential welds
[n/cm2/sec]');
Cu_cw=input('Input the Copper content of circumferential welds (%):   ');
Ni_cw=input('Input the Nickel content of circumferential welds (%):   ');
P_cw=input('Input the Phosphorus content of circumferential welds (%):   ');
Mn_cw=input('Input the Manganese content of circumferential welds (%):   ');
if flux_cw>=4.3925e10
   fluence_e_cw=flux_cw.*t;
else
   fluence_e_cw=flux_cw.*t.*(4.3925e10./flux_cw).^.2595;
end
% Calculate MD of circumferential welds
A_cw=1.417e-7;
MD_cw=A_cw*(1-.001718*Tc)*(1+6.13*P_cw.*Mn_cw.^2.471).*sqrt(fluence_e_c
w);
B_cw=155;
% Calculate effective Cu content of circumferential welds
for n2=1:length(Ni_cw)
   if Ni_cw(n2)<0.5
      Max_Cue_cw(n2)=0.370;
   elseif Ni_cw(n2)>0.75
      Max_Cue_cw(n2)=0.301;
   else
      Max_Cue_cw(n2)=0.2435;
   end
   if Cu_cw(n2)<=.072
      Cue_cw(n2)=0;
   else
      Cue_cw(n2)=min(Cu_cw(n2),Max_Cue_cw(n2));
   end
   % Calculate function f of axial welds
   if Cu_cw(n2)<=.072
      f_cw(n2)=0;
   elseif Cu_cw(n2)>.072 & P_cw(n2)<=.008
      f_cw(n2)=(Cue_cw(n2)-.072)^.6679;
   else
      f_cw(n2)=(Cue_cw(n2)-.072+1.359*(P_cw(n2)-.008))^.6679;
   end
   % Calculate function g of axial welds

g_cw(n2)=0.5+0.5*tanh((log10(fluence_e_cw(n2))+1.139*Cue_cw(n2)-.4483*N
i_cw(n2)-18.12025)/0.6287);
   CRP_cw(n2)=B_cw*(1+3.769*Ni_cw(n2)^1.191)*f_cw(n2)*g_cw(n2);
   DRTNDT_cw(n2)=MD_cw(n2)+CRP_cw(n2);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Calculate the shift RTNDT of plates (DRTNDT)
% Input the parameters of plates
RTNDTu_pl=input('Input the unirradiated RTNDT of plates (F):   ');
flux_pl=input('Input the fast neutron flux on plates [n/cm2/sec]');
Cu_pl=input('Input the Copper content of plates (%):   ');
```

```
Ni_pl=input('Input the Nickel content of plates (%):   ');
P_pl=input('Input the Phosphorus content of plates (%):   ');
Mn_pl=input('Input the Manganese content of plates (%):   ');
check_pl=input('Input the manufacturer, for "1" is non-CE, and "2" is CE
vessel:   ');
if flux_pl>=4.3925e10
   fluence_e_pl=flux_pl.*t;
else
   fluence_e_pl=flux_pl.*t.*(4.3925e10./flux_pl).^.2595;
end
% Calculate MD of plates
A_pl=1.561e-7;
MD_pl=A_pl*(1-.001718*Tc)*(1+6.13*P_pl.*Mn_pl.^2.471).*sqrt(fluence_e_p
l);
if check_pl-1<=0.5
   B_pl=102.5;
else
   B_pl=135.2;
end
% Calculate effective Cu content of plates
for n3=1:length(Ni_pl)
   if Ni_pl(n3)<0.5
      Max_Cue_pl(n3)=0.370;
   elseif Ni_pl(n3)>0.75
      Max_Cue_pl(n3)=0.301;
   else
      Max_Cue_pl(n3)=0.2435;
   end
   if Cu_pl(n3)<=.072
      Cue_pl(n3)=0;
   else
      Cue_pl(n3)=min(Cu_pl(n3),Max_Cue_pl(n3));
   end
   % Calculate function f of plates
   if Cu_pl(n3)<=.072
      f_pl(n3)=0;
   elseif Cu_pl(n3)>.072 & P_pl(n3)<=.008
      f_pl(n3)=(Cue_pl(n3)-.072)^.6679;
   else
      f_pl(n3)=(Cue_pl(n3)-.072+1.359*(P_pl(n3)-.008))^.6679;
   end
   % Calculate function g of axial welds

g_pl(n3)=0.5+0.5*tanh((log10(fluence_e_pl(n3))+1.139*Cue_pl(n3)-.4483*N
i_pl(n3)-18.12025)/0.6287);
   CRP_pl(n3)=B_pl*(1+3.769*Ni_pl(n3)^1.191)*f_pl(n3)*g_pl(n3);
   DRTNDT_pl(n3)=MD_pl(n3)+CRP_pl(n3);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Calculate the shift RTNDT of forgings (DRTNDT)
% Input the parameters of forgings
RTNDTu_fo=input('Input the unirradiated RTNDT of forgings (F):   ');
flux_fo=input('Input the fast neutron flux on forgings [n/cm2/sec]');
Cu_fo=input('Input the Copper content of forgings (%):   ');
Ni_fo=input('Input the Nickel content of forgings (%):   ');
P_fo=input('Input the Phosphorus content of forgings (%):   ');
```

```
Mn_fo=input('Input the Manganese content of forgings (%):   ');
if flux_fo>=4.3925e10
   fluence_e_fo=flux_fo.*t;
else
   fluence_e_fo=flux_fo.*t.*(4.3925e10./flux_fo).^.2595;
end
% Calculate MD of forgings
A_fo=1.14-7;
MD_fo=A_fo*(1-.001718*Tc)*(1+6.13*P_fo.*Mn_fo.^2.471).*sqrt(fluence_e_f
o);
B_fo=102.3;
% Calculate effective Cu content of forgings
for n4=1:length(Ni_fo)
   if Ni_fo(n4)<0.5
      Max_Cue_fo(n4)=0.370;
   elseif Ni_fo(n4)>0.75
      Max_Cue_fo(n4)=0.301;
   else
      Max_Cue_fo(n4)=0.2435;
   end
   if Cu_fo(n4)<=.072
      Cue_fo(n4)=0;
   else
      Cue_fo(n4)=min(Cu_fo(n4),Max_Cue_fo(n4));
   end
   % Calculate function f of forgings
   if Cu_fo(n4)<=.072
      f_fo(n4)=0;
   elseif Cu_fo(n4)>.072 & P_fo(n4)<=.008
      f_fo(n4)=(Cue_fo(n4)-.072)^.6679;
   else
      f_fo(n4)=(Cue_fo(n4)-.072+1.359*(P_fo(n4)-.008))^.6679;
   end
   % Calculate function g of forgings

g_fo(n4)=0.5+0.5*tanh((log10(fluence_e_fo(n4))+1.139*Cue_fo(n4)-.4483*N
i_fo(n4)-18.12025)/0.6287);
   CRP_fo(n4)=B_fo*(1+3.769*Ni_fo(n4)^1.191)*f_fo(n4)*g_fo(n4);
   DRTNDT_fo(n4)=MD_fo(n4)+CRP_fo(n4);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

RT_max_aw=max([max(RTNDTu_aw+DRTNDT_aw),max(RTNDTu_pl+DRTNDT_pl)])
RT_max_cw=max([max(RTNDTu_cw+DRTNDT_cw),max(RTNDTu_pl+DRTNDT_pl),max(RT
NDTu_fo+DRTNDT_fo)])
RT_max_pl=max(RTNDTu_pl+DRTNDT_pl)
RT_max_fo=max(RTNDTu_fo+DRTNDT_fo)
```

附件三　核一廠1號機之更新FAVPFM輸入檔

```
****************************************************************************************************
*                    ALL RECORDS WITH AN ASTERISK(*) IN COLUMN 1 ARE COMMENT ONLY                  *
****************************************************************************************************
*                               FAVPFM file -BWR -  Chinshan Unit 1 - 32 EFPY                                        *
*                                                                                                  *
****************************************************************************************************
*  ==================                                                                              *
*  Control Record CNT1                                                                             *
*  ==================                                                                              *
*--------------------------------------------------------------------------------------------------*
*  NSIM           = NUMBER OF RPV SIMULATIONS                                                      *
*--------------------------------------------------------------------------------------------------*
*  IPFLAW         = FLAW POPULATION MODEL                                                          *
*                                                                                                  *
*  IPFLAW         = 1 Identical to previous version of FAVOR - primarily for cooldown transients.  *
*                                                                                                  *
*                     All Surface flaws (in surface flaw characterizatiuon file) will be inner surface  *
*                     breaking flaws. Only those embedded flaws (in weld and plate flaw characterization *
*                     files) in the inner 3/8 of the RPV wall thickness would be included in the model.  *
*                                                                                                  *
* IPFLAW         = 2  Similar to previous version of FAVOR-HT - primarily for heat-up transients.  *
*                                                                                                  *
*                     All surface breaking flaws (in surface flaw characterization file) would be  *
*                     external surface breaking flaws. Only those embedded flaws in the outer 3/8 of the *
*                     RPV wall thickness would be included in the model.                           *
*                                                                                                  *
* IPFLAW         = 3  The number of postulated surface breaking flaws (in surface flaw characterization  *
*                     file) would be double that of options 1 and 2; evenly divided between internal  *
*                     and external surface breaking flaws. All of the embedded flaws uniformly     *
*                     distributed through the RPV wall thickness would be included in the model.   *
*                                                                                                  *
* See Theory Manual for further discussion.                                                        *
*--------------------------------------------------------------------------------------------------*
*  IGATR          =   NUMBER OF INITIATION-GROWTH-ARREST (IGA) TRIALS PER FLAW                     *
*--------------------------------------------------------------------------------------------------*
*  WPS_OPTION     = 0 DO NOT INCLUDE WARM-PRESTRESSING IN ANALYSIS                                 *
*  WPS_OPTION     = 1        INCLUDE TRADITIONAL FAVOR BASELINE WARM-PRESTRESSING Model IN ANALYSIS  *
*  WPS_OPTION     = 2        INCLUDE Conservative Principal WARM-PRESTRESSING MODEL IN ANALYSIS    *
