INER-F1036 **INER-F1036**

出國報告（出國類別：其他）

參加 2016 年放射性廢棄物管理國際研討會(WM symposium)與拜訪德州 WCS 及新墨西哥州 URENCO 公司

服務機關：核能研究所
姓名職稱：胡長良　研究助理
派赴國家：美國
出國期間：105 年 3 月 4 日~105 年 3 月 18 日
報告日期：105 年 4 月 19 日

摘　要

核能研究所化工組研究助理胡長良赴美國公差，自 105 年 3 月 4 日至 18 日共計 15 天，目的在參加於亞歷桑納州鳳凰城市舉行之 2016 年廢棄物管理國際研討會 (Waste Management Symposium, WM 2016)並發表論文，會後轉赴德州 Andrews WCS 公司與新墨西哥州 URENCO 公司參訪。

WM 研討會內容包括低/中放射性廢棄物管理、用過核子燃料與高放射性廢棄物管理、設施除污與除役、環境復育、環境管理及民眾參與等相關議題，分別並行 132 Sessions ，包括 84 場次論文口頭發表與海報發表及 48 場座談會，計有來自 30 個國家，約 2000 人與會。作者胡員於會議中宣讀論文：Development of Treatment Process for Radioactive Wastewater Generated from Molybdenum-99 Study，發表對鉬-99 無機廢液之處理技術與操作經驗，作者並藉由參加主題討論及各單元之技術報告研討，與核能先進國家如法國、美國、澳洲、韓國、及日本等專家學者進行討論與交流，蒐集有關各國放射性廢棄物處理現況與管理技術。

會後赴 WCS 公司與 URENCO 公司，洽談核研所六氟化鈾運美安定化處理事宜。URENCO 公司表示可以接受以 30B 與 48Y 桶裝填之六氟化鈾安定化處理，另外瞭解 WCS 公司對低中放射性廢棄物的處理運作管理作業，並蒐集相關資料可提供國內未來在放射性廢棄物安全管理技術的精進，確保民眾健康及環境保護等相關議題研究規劃時之參考與借鏡。

關鍵字：WM symposium 2016、Waste Control Specialists LLC 低放處置場、URENCO 鈾濃縮公司

目　次

一、目的

核能研究所化工組研究助理胡長良赴美國公差，目的在參加於亞歷桑納州鳳凰城市舉行之 2016 年廢棄物管理國際研討會(Waste Management Symposium, WM 2016)並發表論文，會後轉赴德州 Andrews WCS 公司與新墨西哥州 URENCO 公司參訪，洽談核研所六氟化鈾運美安定化處理事宜，順道觀摩與瞭解其處理設施之運作、管理與管制作業情形，可提供未來國內核電廠除役作業或核設施處理運作用之參考與借鏡。

二、過程

(一)行程及工作摘要

公差期間為 105 年 3 月 4 日至 18 日，計 15 天，公差行程如下表 1 所示。

表 1　公差行程表

時 間	地 點	活 動 項 目	活 動 內 容
03 月 04 日~ 03 月 04 日	桃園→鳳凰城 (Phoenix, AR)	去程	桃園搭機經洛杉磯轉赴亞利桑那州鳳凰城
03 月 05 日~ 03 月 10 日	亞利桑那州鳳凰城	參加 WM 2016 國際會議並發表論文	
03 月 11 日	鳳凰城→德州米德蘭 (Midland, TX)	路程	
03 月 12~ 03 月 13 日	德州米德蘭	週末	資料整理
03 月 14 日	拜訪 WCS 公司	參訪，洽公	
03 月 15 日	拜訪 URENCO 公司	參訪，洽公	
03 月 16 日~ 03 月 18 日	德州米德蘭→桃園	返程	米德蘭經由休士頓轉機返回桃園

(二) 第 42 屆廢棄物管理國際研討會(WM 2016)會議議程及研討會內容

WM 研討會提供一個開放的交流論壇，討論和尋求安全且對環境負責、技術可靠和具有成本效益的解決方案來管理放射性廢棄物處置及核設施除役，提升全球放射性廢棄物管理的透明度和信譽。WM 2016 的口號是對放射性廢棄物和放射性材料的安全管理與處置。

1. 會議說明：

WM symposium 每年春季在美國亞歷桑納州鳳凰城市舉行，是目前全球規模最大、負有盛名之有關處置、除役、包裝、運輸、設施選址和環境復育的放射性廢棄物管理研討會議。今年會議計有 30 個國家，超過 2000 名學者專家與會，參加者身分包括：政府官員、學校教授、研究生、工程師、公司經理、總監、企業代表與設備供應商等，可以從中了解新近的管理趨勢和發展、全球各領先企業的服務及產品展示新方案。會議共有超過 600 篇技術專題報告、48 場小組討論會、現場海報展示與設備供應商展覽等，促進與會者能進行全球性廣泛的技術、業務、管理方法、經濟學、環境整治和放射性廢棄物管理的關鍵領域的公共政策等資訊交流與討論。相關小組討論會議對象包括對於能源部環境署(DOE/EM)所負責國家實驗室、超鈾元素(TRU)處置場等，例如 ORNL、SNL、the Portsmouth/Paducah Project Office。

大會為了歡迎青年學子能夠一起來參與，由 Roy G. Post Foundation 提供在學學生獎學金，含交通費、報名費、住宿費與生活費。本次有 5 個國家、22 位研究生前往參與會議並報告其研究成果，未來國內學術單位可鼓勵研究生爭取參加的機會。

2. 會議地點—Phoenix Convention Center 國際會議中心

美國亞利桑那州鳳凰城市是亞利桑那州首都和最大城市，鳳凰城都會區也被稱為太陽之谷，屬亞熱帶沙漠氣候，環境舒適。舉辦地點在國際會議中心 Phoenix Convention Center ，離機場約 10 分鐘車程(如圖 1 所示)。

圖 1. 會議地點 Phoenix Convention Center 國際會議中心

3. 會議議程與研討會內容

會議議程與每天的討論主題內容參見附件 1 與附件 2。

研討會內容：

研討會分成 9 項議題：

Track 1: Crosscutting Policies and Programs (CPP)
Track 2: High-Level Radioactive Wastes, Spent Nuclear Fuel/Used Nuclear Fuel (SNF/UNF) and Long-Lived Alpha/Transuranic Radioactive Waste (HLW)
Track 3: Low-Level, Intermediate Level, Mixed Waste, NORM, & TENORM (LLW)
Track 4: Nuclear Power Plant Waste & On-Site SNF/UNF Management (NPP)
Track 5: Packaging and Transportation (P&T)
Track 6: Decontamination & Decommissioning (D&D)
Track 7: Environmental Remediation (ER)
Track 8: Communications, Education and Training of Technical and Management Issues & Impacts (CE&T)
Track 9: Special Topics Including Safety, Security, & Safeguards (ST)