*  WPS_OPTION     = 3        INCLUDE Best-Estimate WARM-PRESTRESSING MODEL IN ANALYSIS             *
*                                                                                                  *
*  See Theory Manual for details regarding WARM_PRESTRESS Models                                   *
*  Note: Previous Versions of FAVOR prior to the 09.1 included only options 0 and 1.               *
*--------------------------------------------------------------------------------------------------*
*  CHILD_OPTION   = 0 DO NOT INCLUDE CHILD SUBREGION REPORTS                                   [-] *
*  CHILD_OPTION   = 1        INCLUDE CHILD SUBREGION REPORTS                                   [-] *
*--------------------------------------------------------------------------------------------------*
*  RESTART_OPTION = 0 THIS IS NOT A RESTART CASE                                               [-] *
*  RESTART_OPTION = 1 THIS IS A RESTART CASE                                                   [-] *
*--------------------------------------------------------------------------------------------------*
*  ============================                                                                    *
*  Notes for Control Record CNT1                                                                   *
*  ============================                                                                    *
*  IN A TYPICAL PFM ANALYSIS, A SUBSTANTIAL FRACTION OF THE TOTAL FLAWS ARE CATEGORY 3 FLAWS IN    *
*  PLATE REGIONS. BASED ON EXPERIENCE AND SOME DETERMINISTIC FRACTURE ANALYSES, THESE FLAWS VERY   *
*  RARELY CONTRIBUTE TO THE CPI OR CPF WITH THE PLATE FLAW SIZE DISTRIBUTIONS TYPICALLY USED.      *
*  THEREFORE, INVOKING IP3OPT = 0 CAN RESULT IN A SIGNIFICANT REDUCTION IN EXECUTION TIME WITHOUT  *
*  AFFECTING THE SOLUTION, UNLESS THERE ARE UNUSUAL CIRCUMSTANCES SUCH AS A NEW FLAW-SIZE          *
*  DISTRIBUTION FOR PLATE FLAWS. IN EITHER CASE, CATEGORY 3 PLATE FLAWS ARE INCLUDED IN ALL REPORTS.  *
*                                                                                                  *
*  IF IPFLAW = 3; THEN PC3_OPTION AUTOMATICALLY OVER-RIDES AND SETS PC3_OPTION = 1                 *
*                                                                                                  *
*  Notes on Restart Option:                                                                        *
*                                                                                                  *
*  The restart option flag can also be used to control the frequency with which restart files are  *
*  created. If RESTART_OPTION is given a value other than 0 or 1, then the absolute value of this flag  *
*  sets the checkpoint interval at which the restart file will be created during the run. For example,  *
*                                                                                                  *
* 1.RESTART_OPTION = -200 ==> This is not a restart case; restart files will be created every 200 trials *
* 2.RESTART_OPTION =    0 ==> Same as example No. 1.                                               *
* 3.RESTART_OPTION =  200 ==> This is a restart case;     restart files will be created every 200 trials.*
* 4.RESTART_OPTION =    1 ==> Same as example No. 3.                                               *
* 5.RESTART_OPTION =  -50 ==? This is not a restart case; restart files will be created every 50 trials. *
                                                                                          *
*--------------------------------------------------------------------------------------------------*
****************************************************************************************************
CNT1  NSIM=300000  IPFLAW=3 IGATR=100   WPS_OPTION=1    PC3_OPTION=0    CHILD_OPTION=1   RESTART_OPTION=500
****************************************************************************************************
*  ==================                                                                              *
*  Control Record CNT2                                                                             *
*  ==================                                                                              *
*--------------------------------------------------------------------------------------------------*
* EMBRITTLEMENT CORRELATION FOR ESTIMATING RADIATION-INDUCED SHIFT IN RTNDT                         *
* IRTNDT     = 992   ==> USE RG 1.99, REV                                                           *
* IRTNDT     = 2000  ==> USE E2000                                                                  *
* IRTNDT     = 2006  ==> USE modified E2006                                                         *
* IRTNDT     = 20071 ==> USE EricksonKirk 2007                                                      *
* IRTNDT     = 20072 ==> USE RADAMO                                                                 *
```

```
* IRTNDT     = 20073 ==> USE cOMBINED EricksonKirk 2007 + RADAMO                                          *
*---------------------------------------------------------------------------------------------------------*
* TC         = INITIAL RPV COOLANT TEMPERATURE (applicable only when IRTNDT=2000 or 2006)             [F] *
*---------------------------------------------------------------------------------------------------------*
* EFPY       = EFFECTIVE FULL-POWER YEARS OF OPERATION                                            [YEARS] *
*---------------------------------------------------------------------------------------------------------*
* IDT_OPTION = 0  DO NOT INCLUDE DUCTILE TEARING AS A POTENTIAL FRACTURE MODE                         [-] *
* IDT_OPTION = 1         INCLUDE DUCTILE TEARING AS A POTENTIAL FRACTURE MODE                         [-] *
*---------------------------------------------------------------------------------------------------------*
* IDT_INI    = 0  DO NOT CREATE A LOG OF POTENTIAL DUCTILE TEARING INITIATIONS                        [-] *
* IDT_INI    = 1         CREATE A LOG OF POTENTIAL DUCTILE TEARING INITIATIONS                        [-] *
*---------------------------------------------------------------------------------------------------------*
* ILONG_OUT  = 0  DO NOT CREATE Major-Region ITRAN Files                                              [-] *
* ILONG_OUT  = 1         CREATE Major-Region ITRAN Files                                              [-] *
*                                                                                                         *
* The capability to generate this specific report was requested by Steve Long of NRR                      *
***********************************************************************************************************
CNT2 IRTNDT=2006 TC=556 EFPY=32  IDT_OPTION=1  IDT_INI=0  ILONG_OUT=0
***********************************************************************************************************
*  ====================                                                                                   *
*  Control Record CNT3                                                                                    *
*  ====================                                                                                   *
*---------------------------------------------------------------------------------------------------------*
* FLWSTR = UNIRRADIATED FLOW STRESS USED IN PREDICTING FAILURE BY REMAINING LIGAMENT INSTABILITY    [ksi] *
*---------------------------------------------------------------------------------------------------------*
* USKIA  = MAXIMUM VALUE ALLOWED FOR KIc or KIa                                              [ksi-in^1/2] *
*---------------------------------------------------------------------------------------------------------*
* KIa_Model    = 1 Use high-constraint KIa model based on CCA specimens                               [-] *
* KIa_Model    = 2 Use KIa model based on CCA + large specimen data                                   [-] *
*---------------------------------------------------------------------------------------------------------*
* LAYER_OPTION = 0 DONOT RESAMPLE PF WHEN ADVANCING INTO NEW WELD LAYER                               [-] *
* LAYER_OPTION = 1       RESAMPLE PF WHEN ADVANCING INTO NEW WELD LAYER                               [-] *
*---------------------------------------------------------------------------------------------------------*
* FAILCR       = FRACTION OF WALL THICKNESS FOR VESSEL FAILURE BY THROUGH-WALL CRACK PROPAGATION      [-] *
*---------------------------------------------------------------------------------------------------------*
*  =============================                                                                          *
*  Notes for Control Record CNT3                                                                          *
*  =============================                                                                          *
*        If ductile tearing model is included, then the values for USKIA and KIa_Model are ignored.       *
*        They are automatically set internally to KIa_Model=2 and there is no upper limit on USKIa.       *
*        If ductile tearing is not included in the analysis (IDT_OPTION = 0 on CNT1), both the KIa_Model *
*        and USKIA are user-specified on CNT3.                                                            *
*                                                                                                         *
***********************************************************************************************************
CNT3 FLWSTR=80.  USKIA=800. KIa_Model=2  LAYER_OPTION=0  FAILCR=0.9
***********************************************************************************************************
*  ====================                                                                                   *
*      Record GENR                                                                                        *
*  ====================                                                                                   *
*---------------------------------------------------------------------------------------------------------*
*   SIGFGL = A MULTIPLIER ON THE BEST ESTIMATE OF FLUENCE FOR A GIVEN SUBREGION                       [-] *
*            PRODUCES THE STANDARD DEVIATION FOR THE NORMAL DISTRIBUTION USED TO SAMPLE THE MEAN          *
*            OF THE LOCAL FLUENCE DISTRIBUTION.                                                           *
*---------------------------------------------------------------------------------------------------------*
*   SIGFLC = A MULTIPLIER ON THE SAMPLED MEAN OF THE LOCAL FLUENCE FOR A GIVEN  SUBREGION             [-] *
*            PRODUCES THE STANDARD DEVIATION FOR THE NORMAL DISTRIBUTION USED TO SAMPLE THE LOCAL FLUENCE*
*---------------------------------------------------------------------------------------------------------*
*  ======================                                                                                 *
*  Notes for Record GENR                                                                                  *
*  ======================                                                                                 *
*  Let "flue" be the best estimate for the subregion neutron fluence at inside surface of the RPV wall.  *
*  flue_STDEV_global = SIGFGL*flue                                                                        *
*  flue_MEAN_local  << Normal(flue,flue_STDEV_global)                                                     *
*  flue_STDEV_local  = SIGFLC*flue_MEAN_local                                                             *
*  flue_local       << Normal(flue_MEAN_local,flue_STDEV_local)                                           *
*                                                                                                         *
***********************************************************************************************************
GENR SIGFGL=0.118 SIGFLC=0.056
***********************************************************************************************************
*  ====================                                                                                   *
*      Record SIGW                                                                                        *
*  ====================                                                                                   *
*  STANDARD DEVIATIONS (STDEV) OF NORMAL DISTRIBUTIONS FOR WELD CHEMISTRY SAMPLING:                       *
*  WSIGCU = STANDARD DEVIATION FOR COPPER CHEMISTRY SAMPLING IN WELDS                                 [wt%] *
*  WSIGNI = STANDARD DEVIATION FOR NICKEL CHEMISTRY SAMPLING IN WELDS                                 [wt%] *
*  WSIGP  = STANDARD DEVIATION FOR PHOSPHOROUS CHEMISTRY SAMPLING IN WELDS                            [wt%] *
*---------------------------------------------------------------------------------------------------------*
*  ======================                                                                                 *
*  Notes for Record SIGW                                                                                  *
*  ======================                                                                                 *
*  FOR NICKEL IN WELDS THERE ARE TWO POSSIBILITIES.                                                       *
*  (1) FOR HEATS 34B009 AND W5214 (Ni - addition welds)                                                   *
*      WSIGNI = 0.162 wt% using a normal distribution.                                                    *
*  (2) For other heats, the standard deviation (WSIGNI) shall be sampled from a normal distribution       *
*      with mean equal to 0.029 wt% and standard deviation = 0.0165 wt%                                   *
***********************************************************************************************************
SIGW   WSIGCU=0.167   WSIGNI=0.162    WSIGP=0.0013
```

```
**********************************************************************************************************
*  ===================                                                                                   *
*      Record SIGP                                                                                       *
*  ===================                                                                                   *
*  STANDARD DEVIATIONS (STDEV) OF NORMAL DISTRIBUTIONS FOR PLATE CHEMISTRY SAMPLING:                     *
*  PSIGCU = STANDARD DEVIATION FOR COPPER CHEMISTRY SAMPLING IN PLATES                             [wt%] *
*  PSIGNI = STANDARD DEVIATION FOR NICKEL CHEMISTRY SAMPLING IN PLATES                             [wt%] *
*  PSIGP  = STANDARD DEVIATION FOR PHOSPHOROUS CHEMISTRY SAMPLING IN PLATES                        [wt%] *
*--------------------------------------------------------------------------------------------------------*
*  =====================                                                                                 *
*  Notes for Record SIGP                                                                                 *
*  =====================                                                                                 *
*  RECOMMENDED VALUES ARE: 0.0073, 0.0244, 0.0013 for Cu, Ni, and P, respectively.                       *
**********************************************************************************************************
SIGP  PSIGCU=0.0073   PSIGNI=0.0244   PSIGP=0.0013
**********************************************************************************************************
*  ==============================                                                                        *
*  Notes for RecordS SIGW and SIGP                                                                       *
*  ==============================                                                                        *
*  THE ABOVE DISTRIBUTIONS ARE FOR THE 1ST FLAW POSITIONED IN A PARTICULAR SUBREGION.                    *
*  IF THE CURRENT FLAW IS THE 2ND OR MORE FLAW FOR THIS SUBREGION, THEN FAVPFM WILL USE                  *
*  THE LOCAL VARIABILITY SAMPLING PROTOCOLS PRESENTED IN THE THEORY MANUAL.                              *
**********************************************************************************************************
*  ===================                                                                                   *
*     Record TRAC                                                                                        *
*  ===================                                                                                   *
*   ITRAN           = TRANSIENT NUMBER                                                               [-] *
*   RPV             = RPV SIMULATION                                                                 [-] *
*   KFLAW           = FLAW NUMBER                                                                    [-] *
*   FLAW_LOG_OPTION = 0 DO NOT CREATE FLAW LOG TABLES                                                [-] *
*   FLAW_LOG_OPTION = 1 DO     CREATE FLAW LOG TABLES                                                [-] *
*--------------------------------------------------------------------------------------------------------*
*  ==============================                                                                        *
*  Notes for Record TRAC                                                                                 *
*  ==============================                                                                        *