議題一: 跨部門的政策和整合

包含整體跨領域政策和重大計畫，廢棄物種類（例如高階放射性廢棄物，SNF，LLW等）或處理程序（例如ER，D＆D等）的整合。從國家和國際合作層面來探討廢棄物管理政策，其更深層的議題包括跨領域監控、承包(contract)事務、法律議題、許可證照及相關合法事宜、規範和標準的建立、私有領域的問題、立法、US Price-Anderson Act、Paris Conventions、執行機構和包括多方協議，相關事務的介面、其他高層次涉及多樣廢棄物類型/策略交叉議題。

議題二 ： 高階放射性廢棄物(HLW)、用過核子燃料(SNF/UNF)、長半衰期 α 核種與 TRU 廢棄物處理

主要討論如何處理和處置有關長半衰期α核種與TRU廢棄物、核電廠用過核子燃料及高階放射性廢料，及相關技術的開發和應用、回收/再處理策略和技術、廢棄物清除和處置的具體成果。其中攸關重疊的問題，包括SNF和高放廢物中期和最終處置策略、貯存廢棄物環境許可證書及監測議題，廢棄物處理的替代程序、廢棄物的形式、深層處置和操作設施發展及風險評估，與直接相關的法規和標準的影響。

議題三： 低階放射性廢棄物(LLW)、中階放射性廢棄物(ILW)、混合形式廢棄物(MW)產物質、技術操作產生的天然放射性物質、殘留的天然放射性物質(NORM)與乏鈾

對處理到處置所需的操作技術、技術開發、小量處理示範和部署安排，重疊議題包含廢棄物如何最小化、廢棄物特性分析、排放水監測、廢棄物形式和設施營運評核、法規和標準、而各類設施型態從醫院、加速反應器、研究反應器、政府設施，處置場等。該議題也涉及了鈾或鈈礦石廢棄物管理以及“從 GTCC 至低放廢棄物”，二次廢棄物、技術操作產生的天然放射性物質、殘留的天然放射性物質(NORM)。

議題四：核能電廠廢棄物管理

涵蓋核電廠營運時產生的廢棄物的特性分析、如何最小化、處理、包裝與管理，及核電廠操作過程中所產生廢棄物及用過核子燃料的貯存與管理

議題五：包裝與運輸(P&T)

主要是攸關放射性物質的安全、穩固、商業的包裝和運輸問題。放射性物質包括了 HLW、TRU、LLW、ILW 和 MW；還包括未照射與照射的核子燃料，受污染的介質及雜物，同位素和放射源，六氟化鈾等。小組討論包括國際正規活動、議題和倡議，包裝發展及相關議題，物流和運輸業務，包括大型項目從除役、整合計畫和行程表，針對大型航運活動的議題與情形，與利益相關者和公眾互動議題。

議題六：除污與除役(D&D)

探討有關停役核電廠與反應器的除役事宜，或執照即將中止的計畫與如何成為綠地，包含表徵、去污、拆除、拆遷、廢棄物處理、最終調查，以及相關新技術的發展為政府和商業核電和非核電設施。包括世界各國的除役技術和相關策略，以及監管方面的問題。

議題七：環境上的復育(EM)

主題包括了污染場址的評估、清理和封閉，探討如何恢復和保護人們健康和環境，透過調查、清理、封閉、長時間場址管理。著重在是地上和地下補救措施和清理活動，包括現場檢查、鑑定和評價、採樣和分析、符合法規的監測、解決監管問題影響清理、含水層和土壤修復、從管理的清掃活動產生的廢物、修復的設計和實施、透過技術或程序改善加速清理、封閉、永續的綠化修復和傳統管理/長期監控。

議題八：技術議題與影響、教育與培訓上的交流

此議題被分成多樣小組會議，其中包括技術交流，教育和培訓，社會正義和公平，政府間組織和永續發展問題，知識管理，公眾參與，風險溝通，保存文化資源當拆除老化設施和基礎設施技術。美國能源部環境管理署場址的經驗分享。它集合了較為廣泛的議題有關規模形式涉及廢棄物管理，包括文化、公平、社會、環境、政策、交流、培訓和教育的問題，這也解決了美國國家環境政策法規方面的環境評估問題（環境影響報告書）。

議題九：特別主題討論和跨多個議題技術討論

此議題包含美國和非美國在國際安全、保安和安全導則和美國國土和國際安全問題。它也包括技術議題橫跨幾個 WM 主題有關不知名的廢棄物源和密封源，綜合風險管理、模示建立、合規行動，規範和標準的建立，自然資源損害評估（NRDA），技術部署，儀器儀表，過濾，高級技術，極端環境下的操作技術，技術驅動程序的影響和驅動程序，與涉及多個廢料形式或放射性物質等技術交叉問題。

4. 會議過程

(1)第一天報到 March 05, 2016 Saturday

領取大會手冊(包含投稿會議之論文全文光碟)等資料，工作人員解說會議之舉辦方式、時間及參加該注意之事項。

圖 2.報到櫃台在地下室與廠商展示區在同一區塊

(2)第二天-參加講習訓練課程 , March 06, 2016, Sunday

參加大會舉辦之訓練課程 Critical Decisions (and Tools) for First-Time and Experienced Managers，授課講師 James M. Hylko，課程內容針對一位專業技術人員如何成為一位稱職的部門管理員，循序漸進地引導可評估的關鍵點，提供一個有效領導與管理培訓核心要素，如何從自我的探索中，去發現周遭的問題與連結，且從他人獲得好的資訊及培養工作技巧，與管理者及同儕們建立一個穩固的人際關係、處理好情緒行為等，更從整合能源安全管理系統及職業安全與健康保護管理程序。

圖 3. Workshop—How to Become A Manager

(3)第三天-參加大會開議, March 07, 2016 , Monday

圖 4. 大會會場展示我國國旗

主題：Opening Plenary Session　主席：James W. Voss

大會開始，主席 James W. Voss 歡迎大家的到來，說明此會議是每年於鳳凰城市舉行，一直順利且成功地舉辦，至今已是第 42 屆，也講述會議促進大家的交流與研討，針對於政府和行業世界各國領導人在 2016 年及以後面臨的放射性廢棄物管理的迫切問題研討(圖 5)。

圖5. 大會主席James W. Voss，Managing Director 報告

Waste Management Symposium 2016 Plenary Session

大會開議當天三場全體與會人員參加的主題報告(Plenary discussion)如下所示：

邀約演講者：John Clarke, CEO and Accounting Officer, NDA Board UK

Tom Jones, Vice President of Clean Energy Europe, UK

Monica Regalbuto, Assistant Secretary for DOE/EM, US

第一位主題報告者：約翰·克拉克(John Clarke)