*  THE ABOVE FLAGS IDENTIFY A SPECIFIC TRANSIENT, RPV SIMULATION, AND FLAW NUMBER WHOSE COMPLETE         *
*  HISTORY WILL BE GIVEN IN THE FILES: "TRACE.OUT" AND "ARREST.OUT"                                      *
*  SEE THE USER'S GUIDE FOR DETAILS ON THE CONTENTS OF THESE FILES                                       *
*                                                                                                        *
**********************************************************************************************************
TRAC ITRAN=1  IRPV=1  KFLAW=1  FLAW_LOG_OPTION=0
**********************************************************************************************************
*  ===================                                                                                   *
*     Record LDQA - This record is only applicable if IQA = 1                                            *
                                                                                  *
*  ===================                                                                                   *
* THE LDQA RECORD PROVIDES THE OPPORTUNITY TO CHECK LOAD-RELATED SOLUTIONS                               *
* SUCH AS TEMPERATURE, STRESSES, AND KI.                                                                 *
*                                                                                                        *
*   IQA   = 0 ==> THIS EXECUTION IS NOT FOR LOAD QA                                                  [-] *
*   IQA   = 1 ==> THIS EXECUTION IS FOR LOAD QA                                                      [-] *
*--------------------------------------------------------------------------------------------------------*
*   IOPT  = 1 ==> GENERATE TIME HISTORY AT SPECIFIC THROUGH WALL LOCATION                            [-] *
*   IOPT  = 2 ==> GENERATE THROUGH WALL DISTRIBUTION AT SPECIFIC TIME                                [-] *
*--------------------------------------------------------------------------------------------------------*
*   IFLOR = 1 ==> FLAW ORIENTATION IS AXIAL                                                          [-] *
*   IFLOR = 2 ==> FLAW ORIENTATION IS CIRCUMFERENTIAL                                                [-] *
*--------------------------------------------------------------------------------------------------------*
*   IWELD = 0  ==> DOES NOT INCLUDE THRU-WALL WELD RESIDUAL STRESS                                   [-] *
*   IWELD = 1  ==> DOES INCLUDE THRU-WALL WELD RESIDUAL STRESS                                       [-] *
*--------------------------------------------------------------------------------------------------------*
*   IKIND = 1  ==> INNER-SURFACE BREAKING FLAW                                                       [-] *
*   IKIND = 2  ==> EMBEDDED FLAW                                                                     [-] *
*--------------------------------------------------------------------------------------------------------*
*   XIN IS ONLY USED IF IKIND=2 (EMBEDDED FLAWS)                                                         *
*   XIN   =  IF IOPT=1; LOCATION OF INNER CRACK TIP FROM INNER SURF.                                [IN] *
*   XIN   =  IF IOPT=2; FLAW DEPTH                                                                  [IN] *
*--------------------------------------------------------------------------------------------------------*
*   XVAR:    IF IOPT=1; XVAR=FLAW DEPTH                                                             [IN] *
*            IF IOPT=2; XVAR=TIME                                                                  [MIN] *
*--------------------------------------------------------------------------------------------------------*
*   ASPECT = ASPECT RATIO; FOR SURFACE BREAKING FLAWS: 2,6,10,999 (infin)                            [-] *
*                         FOR EMBEDDED FLAWS: ANY VALUE > 0                                              *
*--------------------------------------------------------------------------------------------------------*
*  ==============================                                                                        *
*  Notes for Record LDQA                                                                                 *
*  ==============================                                                                        *
* IQA = 0 NO VALIDATION REPORTS WILL BE GENERATED, PFM ANALYSIS WILL BE PERFORMED                        *
* IQA = 1 LOAD PARAMETERS WILL BE GENERATED FOR VERIFICATION PURPOSES, PFM ANALYSIS WILL NOT BE PERFORMED*
**********************************************************************************************************
LDQA IQA=0 IOPT=2 IFLOR=1 IWELD=1 IKIND=1 XIN=2.0 XVAR=50 ASPECT=999
**********************************************************************************************************
*  ===================                                                                                   *
*      Record DTRF                                                                                       *
*  ===================                                                                                   *
*--------------------------------------------------------------------------------------------------------*
*   NT = number of ISQ records that follow                                                           [-] *
```

```
*   NT = 0 no ISQ records follow                                                                        *
*-------------------------------------------------------------------------------------------------------*
*   FOLLOWING THE DTRF RECORD, THERE SHOULD BE "NT" SUBRECORDS                                          *
*-------------------------------------------------------------------------------------------------------*
*   ISQ  ITRAN=  ISEQ=  TSTART=   TEND=                                                                 *
*-------------------------------------------------------------------------------------------------------*
*   ITRAN  = sequential number in FAVLoad transient stack                                           [-] *
*   ISEQ   = Thermal Hydraulic trasient sequence number                                             [-] *
*   TSTART = starting time for FAVPFM analysis                                                    [MIN] *
*   TEND   = ending time for FAVPFM analysis                                                      [MIN] *
*********************************************************************************************************
DTRF NT=0
*********************************************************************************************************
*  ===================                                                                                  *
*     Record WELD                                                                                       *
*  ===================                                                                                  *
*  NWSUB = NUMBER OF WELD SUBREGIONS                                                                [-] *
*  NWMAJ = NUMBER OF WELD MAJOR REGIONS                                                             [-] *
*********************************************************************************************************
WELD NWSUB=7   NWMAJ=7
*********************************************************************************************************
*  ===================                                                                                  *
*     Record PLAT                                                                                       *
*  ===================                                                                                  *
* NPSUB = NUMBER OF PLATE SUBREGIONS                                                                [-] *
* NPMAJ = NUMBER OF PLATE MAJOR REGIONS                                                             [-] *
*********************************************************************************************************
PLAT NPSUB=6  NPMAJ=6
***********************************************************************************************************
*                        PLATE/WELD EMBRITTLEMENT / FLAW DISTRIBUTION MAP RECORDS                         *
***********************************************************************************************************
*=========================================================================================================*
*  Field             DESCRIPTION                                                                  [UNITS] *
*=========================================================================================================*
*---------------------------------------------------------------------------------------------------------*
*  (1) RPV subregion number   -   parent                                                              [-] *
*---------------------------------------------------------------------------------------------------------*
*  (2) adjacent RPV subregion - 1st child                                                             [-] *
*---------------------------------------------------------------------------------------------------------*
*  (3) adjacent RPV subregion - 2nd child                                                             [-] *
*---------------------------------------------------------------------------------------------------------*
*  (4) RPV major region number                                                                        [-] *
*---------------------------------------------------------------------------------------------------------*
*  (5) best estimate neutron fluence at RPV inside surface                         [10^19 neutrons/cm^2] *
*---------------------------------------------------------------------------------------------------------*
*  (6) best estimate copper (Cu) content                                                         [wt% Cu] *
*---------------------------------------------------------------------------------------------------------*
*  (7) best estimate nickel (Ni) content                                                         [wt% Ni] *
*---------------------------------------------------------------------------------------------------------*
*  (8) best estimate phosphorus (P) content                                                      [wt%  P] *
*---------------------------------------------------------------------------------------------------------*
*  (9) best estimate manganese (Mn) content                                                      [wt% Mn] *
*---------------------------------------------------------------------------------------------------------*
*  (10) product form flags for DT30 shift correlation                                                     *
*                                                                                                         *
*      Welds : set distribution for sampling standard                                                     *
*              deviation for Ni content in welds                                                          *
*             = 1 use normal distribution                                                             [-] *
*             = 2 use Weibull distribution                                                            [-] *
*      Plates:                                                                                            *
*          CE = 1 (if IRTNDT=2000 then set B = 206)                                                   [-] *
*      Not CE = 2 (if IRTNDT=2000 then set B = 156)                                                   [-] *
*      where CE is a Combustion Engineering vessel                                                        *
*---------------------------------------------------------------------------------------------------------*
* (11) copper saturation flag = 0 for plates and forgings                                             [-] *
*                             = 1 for Linde 80 and Linde 0091 weld fluxes                                 *
*                             = 2 for all weld fluxes other than L80, L0091, and L1092                    *
*                             = 3 for Linde 1092 weld flux                                                *
*       N.B.:                                                                                             *
*         for IRTNDT = 2000                                                                               *
*               maximum value of copper content (copper saturation)                                       *
*             = 0.25 for Linde 80 and = 0.305 for all others                                              *
*         for IRTNDT = 2006                                                                               *
*               maximum value of copper content (copper saturation)                                       *
*             = 0.37 for Ni < 0.5 wt%                                                                     *
*             = 0.2435 for 0.5 <= Ni <= 0.75 wt%                                                          *
*             = 0.301 for Ni > 0.75 wt% (all welds with Linde 1092 weld flux)                             *
*                                                                                                         *
*---------------------------------------------------------------------------------------------------------*
* (12) unirradiated best estimate (mean) for RTNDT0                                                   [F] *
*---------------------------------------------------------------------------------------------------------*
* (13) unirradiated standard deviation for RTNDT0                                                     [F] *
*---------------------------------------------------------------------------------------------------------*
* (14) PF flag      Product Form        CF Override                                                       *
*      -------      ------------        -----------                                                       *
*      = 11             weld                no                                                        [-] *
*      = 12             weld                yes                                                       [-] *
```

```
*      = 21             plate                  no                                                  [-] *
*      = 22             plate                  yes                                                 [-] *
*      = 31            forging                 NA                                                  [-] *
*------------------------------------------------------------------------------------------------------*
* (15) angle of subregion element                                                            [degrees] *
*------------------------------------------------------------------------------------------------------*
* (16) axial height of subregion element:                                                    [inches]  *
*------------------------------------------------------------------------------------------------------*
* (17) weld fusion area:                                                                   [inches^2] *
*------------------------------------------------------------------------------------------------------*
* (18) weld orientation: 1 ===> axial; 2===> circumferential                                       [-] *
*------------------------------------------------------------------------------------------------------*
* (19) chemistry factor override                                                                   [-] *
*------------------------------------------------------------------------------------------------------*
* (20) unirradiated upper shelf CVN engergy                                                   [ft-lbf] *
*======================================================================================================*
*    Notes:                                                                                            *
*                                                                                                      *
*    1. Fields 1-4  : contain RPV beltline discretization and connectivity data for weld fusion line   *
*    2. Fields 5-20 : contain RPV beltline embrittlement-related data                                   *
*    3. Field   13  : PF means Product Form                                                            *
*    4. Field   13  : CF means chemistry factor override                                               *
*    5. Field   18  : only applies to weld subregions. For plates set to 0.                            *
*    6. Field   20  : applicable only if IRTNDT=2000 on CNT2 and Field 13 = 12 or 22                   *
*                                                                                                      *
*======================================================================================================*
********************************************************************************************************
* 1     2     3    4    5     6     7     8     9  10  11    12      13  14    15      16      17  18 19  20
********************************************************************************************************
* Axial welds above the circ weld                                                                      *