主題題目：Sharing our approach to waste management globally

職稱與公司：執行長(Chief Executive Officer and Accounting Officer)

核能除役管理局(Nuclear Decommissioning Authority)

Dr. Clarke 是英國除役管理局(NDA)執行長，NDA 並非政府機構是一公共性機構，說明了英國對核電廠除役的整理性策略及尋求國際上合作，及所處理的成果展現，十年來他們制定正確的戰略和計劃、合理的資金需求、制定合適的安排、推動策略和進展。他們扮演策略性的角色，在大方向上是擬訂除役預算、設定目標、定期檢核進度情況。提及在處置部分遇到困難及挫折，但有信心擬定一個合適的辦法並公開接受選擇處置點。在這段研討會期間，針對英國的相關議題有數個小組討論會議，針對英國核能政策、除役、廢棄物管理與承包(contracting)議題。

圖6. John Clarke (NDA) Speech

圖 7. NDA 負責英國核電廠除役的相關事務情形

第二位主題報告者：Mr. Tom Jones

主題：Strategy and Business Development

職位與公司：Vice President of AMEC Foster Wheeler’s Clean Energy Business

阿美科工程諮詢有限公司的清潔能源業務副總裁

圖 8. Tom Jones, AMEC Foster Wheeler

AMEC 阿美科工程諮詢有限公司的清潔能源業務，在核能工業上已有 60 年以上的經驗，超過 4000 位核能專家、工程師、計畫管理和現場管理人員、科學家和技術人員，針對核循環每個部份皆有提供處理與解決問題，清潔能源市場、提供工程設計、諮詢和各項管理服務等，包括新的和現有民用核能、可再生能源，傳統的電和核電的安全防護等，它們的使命是成為在世界上面對新能源挑戰的合作夥伴。

Tom Jones 的報告內容中提及有核能全球性的問題和機會，說明未來 15 年估計有超過 1 兆美金的市場，超過 200 個核反應器即將關閉，數十萬立方米的高階放射性廢棄物需要安全處置，數百萬立方米的低中階放射性廢棄物需要處理與處置。針對未來特別的挑戰提出：(1)老舊傳統設施與主要意外場址、(2)推遲支出趨勢(Tendency to delay spending)、(3)需要特別長的處理程序、(4)如何從障礙到相互合作、(5)針對深層地質處置庫，如何能取得公眾的同意。針對未來產業嚴峻的挑戰：(1)針對高階放射性廢棄物，透過建立長期的解決方案以完成核循環、(2)視廢棄物管理和除役為一種投資而不是困擾的事。對於未來的機會(有效經驗傳承)的期許：(1)使世界成為一個安全地方、(2)在工業上加速大眾們的信心、(3)能在高價值的技術上，更訓練出優秀的工程師群。最後說道全

球議題給我們的啟發是面對艱鉅的挑戰，我們需要一起合作以降低環境上的風險，這個大的機會需要我們改變操作與運輸的模式，這是我們共同的產業，在未來上，讓我們做最好的學習、挑戰與激勵。