********************************************************************************************************
00001 00009 00010  1 0.0372 0.180 0.340 0.011 1.200  2  1  -50.0   17.0 11  0.7791  105.475  526.848 1  0   0
00002 00008 00010  2 0.0760 0.180 0.340 0.011 1.200  2  1  -50.0   17.0 11  0.7791  105.475  526.848 1  0   0
00003 00008 00009  3 0.0502 0.180 0.340 0.011 1.200  2  1  -50.0   17.0 11  0.7791  105.475  526.848 1  0   0
********************************************************************************************************
* Axial welds below the circ weld
*********************************************************************************************************
00004 00012 00013  4 0.0360 0.180 0.390 0.010 1.150  2  1  -50.0   17.0 11  0.7791   42.875  214.161 1  0   0
00005 00011 00013  5 0.0254 0.180 0.390 0.010 1.150  2  1  -50.0   17.0 11  0.7791   42.875  214.161 1  0   0
00006 00011 00012  6 0.0447 0.180 0.390 0.010 1.150  2  1  -50.0   17.0 11  0.7791   42.875  214.161 1  0   0
********************************************************************************************************
* Circ weld
********************************************************************************************************
00007 00010 00013  7 0.0507 0.180 0.390 0.010 1.150  2  1  -50.0   17.0 11  360.00   1.2500 3252.141 2  0  0
********************************************************************************************************
* Lower Intermediate Shell Plates (above Circ weld)
********************************************************************************************************
00008 00008 00008  8 0.0760 0.130 0.540 0.010 1.430  1  0    8.0   17.0 21 119.221   105.475  0.0000 0  0   0
00009 00009 00009  9 0.0760 0.180 0.560 0.009 1.430  1  0   10.0   17.0 21 119.221   105.475  0.0000 0  0   0
00010 00010 00010 10 0.0760 0.180 0.610 0.016 1.480  1  0   0.00   17.0 21 119.221   105.475  0.0000 0  0   0
*********************************************************************************************************
*  Lower Shell Plates (below Circ weld)
********************************************************************************************************
00011 00011 00011 11 0.0760 0.160 0.590 0.013 1.380  1  0   30.0   17.0 21 119.221    42.875  0.0000 0  0   0
00012 00012 00012 12 0.0760 0.220 0.560 0.013 1.380  1  0   0.00   17.0 21 119.221    42.875  0.0000 0  0   0
00013 00013 00013 13 0.0760 0.180 0.530 0.013 1.450  1  0    0.0   17.0 21 119.221    42.875  0.0000 0  0   0

****************************** END OF EMBRITTLEMENT MAP ***************************************************
```

附件四　以 FAVOR 09.1 進行之 Deterministic Minimization 計算練習結果

Table1 Deterministic minimization of Chinshan Unit 1 for cool-down transients

	EFPY	Criteria	Rate (°F/hr)	Aspect ratio	WPS_option=0	WPS_option=1	WPS_option=2
Cool-down Transient	32	ASME B&PV Appendix G	50	2	No value	No value	No value
				6	202.62	202.65	202.65
				10	183.11	183.39	183.39
				999	195.98	196.13	196.13
			75	2	No value	No value	No value
				6	189.58	189.98	189.98
				10	173.48	174.10	174.10
				999	184.32	184.83	184.83
			100	2	No value	No value	No value
				6	179.00	179.82	179.82
				10	162.71	166.18	166.18
				999	174.63	175.55	175.55
		Risk-informed	50	2	No value	No value	No value
				6	271.80	272.36	272.36
				10	155.56	245.89	155.56
				999	192.85	263.93	192.85
			75	2	No value	No value	No value
				6	190.36	255.30	190.36
				10	140.80	235.29	140.80
				999	164.58	249.36	164.58

			100	2	No value	No value	No value
				6	163.81	244.24	163.81
				10	130.14	227.87	130.14
				999	148.01	239.63	148.01
	60	ASME B&PV Appendix G	50	2	No value	No value	No value
				6	231.84	231.84	231.84
				10	210.07	210.07	210.07
				999	224.67	224.67	224.67
			75	2	No value	No value	No value
				6	216.67	216.55	216.55
				10	199.22	199.22	199.22
				999	211.13	211.13	211.13
			100	2	No value	No value	No value
				6	205.68	205.68	205.68
				10	191.07	191.07	191.07
				999	201.29	201.29	201.29
		Risk-informed	50	2	No value	No value	No value
				6	306.32	306.32	306.32
				10	274.28	274.28	159.94
				999	296.25	296.25	203.10
			75	2	No value	No value	No value
				6	284.44	284.44	220.27

				10	261.69	261.69	144.00
				999	277.92	277.92	169.87
			100	2	No value	No value	No value
				6	271.30	271.30	169.15
				10	253.41	253.41	132.72
				999	266.49	266.49	151.70

Table2 Deterministic minimization of Chinshan Unit 1 for heat-up transients

	EFPY	Criteria	Rate (°F/hr)	Aspect ratio	WPS_option=0			WPS_option=1			WPS_option=2		
					internal	external		internal	external		internal	external	
						Cir.	Axial		Cir.	Axial		Cir.	Axial
Heat-up Transient	32	ASME B&PV Appendix G	50	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	272.8	No value	No value	272.8	No value	No value	272.8	No value	No value
				999	No value	No value	168.26	No value	No value	168.26	No value	No value	168.26
			75	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	No value	No value	No value	No value	No value	No value	No value	No value	No value
				999	No value	No value	161.75	No value	No value	161.75	No value	No value	161.75
			100	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	No value	No value	No value	No value	No value	No value	No value	No value	No value

				999	No value	No value	155.49	No value	No value	155.49	No value	No value	155.49
		Risk-informed	50	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	191.57	No value	No value	191.57	No value	No value	No value	No value	No value
				999	No value	No value	210.39	No value	No value	210.39	No value	No value	210.39
			75	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	191.57	No value	No value	191.57	No value	No value	No value	No value	No value
				999	No value	No value	203.68	No value	No value	203.68	No value	No value	203.68
			100	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	191.57	No value	No value	191.57	No value	No value	No value	No value	No value
				999	No value	No value	197.37	No value	No value	197.37	No value	No value	197.37
	60	ASME B&PV Appendix G	50	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	368.93	No value	No value	368.93	No value	No value	368.93	No value	No value
				999	No value	No value	189.67	No value	No value	189.67	No value	No value	189.67
			75	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	No value	No value	No value	No value	No value	No value	No value	No value	No value
				999	No value	No value	182.54	No value	No value	182.54	No value	No value	182.54
			100	2	No value	No value	No value	No value	No value	No value	No value	No value	No value

				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	No value	No value	No value	No value	No value	No value	No value	No value	No value
				999	No value	No value	176.40	No value	No value	176.40	No value	No value	176.40
		Risk-informed	50	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	201.43	No value	No value	201.43	No value	No value	No value	No value	No value
				999	No value	No value	231.66	No value	No value	231.66	No value	No value	231.66
			75	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	201.43	No value	No value	201.43	No value	No value	No value	No value	No value
				999	No value	No value	224.98	No value	No value	224.98	No value	No value	224.98
			100	2	No value	No value	No value	No value	No value	No value	No value	No value	No value
				6	No value	No value	No value	No value	No value	No value	No value	No value	No value
				10	201.43	No value	No value	201.43	No value	No value	No value	No value	No value
				999	No value	No value	218.60	No value	No value	218.60	No value	No value	218.60

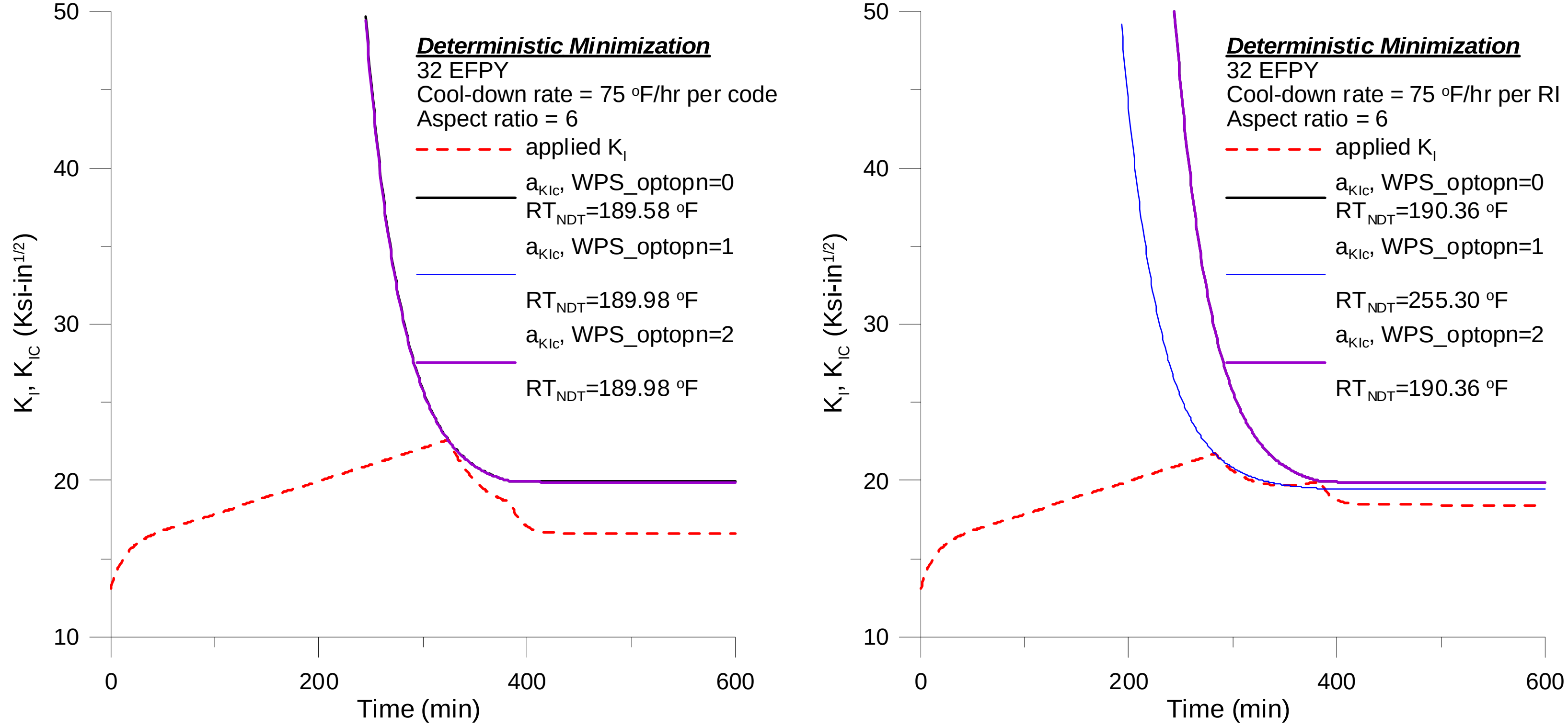


Fig.1 Applied K_I and a_{KIc} of 75 °F/hr cool-down transient for 32 EFPY Chinshan Unit 1 per code and risk-informed, respectively (aspect ratio = 6)

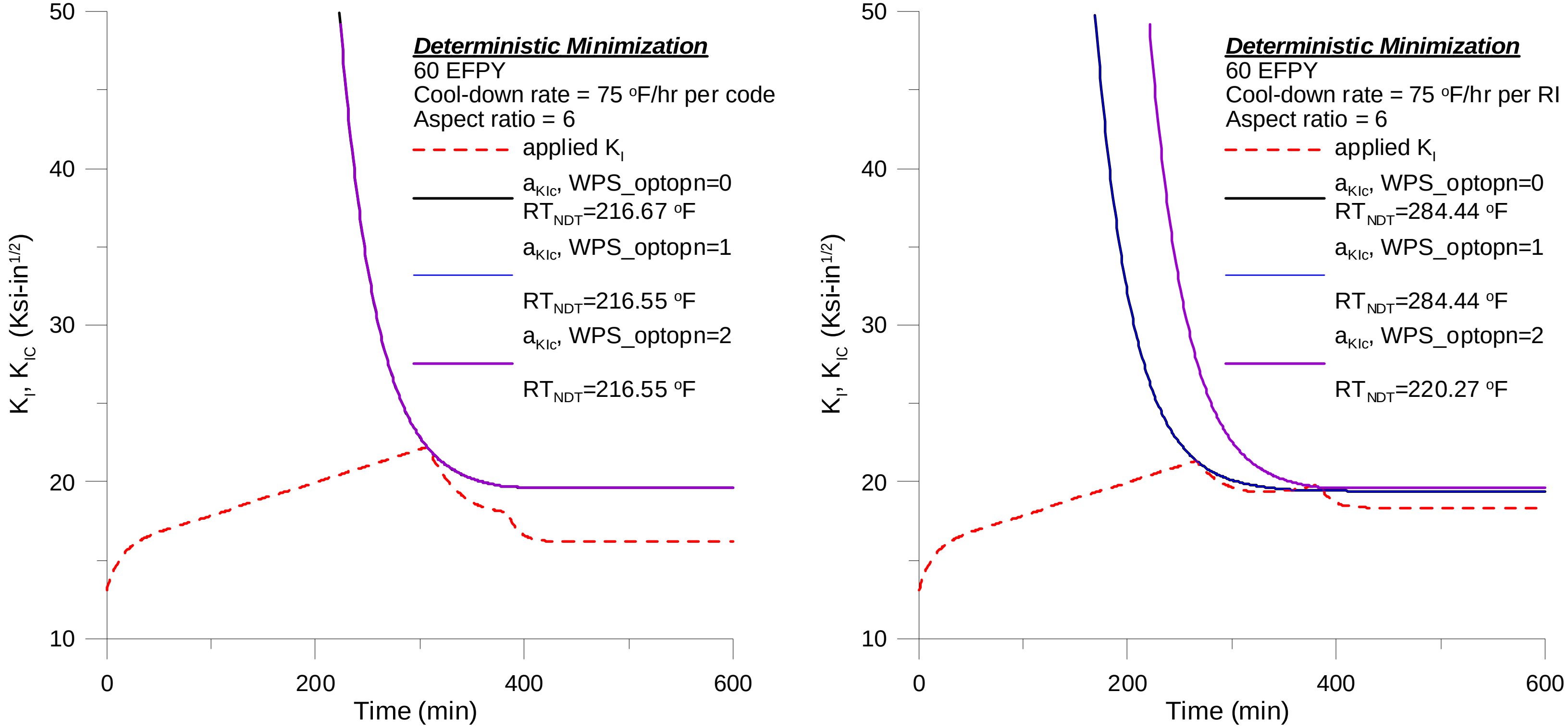


Fig.2 Applied K_I and a_{KIc} of 75 °F/hr cool-down transient for 60 EFPY Chinshan Unit 1 per code and risk-informed, respectively (aspect ratio = 6)

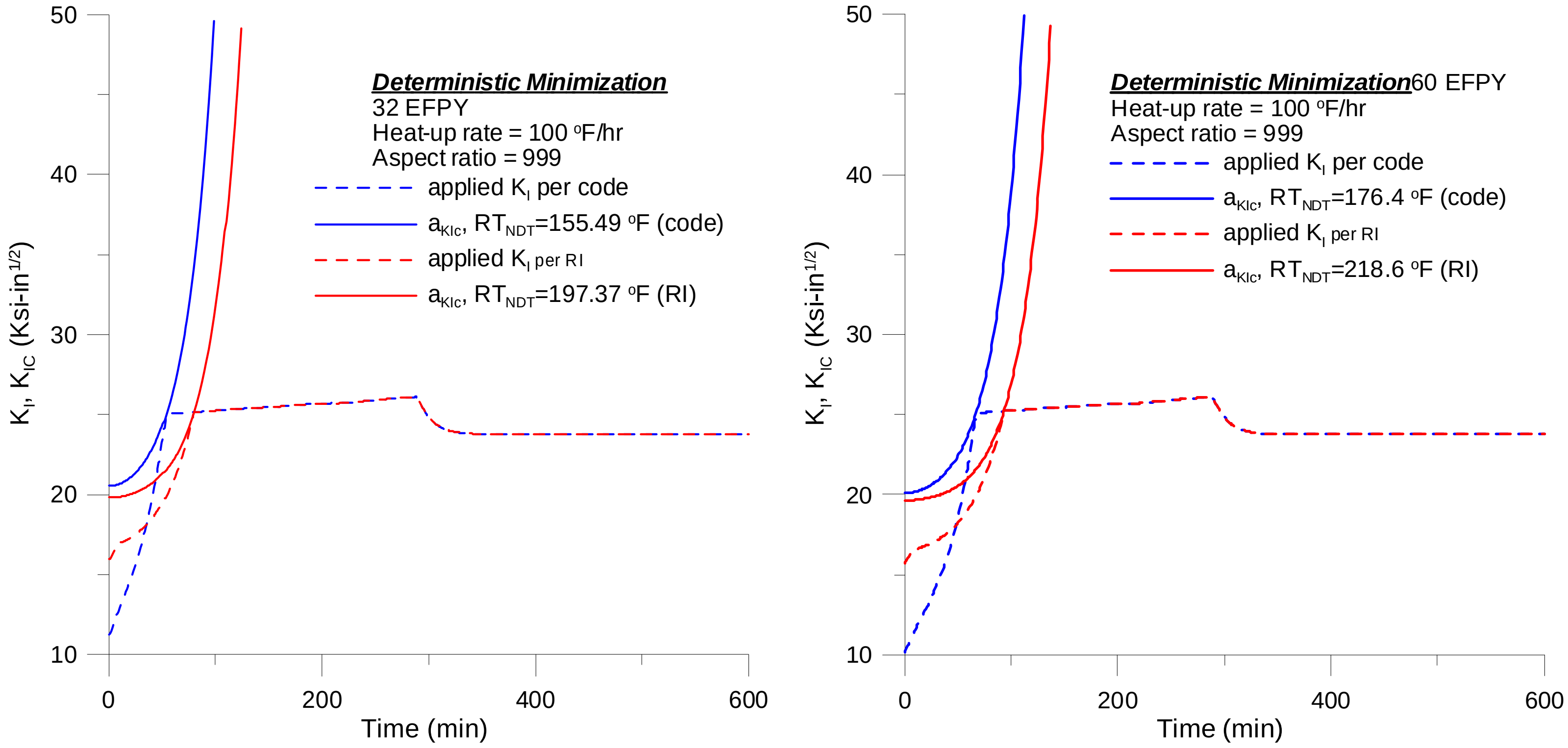


Fig.3 Applied K_I and a_{KIc} of 100 °F/hr heat-up transient for 32 and 60 EFPY Chinshan Unit 1 per code and risk-informed, respectively (aspect ratio = inf.)

附件五　職與 Mr. Terry Dickson 等人欲投稿 2011 年 ASME PVP Conference 之論文摘要初稿

Review of the Derivation of the New Pressurized Thermal Shock Screening Criteria

Proceedings of PVP2011:
2011 ASME Pressure Vessels and Piping Conference
July 17-21, 2011, Baltimore, Maryland

REVIEW OF THE DERIVATION OF THE NEW PRESSURIZED THERMAL SHOCK SCREENING CRITERIA(1)

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As a result of a multi-year, multi-disciplinary effort on the part of the United States Nuclear Regulatory Commission (USNRC), its contractors, and the nuclear industry, a technical basis was established to support a relaxation to the pressurized thermal shock (PTS) regulations, previously derived in the 1980s. The new relaxed rule provides alternative screening criteria as specified in 10 CFR 50.61(a).