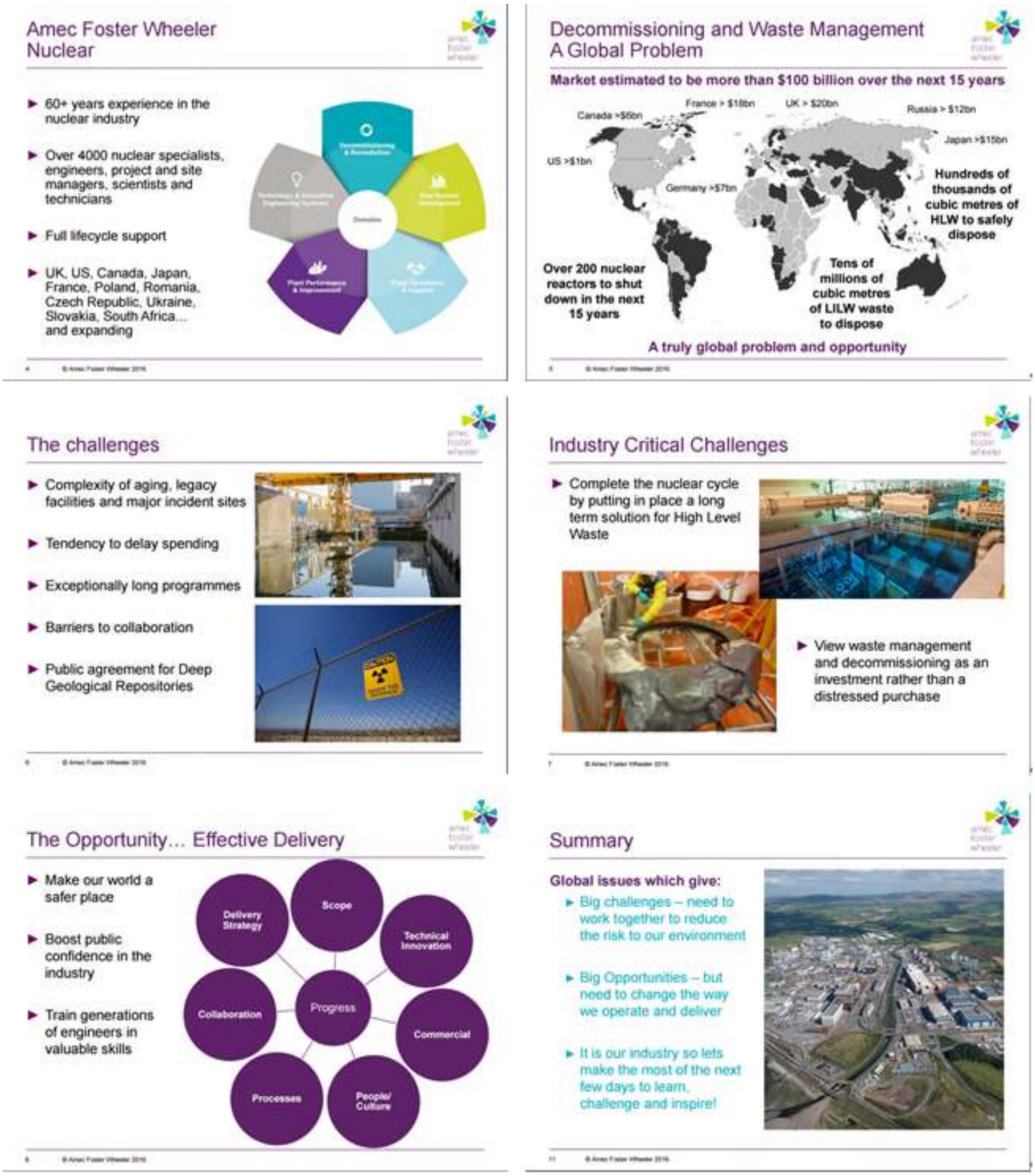


圖 9. Tom Jones 針對 AMEC 及未來核循環所面臨的挑戰與機會

第三位主題報告者：Dr. Monica Regalbuto

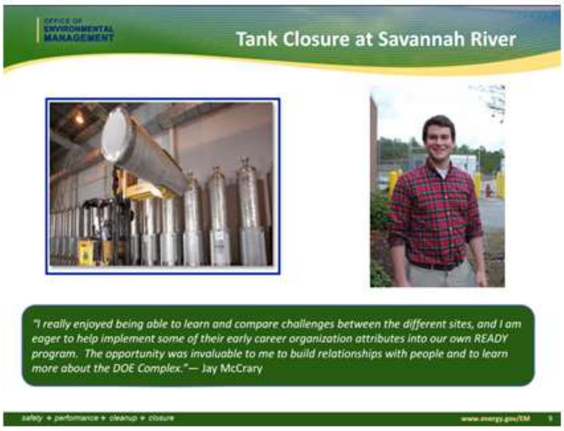
主題：Achieving Cleanup Progress Today and Preparing for the EM of Tomorrow

職位與公司： Assistant Secretary for Environmental Management, DOE

能源部環境管理署助理部長

圖 10. Dr. Monica Regalbuto, Assistant Secretary for Environmental Management

Dr. Monica Regalbuto 於 2015 年 8 月被通過參議院的人事案，正式成為能源部環境管理署(DOE/EM)的助理部長，其領導團隊繼續針對過去五十年的核武器的發展和政府資助的核能研究所遺留下來的相關設施或物料進行安定化的處理，研發項目包括 10 個國家實驗室、32 所大學、400 多個科學家及 300 名教授。報告提及關於環境管理署（EM）的任務及進展的情形，完成既定的清理工作與減少風險程序，例如：EM 的建設和運營設施，以治療放射性液貯存為一個安全，穩定的形式，使最終處置。確保和儲存核物料在最安全且穩定情況，並維護國家的安全。鈾和低放廢棄物處置在安全與低成本效益的方式，以減少風險。除污和除役設施，並進行清理最大限度地利用資源。補救受污染的放射性和有害成分的土壤和地下水。履行承諾降低整個場址的所有風險，並為世世代代清理完全，規劃一個美國的元素汞 DOE/EM 可以長期管理和存儲設施。



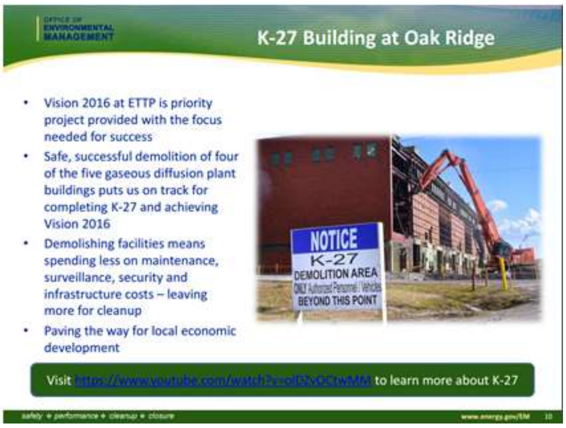


圖 11. Dr. Monica Regalbuto 報告 DOE/EM 他們的任務及相關場址處理情形

大會開幕午餐演講會(Lunch Speech)

演講者：Yasuharu Igarashi, Executive Director,
The Nuclear Damage Compensation Facilitation
Corporation (NDF)

Mr. Igarashi 在日本核能界是位高級主管，已有四十年的經驗，在 2014 年加入核損害賠償和除役便利化公司之前，他擔任日本電力系統公司的執行董事，領導 NDF 團隊面對許多挑戰任務與和有見地執行力。報告內容中提及 NDF 有來自日本和世界各地專家，制定重要中期和長期策略，因應福島第一核電站除役等，因核子燃料棒融化、斷裂（燃料碎片）和放射性廢物的處理。該策略計劃從 2015 年 4 月 30 日啟動，2015 年該計劃主要為政府的中期和長期規劃。堅固與紮實的技術基礎，確保其穩定實施和促進修訂的考量規劃。此外，在 NDF 諮詢等形式提供技術援助，為解決日本政府和東京電力公司，目前推廣的重要問題如污染的水應對措施。

福島第一核電廠除役策略原則，是持續性降低整體環境的風險，以降低人民所受到環境上放射性物質的危害為最高原則，其中期至長期為考量，其整體考量的安排依循是(1)安全原則、(2)高效率原則、(3)及時處理原則、(4)考量放射性物質和工作安全（環境影響和暴露於操作人員的考量），並應用靈活且可靠風險磁場定向減少技術資源（人力，資本，金錢和空間等），以有效地利用時間軸以達到實際到位、實際的部件和實際情況。