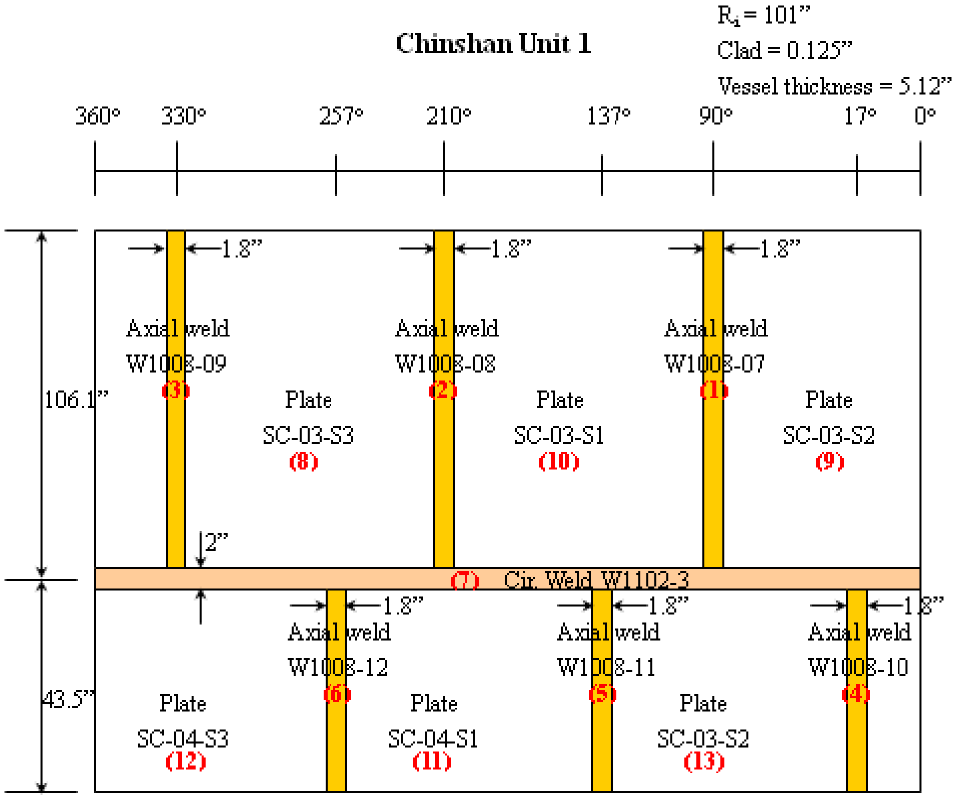
Such a relaxation is having and will continue to have profound favorable implications for current and future nuclear plant license extension considerations. The relaxed regulations will not prevent any of the 67 domestic commercial pressurized water reactor (PWRs) from being relicensed for an additional 20 years (from 40 to 60 years). Subsequently, regulators are now considering researching the feasibility of future license extensions from 60 to 80 years.

Many papers and reports have been published regarding the many and various analyses and results; however, little has been published regarding how the results of these analyses were applied in the derivation of the more relaxed alternative PTS screening criteria.

The objective of this paper is to review a non-trivial sequence of mathematical operations performed on the results of these analysis results to derive the new relaxed alternative PTS screening criteria.

附件六　以 FAVOR 09.1 分析我國核一廠 1 號機 RPV 於 Heat-up 與 Cool-down 暫態條件下之 PFM 分析結果整理

PFM Analysis Results for Taiwanese BWR



Taiwanese BWR – All (modified Eason – 2007 per NUREG 1874)

EFPY	RT$_{NDT}$ @ ID	RT$_{NDT}$ @ t/4	RT$_{NDT}$ @ 3t/4	Sub region	Major region	ID fluence	Copper	Nickel	Phos	Mn	RT$_{NDT\ (u)}$
32	96.17	88.07	72.32	11	Plate-11	0.076	0.160	0.590	0.013	1.380	30
60	116.83	109.77	94.26	11	Plate-11	0.076	0.160	0.590	0.013	1.380	30

(1) Table P1 - Integrated Results for CPI_{mean}

(2) Table P2 – Integrated Results for CPF_{mean}

(3) Table PC3 - Surface Breaking Flaws subjected to cool-down transients

(4) Table PC4 – Embedded Flaws subjected to cool-down transients

(5) Table PC5 – Allocation of risk for surface breaking flaws subjected to cool-down transients

(6) Table PC6 – Allocation of risk for embedded flaws subjected to cool-down transients

(7) Table PH7 - Surface Breaking Flaws subjected to heat-up transients

(8) Table PH8 - Embedded flaws subjected to heat-up transients

(9) Table PH9 – Allocation of risk for surface breaking flaws subjected to heat-up transients

(10) Table PH10 – Allocation of risk for embedded flaws subjected to heat-up transients

Table P1 – Integrated Results for CPI_{mean} for Taiwanese BWR

Plant	EFPY	rate	Pressure derivation	Cool-down			Heat-up			Total embedded	Total SB	Total CPI_{mean}	% SB
				SB	Embedded	Total Cooldown	SB	Embedded	Total Heatup				
TW	32	50	Code	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	**0**
TW	32	50	industry	0.00e0	0.00e0	0.00e0	0.00e0	3.31e-13	3.31e-13	3.31e-13	0.00e0	3.31e-13	**0**
TW	32	75	Code	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	**0**
TW	32	75	industry	0.00e0	0.00e0	0.00e0	0.00e0	3.31e-13	3.31e-13	3.31e-13	0.00e0	3.31e-13	**0**
TW	32	100	Code	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	**0**
TW	32	100	industry	0.00e0	0.00e0	0.00e0	0.00e0	3.31e-13	3.31e-13	3.31e-13	0.00e0	3.31e-13	**0**
TW	60	50	Code	0.00e0	0.00e0	0.00e0	2.23e-13	9.27e-10	9.27e-10	9.27e-10	2.23e-13	9.27e-10	**0.024**
TW	60	50	industry	9.58e-14	0.00e0	9.58e-14	0.00e0	2.28e-9	2.28e-9	2.28e-9	9.58e-14	2.28e-9	**0.004**
TW	60	75	Code	0.00e0	0.00e0	0.00e0	3.29e-12	1.28e-9	1.28e-9	1.28e-9	3.29e-12	1.28e-9	**0.256**
TW	60	75	industry	3.12e-12	0.00e0	3.12e-12	0.00e0	2.48e-9	2.48e-9	2.48e-9	3.12e-12	2.48e-9	**0.126**
TW	60	100	Code	0.00e0	0.00e0	0.00e0	1.47e-11	2.51e-9	2.52e-9	2.51e-9	1.47e-11	2.52e-9	**0.582**
TW	60	100	industry	2.44e-11	0.00e0	2.44e-11	0.00e0	2.56e-9	2.56e-9	2.56e-9	2.44e-11	2.58e-9	**0.937**

Table P2 – Integrated Results for CPF_{mean} for Taiwanese BWR

Plant	EFPY	rate	Pressure derivation	Cool-down			Heat-up			Total embedded	Total SB	Total CPF_{mean}	% SB
				SB	Embedded	Total Cooldown	SB	Embedded	Total Heat-up				
TW	32	50	Code	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	**0**
TW	32	50	industry	0.00e0	0.00e0	0.00e0	0.00e0	3.31e-13	3.31e-13	3.31e-13	0.00e0	3.31e-13	**0**
TW	32	75	Code	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	**0**
TW	32	75	industry	0.00e0	0.00e0	0.00e0	0.00e0	3.31e-13	3.31e-13	3.31e-13	0.00e0	3.31e-13	**0**
TW	32	100	Code	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	0.00e0	**0**
TW	32	100	industry	0.00e0	0.00e0	0.00e0	0.00e0	3.31e-13	3.31e-13	3.31e-13	0.00e0	3.31e-13	**0**
TW	60	50	Code	0.00e0	0.00e0	0.00e0	0.00e0	4.76e-10	4.76e-10	4.76e-10	0.00e0	4.76e-10	**0**
TW	60	50	industry	3.40e-14	0.00e0	3.40e-14	0.00e0	1.82e-9	1.82e-9	1.82e-9	3.40e-14	1.82e-9	**0.002**

TW	60	75	Code	0.00e0	0.00e0	0.00e0	0.00e0	1.34e-10	1.34e-10	1.34e-10	0.00e0	1.34e-10	**0**
TW	60	75	industry	1.08e-12	0.00e0	1.08e-12	0.00e0	1.82e-9	1.82e-9	1.82e-9	1.08e-12	1.82e-9	**0.059**
TW	60	100	Code	0.00e0	0.00e0	0.00e0	0.00e0	2.22e-11	2.22e-11	2.22e-11	0.00e0	2.22e-11	**0**
TW	60	100	industry	8.46e-12	0.00e0	8.46e-12	0.00e0	1.82e-9	1.82e-9	1.82e-9	8.46e-12	1.83e-9	**0.46**

Table PC3- Taiwanese BWR: Surface Breaking Flaws subjected to cool-down transients

Transient numbers	Plant	EFPY	Type	rate	Pressure derivation	P_{min}	ΔPmin	$\Delta t_{initial}$	$\Delta(\Delta t_{initial})$	CPImean	CPFmean	time
7	TW	32	CD	50	Code	0.545		485		0.00e0	0.00e0	
10	TW	32	CD	50	industry	0.749	0.204	425	60	0.00e0	0.00e0	
8	TW	32	CD	75	Code	0.541		325		0.00e0	0.00e0	
11	TW	32	CD	75	industry	0.722	0.185	284	41	0.00e0	0.00e0	
9	TW	32	CD	100	Code	0.537		245		0.00e0	0.00e0	
12	TW	32	CD	100	industry	0.696	0.159	213	32	0.00e0	0.00e0	
7	TW	60	CD	50	Code	0.478		459		0.00e0	0.00e0	
10	TW	60	CD	50	industry	0.733	0.255	399	60	9.58e-14	3.40e-14	
8	TW	60	CD	75	Code	0.470		308		0.00e0	0.00e0	
11	TW	60	CD	75	industry	0.706	0.236	266	42	3.12e-12	1.08e-12	
9	TW	60	CD	100	Code	0.463		232		0.00e0	0.00e0	
12	TW	60	CD	100	industry	0.679	0.216	200	32	2.44e-11	8.46e-12	

Table PC4 –Taiwanese BWR Embedded Flaws subjected to cool-down transients

Transient numbers	Plant	EFPY	Type	rate	Pressure derivation	P_{min}	ΔPmin	$\Delta t_{initial}$	$\Delta(\Delta t_{initial})$	CPImean	CPFmean	time