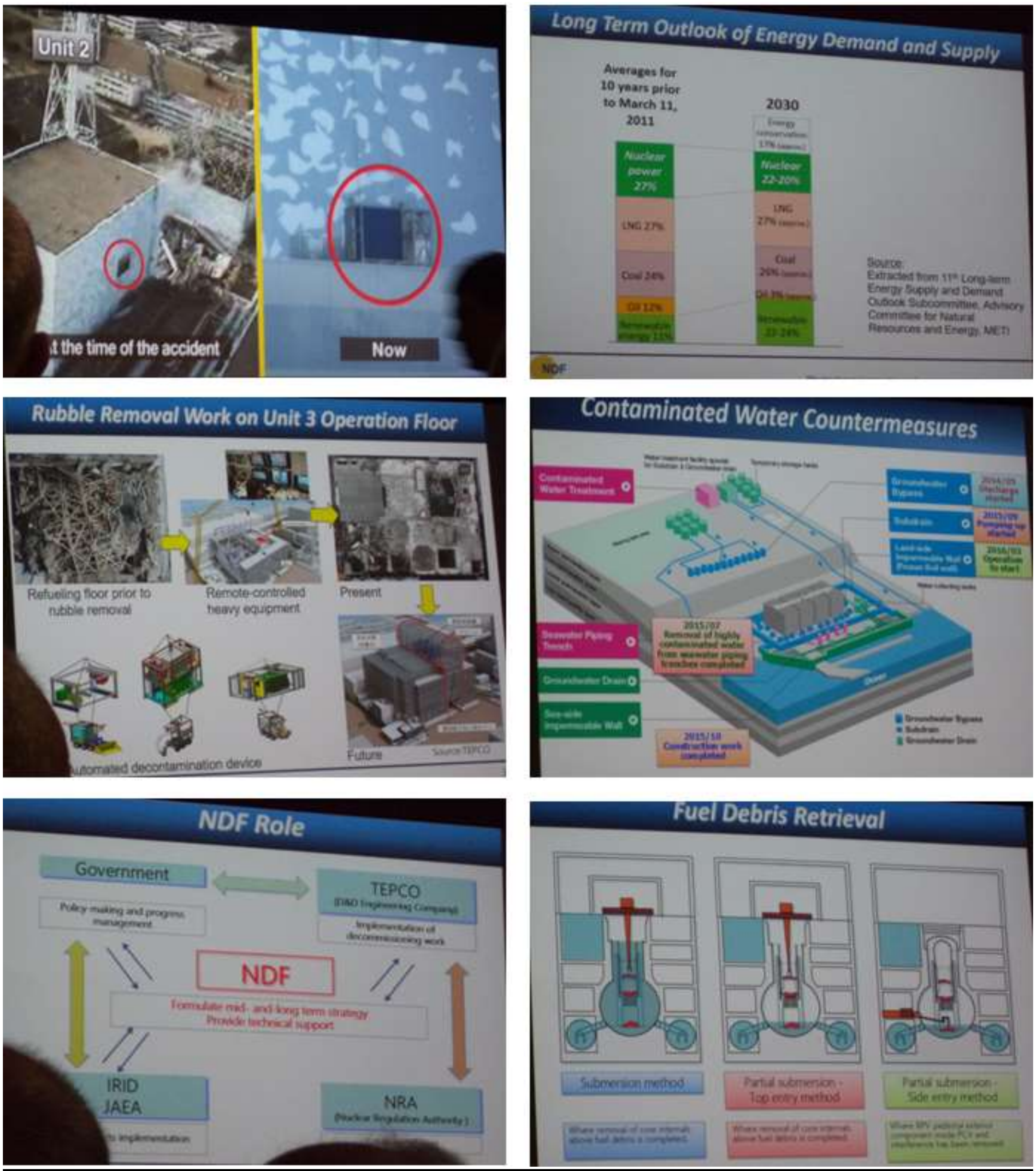


圖 12. Dr. Yasuharu Igarashi 報告 NDF 處理福島核電廠的情形

(4)以下是從第三天下午到第六天下午，作者主要參與之會議簡介、閱覽發表的研究海報、參閱展示廠商提供的相關資料，及和與會人士交流且留影以增加國家與本所的能見度。

①Panel Discussion：

Panel: Featured Country – United Kingdom

此小組會議針對英國面對遺留下來的核能相關設施與研究反應器，在除役與清理工作上所面臨的挑戰，以及現有的核能計劃與新的核電建設如何在安全上及廢棄物處理方面下工夫，會中報告英國針對除役的監管與放射性廢棄物的管制。會議中探討了政府所扮演的角色，NDA的策略，實行在場址的標準及嚴格且富有彈性規定的重要性。也針對美國能源部(US DOE)及英國除役管理局(UK NDA)兩國政府之間的合作關係，希望透過兩國的合作關係，針對創新技術開發、實施、運營經驗學習和管理方法，加速相關清理的工作。

圖13. Featured Country – UK

②Panel: LANL Recovery---Re-Treatment of Problem Waste Stream Nitrate Salts

討論議題：

此小組討論集中於當前存儲在Los Alamos National Laboratory硝酸鹽TRU廢棄物桶，其中包括的熱敏感混合物，之前復育行動處理時所使用的吸附劑是有機的，2014年2月14日廢棄物隔離先導設施(Waste Isolation Pilot Plant, WIPP)的輻射事故，因有一處置罐內的硝酸鹽與有機物貓砂Swheat™ organic kitty litter (fuel)產生放熱反應導致火災與爆裂，主要有機貓砂吸附劑錯誤放置於處置罐所導致，LANL亦進行相關研究進行改善。並提及其所面臨的技術挑戰、法規與策略方面等，會議中也針對了DOE/EM Los Alamos辦公室所負責管理在LANL所留下待處理的相關討論議題。

J.R. Stroble 是能源部TRU場址與運輸部門的主管，說明廢棄物隔離先導設施(WIPP)的現況和全國超鈾（TRU）廢物計劃(NTP)執行情形。David Funk是LANL環境管理部門的副執行者，說明修正硝酸鹽的安全性與處理情形，以及Kathryn Roberts女士(新墨西哥州環境不資源保護組)報告從監管的角度來看對硝酸鹽廢物處理情形。

本所亦有硝酸鹽的存放，以無機吸附劑吸附烘乾後裝桶，是穩定且安全存放。

圖14. LANL Recovery -Re-Treatment of Problem Waste Stream Nitrate Salts

③Panel: Hot Topics in US DOE Environmental Management

此小組會議主要焦點在DOE的高級主管(華盛頓DC)討論有關DOE/EM場址的管理情形

目標：降低生命週期成本，並加速了冷戰的清理。

1. 進行現場清理方案的戰略審查，以確保與納稅人的投資場地修復回報最大化目標
2. 與監管機構和利益相關者合作開發的聯合構想
3. 合規和清理結束狀態
4. 使用風險知情決策，提高優先級設置

目標：執行可持續性的方式以完成 EM 使命。

1. 制定策略執行對場址修復可持續之解決方案
2. 繼續與美國國家環境保護署(EPA)、管理和預算辦公室(OMB)合作，和其他監管機構和相關者落實這些策略。
3. 整合安全管理以確保 EM 場址和策略持續推動。

圖15. Panel: Hot Topics in US DOE Environmental Management

④Panel: Interagency Community of Practice in Risk and Performance Assessment.

此小組會議重點是探討實務機構間性能與風險評估共同體（P＆RA CoP）的情形。從P＆R締約方會議和主題專家與會代表將討論吸取的教訓和建設P＆RA CoP以支持環境處理策略提供反饋。指導委員會由成員來自不同的組織，包括：美國能源部(DOE)、美國核能管理委員會(NRC)、美國國家環境保護署(EPA)、國家監管機構(State regulators)、美國能源部國家實驗室(DOE national labs)、大學院校、工程/環保企業

績效評估(PAs)和風險評估(RAs)評估對人類健康和環境的建議的補救行動的影響，並提供合乎法規和重要的技術投入測試，以滿足監管要求：(1)廢棄物形式開發和實施、(2)、罐桶關閉、(3)廢棄場址場關閉、(4)現場除污和除役、(5)土壤和地下水修復、(6)處置設施(如土地填充或近地表處置設施)的管理。

圖16. Panel: Interagency Community of Practice in Risk and Performance Assessment.

⑤Session 10-track 7-ER

Treatment of Chlorinated Solvents in Groundwater Beneath an Occupied Building at The Young - Rainey STAR Center –Joe Daniel Navarro Research and Engineering, Inc.

報告內容是指地下水中已被氯的溶劑污染，如何去處理它，依循的法規與細部注意事項等。其目標為先確定地下水污染源區的位置(以識別定位方法)，再者處理和穩定地下水污染源區(找出最合適的選擇方式)，第三確保業主和承租人共同合意的方法，最後實施行動不會影響承租人基本生活行為。監管環境以佛羅里達環境部門(FDEP)負責環境整治，許可危險和固體廢物修正案（HSWA），地下水清理是依循最嚴格的標準進行，遵循佛羅里達環境保護部門(FDEP)飲用水標準及美國環保局安全飲用水法案的最大污染物標準（MCLS）。

報告中提及如何解決的問題，承租戶活動防止表徵通過地板，關注的目標區域(首先消除已知潔淨區)，在精確目標區域參照歷史數據(地下水，土壤，次石板蒸氣sub-slab vapor)，執行高分解析表現-- 建築外周長下坡，與確定和實施周邊的處理策略。

其處理途徑中包含技術路線規劃、實用工具識別、定位和映射、站點圖紙審查、設備工程師、場址與設備工程師和工作人員、準備綜合圖紙、初步工具定位和調查、細化圖紙、注重實用所處。保留水平鑽井專家、徵求水平探鑽器、準備計畫文件、臨時修正措施計劃、國家環境政策法評估、計畫各項目評估、事前查核清單、工作安全分析、滲透許可證等。

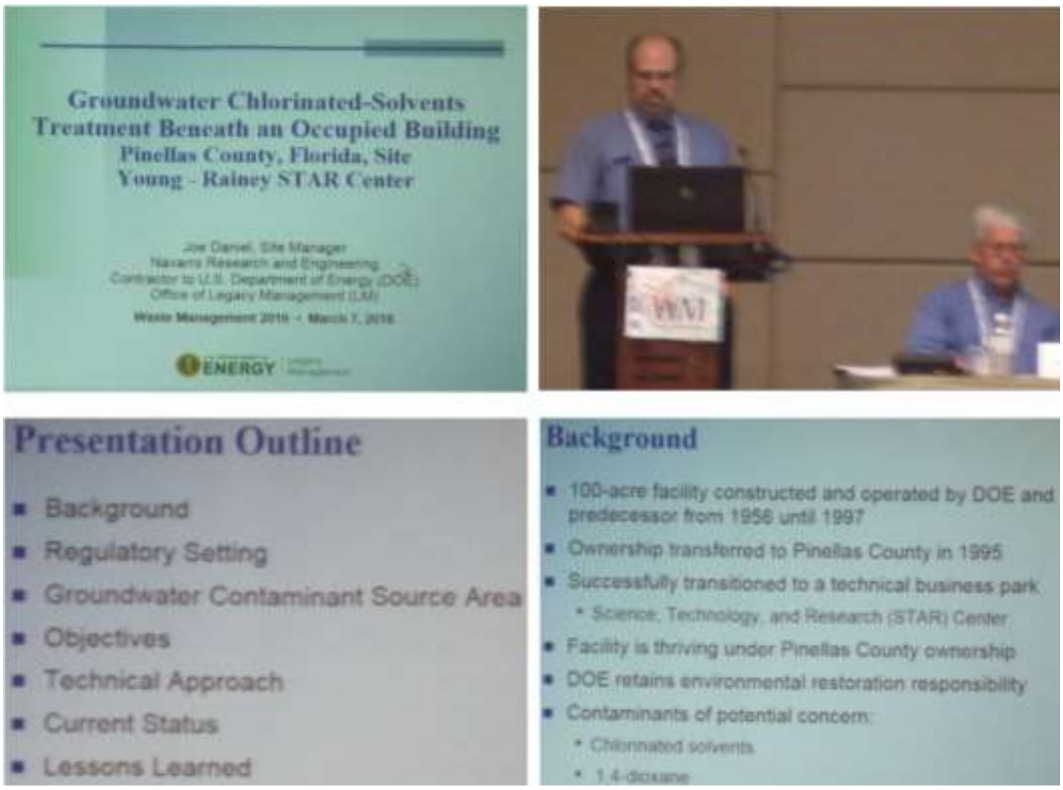


圖17.Wayne Belcher報告如何清除地下水中含有氯的溶劑研究

⑥作者胡員參加報告的小組會議(Session 26)

Development of Novel Waste Forms and Processes for Transuranic and High-Level Wastes
Session Co-Chair: Sharon Marra(SRNL), John Vienna(PNNL)

因作者下午要發表論文，大會安排與會小組主持人與報告者一同使用早餐及互相認識，會議主持人是Sharon Marra(SRNL)與John Vienna(PNNL)，及日本的Kunihiko Nakano、博士後研究生SeungMin Lee (PNNL)、Albert Kruger (US DOE)，及Sharon Robinson (ORNL)，互相討論自己所做的研究內容與自己國家的有趣事務。

(A) Development of Treatment Process for Radioactive Wastewater Generated from Molybdenum-99 Study - Chang-Liang Hu, Hsiao Hsien-Ming, Institute of Nuclear Energy Research (Taiwan)

圖 18.作者於大會報告處理核研所 Mo-99 廢液研究論文

作者胡長良先生(圖22.)於3月07日下午報告論文“Development of Treatment Process for Radioactive Wastewater Generated from Molybdenum-99 Study”，提供核研所針對鉬-99無機廢液之處理技術與操作經驗(報告投影片於附件3)，報告後被提問何謂DT30A，回答其結構如同Zolite A，考量因素是因為它價格便宜，可以在前期處理時先大量吸附放射性的核種，之後再以Cs-treat與Sr-treat放置在管柱，經管柱吸附更徹底清除廢液中的放射性核種。會議結束後，澳洲ANSTO Synroc技術長Gerry Triani特別針對Mo-99處理技術的討論，因為他們也有類似的研究在進行，回國後亦進行電郵聯絡。

(B) Technology Development in Support of Accelerating the Waste Treatment Mission – Albert Kruger, Rodrigo Rimando, US DOE.