7	TW	32	CD	50	Code	0.545		485		0.00e0	0.00e0	
10	TW	32	CD	50	industry	0.749	0.204	425	60	0.00e0	0.00e0	
8	TW	32	CD	75	Code	0.541		325		0.00e0	0.00e0	
11	TW	32	CD	75	industry	0.722	0.185	284	41	0.00e0	0.00e0	
9	TW	32	CD	100	Code	0.537		245		0.00e0	0.00e0	
12	TW	32	CD	100	industry	0.696	0.159	213	32	0.00e0	0.00e0	
7	TW	60	CD	50	Code	0.478		459		0.00e0	0.00e0	
10	TW	60	CD	50	industry	0.733	0.255	399	60	0.00e0	0.00e0	
8	TW	60	CD	75	Code	0.470		308		0.00e0	0.00e0	
11	TW	60	CD	75	industry	0.706	0.236	266	42	0.00e0	0.00e0	
9	TW	60	CD	100	Code	0.463		232		0.00e0	0.00e0	
12	TW	60	CD	100	industry	0.679	0.216	200	32	0.00e0	0.00e0	

Table PC5 – Allocation of risk for surface breaking flaws subjected to cool-down transients

Transient numbers	Plant	EFPY	rate		CPImean allocation				CPFmean allocation			
				Pressure derivation	% CPI Internal(1)	% CPI external(2)	% CPI weld	% CPI plate	% CPF internal	% CPF external	% CPF weld	% CPF plate
7	TW	32	50	Code	-	-	-	-	-	-	-	-
10	TW	32	50	industry	-	-	-	-	-	-	-	-
8	TW	32	75	Code	-	-	-	-	-	-	-	-
11	TW	32	75	industry	-	-	-	-	-	-	-	-
9	TW	32	100	Code	-	-	-	-	-	-	-	-
12	TW	32	100	industry	-	-	-	-	-	-	-	-
7	TW	60	50	Code	-	-	-	-	-	-	-	-

10	TW	60	50	industry	100	0	100	0	100	0	100	0
8	TW	60	75	Code	-	-	-	-	-	-	-	-
11	TW	60	75	industry	100	0	100	0	100	0	100	0
9	TW	60	100	Code	-	-	-	-	-	-	-	-
12	TW	60	100	industry	100	0	100	0	100	0	100	0

(1) Internal surface breaking flaws

(2) External surface breaking flaws

Table PC6 – Allocation of risk for embedded flaws subjected to cool-down transients

Transient numbers	Plant	EFPY	rate		CPImean allocation				CPFmean allocation			
				Pressure derivation	% CPI internal(1)	% CPI external(2)	% CPI weld	% CPI plate	% CPF internal	% CPF external	% CPF weld	% CPF plate
7	TW	32	50	Code	-	-	-	-	-	-	-	-
10	TW	32	50	industry	-	-	-	-	-	-	-	-
8	TW	32	75	Code	-	-	-	-	-	-	-	-
11	TW	32	75	industry	-	-	-	-	-	-	-	-
9	TW	32	100	Code	-	-	-	-	-	-	-	-
12	TW	32	100	industry	-	-	-	-	-	-	-	-
7	TW	60	50	Code	-	-	-	-	-	-	-	-
10	TW	60	50	industry	-	-	-	-	-	-	-	-
8	TW	60	75	Code	-	-	-	-	-	-	-	-
11	TW	60	75	industry	-	-	-	-	-	-	-	-
9	TW	60	100	Code	-	-	-	-	-	-	-	-
12	TW	60	100	industry	-	-	-	-	-	-	-	-

(3) embedded flaws within that half of the vessel thickness nearest the RPV wetted inner surface

(2) embedded flaws within that half of the vessel thickness nearest the RPV outer surface

Table PH7 –Taiwanese BWR Surface Breaking Flaws subjected to heat-up transients

Transient numbers	Plant	EFPY	Type	rate	Pressure derivation	P_{start}	ΔPstart	Δt_{steady}	(Δt_{steady})	CPImean	CPFmean	time
7	TW	32	Heat	50	Code	0.576		102		0.00e0	0.00e0	
10	TW	32	Heat	50	industry	0.842	0.266	154	52	0.00e0	0.00e0	
8	TW	32	Heat	75	Code	0.576		70		0.00e0	0.00e0	
11	TW	32	Heat	75	industry	0.842	0.266	105	35	0.00e0	0.00e0	
9	TW	32	Heat	100	Code	0.576		54		0.00e0	0.00e0	
12	TW	32	Heat	100	industry	0.842	0.266	80	26	0.00e0	0.00e0	
7	TW	60	Heat	50	Code	0.515		128		0.00e0	0.00e0	
10	TW	60	Heat	50	industry	0.828	0.313	180	52	9.58e-14	3.40e-14	
8	TW	60	Heat	75	Code	0.515		88		0.00e0	0.00e0	
11	TW	60	Heat	75	industry	0.828	0.313	122	34	3.12e-12	1.08e-12	
9	TW	60	Heat	100	Code	0.515		67		0.00e0	0.00e0	
12	TW	60	Heat	100	industry	0.828	0.313	94	27	2.44e-11	8.46e-12	

Table PH8 –Taiwanese BWR Embedded flaws subjected to heat-up transients

Transient numbers	Plant	EFPY	Type	rate	Pressure derivation	P_{start}	ΔPstart	Δt_{steady}	(Δt_{steady})	CPImean	CPFmean	time
7	TW	32	Heat	50	Code	0.576		102		0.00e0	0.00e0	
10	TW	32	Heat	50	industry	0.842	0.266	154	52	3.31e-13	3.31e-13	
8	TW	32	Heat	75	Code	0.576		70		0.00e0	0.00e0	
11	TW	32	Heat	75	industry	0.842	0.266	105	35	3.31e-13	3.31e-13	
9	TW	32	Heat	100	Code	0.576		54		0.00e0	0.00e0	
12	TW	32	Heat	100	industry	0.842	0.266	80	26	3.31e-13	3.31e-13	

7	TW	60	Heat	50	Code	0.515		128		9.27e-10	4.76e-10	
10	TW	60	Heat	50	industry	0.828	0.313	180	52	2.28e-9	1.82e-9	
8	TW	60	Heat	75	Code	0.515		88		1.28e-9	1.34e-10	
11	TW	60	Heat	75	industry	0.828	0.313	122	34	2.48e-9	1.82e-9	
9	TW	60	Heat	100	Code	0.515		67		2.51e-9	2.22e-11	
12	TW	60	Heat	100	industry	0.828	0.313	94	27	2.56e-9	1.82e-9	

Table PH9 – Allocation of risk for surface breaking flaws subjected to heat-up transients

Plant	EFPY	rate	Pressure derivation	Allocation of CPImean				Allocation of CPFmean			
				% internal(1)	% external(2)	% weld	% plate	% internal	% external	% weld	% plate
TW	32	50	Code	-	-	-	-	-	-	-	-
TW	32	50	industry	-	-	-	-	-	-	-	-
TW	32	75	Code	-	-	-	-	-	-	-	-
TW	32	75	industry	-	-	-	-	-	-	-	-
TW	32	100	Code	-	-	-	-	-	-	-	-
TW	32	100	industry	-	-	-	-	-	-	-	-
TW	60	50	Code	0	100	100	0	-	-	-	-
TW	60	50	industry	-	-	-	-	-	-	-	-
TW	60	75	Code	0	100	100	0	-	-	-	-
TW	60	75	industry	-	-	-	-	-	-	-	-
TW	60	100	Code	0	100	100	0	-	-	-	-
TW	60	100	industry	-	-	-	-	-	-	-	-

(1) Internal surface breaking flaws
(2) External surface breaking flaws

Table PH10 – Allocation of risk for embedded flaws subjected to heat-up transients

Transient numbers	Plant	EFPY	rate		CPImean allocation				CPFmean allocation(3)			
				Pressure derivation	% CPI internal(1)	% CPI external(2)	% CPI weld	% CPI plate	% CPF internal	% CPF external	% CPF weld	% CPF plate
7	TW	32	50	Code	-	-	-	-			-	-
10	TW	32	50	industry	100	0	100	0			100	0
8	TW	32	75	Code	-	-	-	-			-	-
11	TW	32	75	industry	100	0	100	0			100	0
9	TW	32	100	Code	-	-	-	-			-	-
12	TW	32	100	industry	100	0	100	0			100	0
7	TW	60	50	Code	56.78	43.22	100	0			100	0
10	TW	60	50	industry	80.1	19.9	100	0			100	0
8	TW	60	75	Code	11.37	88.63	100	0			100	0
11	TW	60	75	industry	73.56	26.44	100	0			100	0
9	TW	60	100	Code	0.92	99.08	100	0			100	0
12	TW	60	100	industry	73.13	28.87	100	0			100	0

(1) embedded flaws within that half of the vessel thickness nearest the RPV wetted inner surface

(2) embedded flaws within that half of the vessel thickness nearest the RPV outer surface

(3) **currently not able to propagate flaw from outer surface to inner surface**