Albert Kruger提及美國能源部應用高科技的建立與建構，以更加速提升廢棄物處理的情形及任務。

圖19. Albert Kruger高科技運用以加速廢棄物管理情形

(C) Analysis of Legacy 85Kr Waste Form Samples - Robert Jubin, Stephanie Bruffey, Oak Ridge National Laboratory

Robert Jubin(ORNL主管人員)針對過去遺留下來的產物中85Kr之廢棄物樣品分析情形與報告

圖20. Dr. Robert Jubin報告處理之前遺留設施中所含85Kr的情形

(D) Processing and Disposition of Remote-Handled Transuranic Liquid Waste Generated at Oak Ridge National Laboratory – Sharon Robinson, Robert Jubin, Lee McGetrick, Bradley Patton, Paul Taylor, Oak Ridge National Laboratory

Sharon Robinson(ORNL研究員)主要說明Oak Ridge National Laboratory針對超鈾廢液(TRU)以遠端監控的方式處理與處置的情形，主要避免操作人員受污染，本所處理Mo-99無機廢液亦以遠端監控與處理，一者可以在監控中了解其處理的反應及避免操作人員收污染。

圖21. Dr. Sharon Robinson在ORNL以遠端遙控處理TRU報告

(E) The Countermeasure for the Noble Metal in the HLW Vitrification - the Behavior of the Needle Shape Ruthenium Particle – Kunihiko Nakano, IHI Corporation (Japan)

Kunihiko Nakano(日本IHI副研究員) 針對金屬Ruthenium在高放廢棄物玻璃化的對策–以其針狀顆粒釕的行為表現情形

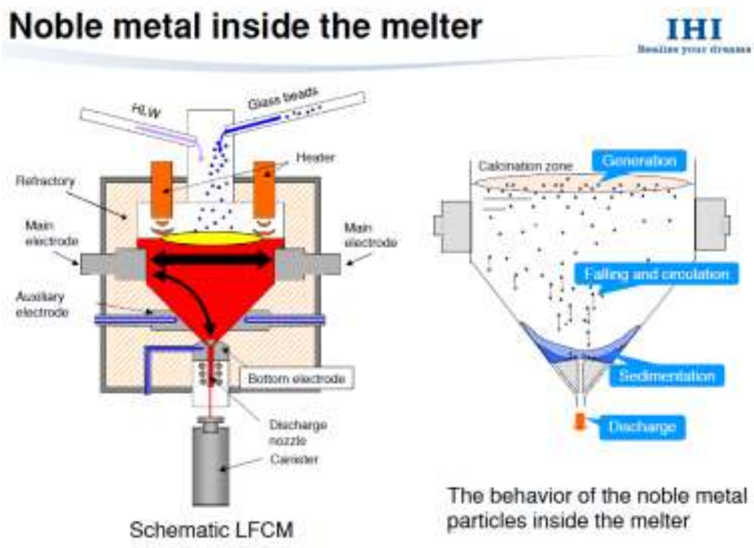


圖22. Dr. Kunihiko Nakano 報告針狀顆粒釕在高放廢棄物玻璃化的情形

因為金屬粒子的沉積過多，亦造成電極與金屬之間的沉積物而產生短路，玻璃的粘度增加許多，且金屬粒子的排出情形為熔爐操作非常重要因素。會產生了兩個主要麻煩，一者放電麻煩，另一者加熱的麻煩。金屬粒子影響玻璃的流動性，Ru是高放廢物貴金屬的主要元素。針形顆粒比的顆粒形狀更可以降低玻璃的流動性，所以研究針狀的Ru對熔爐操作的影響性。

針狀釕顆粒從硝酸亞硝酰基釕（Ⅲ）產生的，但它們不能從的RuO2形成。.針狀釕顆粒從僅玻璃珠，硝酸鈉和硝酸亞硝酰基釕（Ⅲ）形成。銠和鈀它們是金屬元素和Mo作為共存元素沒有用於針形狀的Ru微粒的生長的影響。針狀釕粒子的生成溫度為約800℃。時間影響針狀釕顆粒的產生，但冷卻速度卻不影響它們，增加硝酸亞硝酰基釕（Ⅲ）的玻璃是比加入RuO2的玻璃在流動上快速。

(5)論文海報：閱覽論文海報。

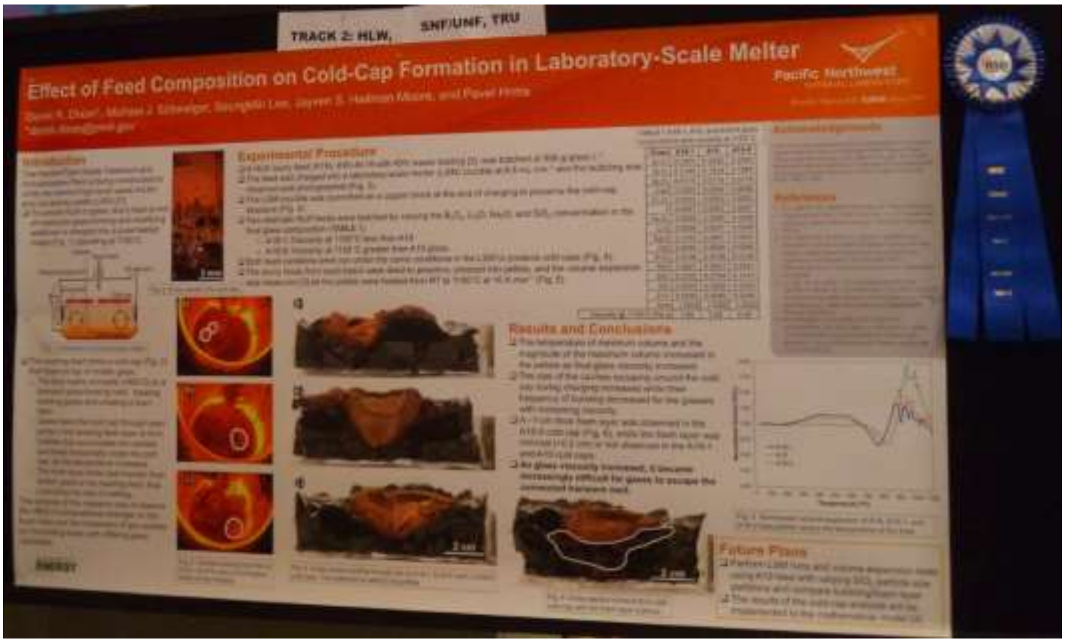


圖 23. Effect of Feed Composition on Cold-Cap Formation in Laboratory-Scale Melter

此篇論文在議題二(HLW, SNF/UNF, TRU)海報發表獲取第一名

探討高階放射性廢棄物被轉化成玻璃，在熱融機內反應進料的浮層稱為 Cold-Cap，此篇論文探討以實驗室級的熱融機內，進料的成分對冷帽形成的影響。

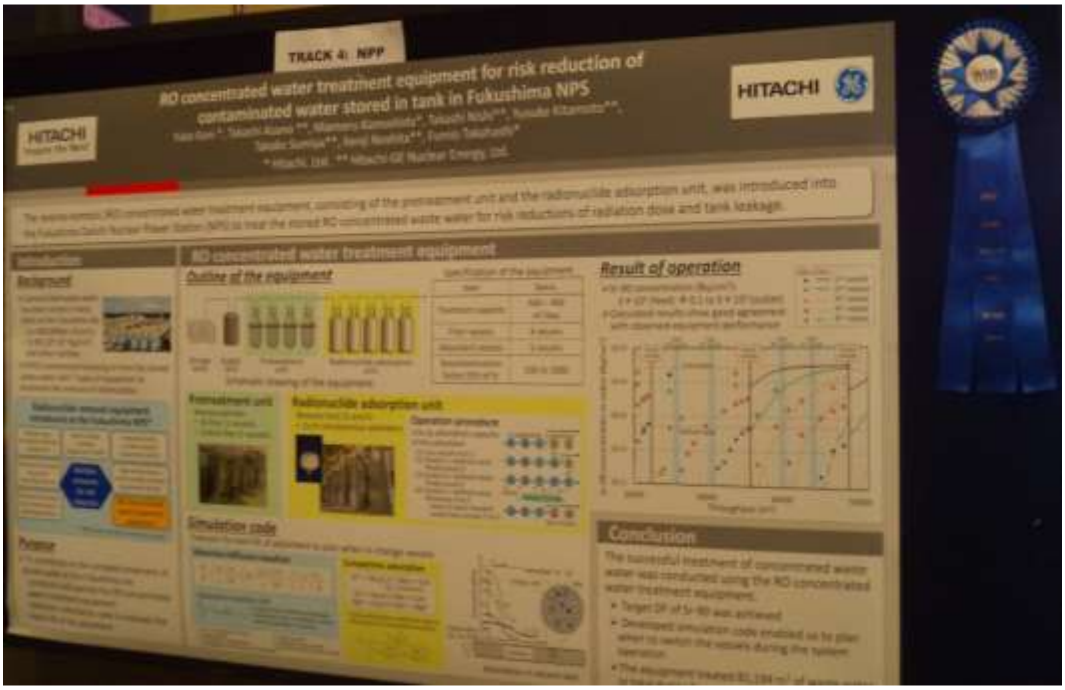


圖 24. RO concentrated water treatment equipment for risk reduction of contaminated water stored in tank in Fukushima NPS 此篇論文在議題四 NPP 海報發表獲取第一名

福島核電廠(NPS)場址中貯存許多待處理廢液，等待運用多管道除核種系統以移除核種。為了加快處理使輻射劑量降低及減少貯存桶外漏的風險，建立逆滲透（RO）廢水處理設備。該設備包含過濾器及五支吸附柱除 Cs 與 Sr 吸附劑，每天的總處理量約 500 至 900 立方米。為了評估吸附劑填充床的介質時間，其開發了一種模擬碼(simulation code)來計算每個容器出口水之 Sr 濃度，其 2015 年 1 月到 5 月已經處理量是 82194 m3，本所早期廢液處理場亦是採用此處理方式，但其考量其成本及處理量，本所現在改採先行活性碳吸附劑後再經無機吸附劑去除放射性核種。

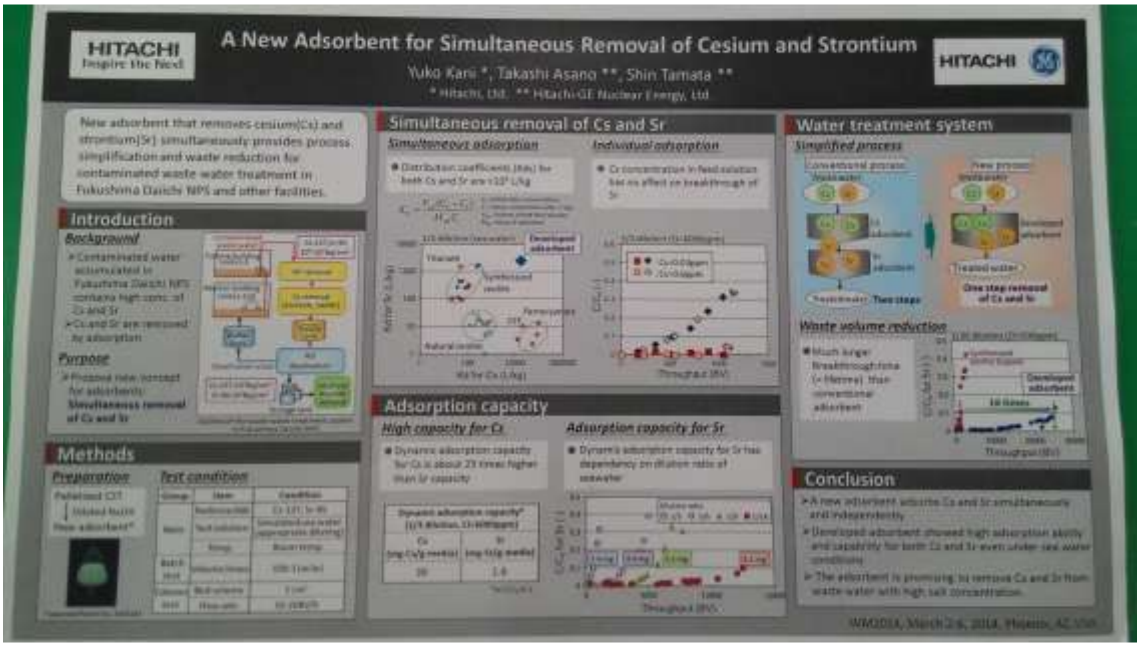


圖 25. A New Adsorbent for Simultaneous Removal of Cesium and Strontium

此篇論文開發的吸附劑主要是運用在高鹽份的廢液中，因福島核電廠當時發生氫爆時，是以海水來灌反應爐，所產生的廢液皆含高鹽份，因海水中有高濃度 Na^{+}、Mg^{2+}與 Ca^{2+}，吸附劑主要目的是吸附放射性何種 Cs^{+}與 Sr^{2+}，但亦會吸附海中 1 價與 2 價的離子，如何使其有高選擇性，是此吸附劑研發的困難點，此篇論文並未將其製作程序說明，本所同仁亦針對此關鍵點進行研究，經所使用的材料改善，使其吸附劑的選擇性提高。

(6)展示廠商 (Sponsors/Exhibitors)

作者利用空檔時間參加廠商展示區

圖 26.作者背後三大桶裝為 Waste Isolation Pilot Plant (WIPP)運送超鈾(TRU)廢料外包裝桶，其運送至 WIPP 的卡車可同時運載三大桶。

圖 27.右邊第一個是運送高階放射性廢棄物的外包裝，右邊第二個是六氟化鈾 30B 外包裝，運送六氟化鈾 30B 桶須要租借此外包裝。

圖 28.美國能源部遺留場址管理署(Office of Legacy Management)

2003 年元 12 月 15 日能源部成立遺留場址管理署(LM），致力於管理二戰和冷戰遺留下來的相關設施及場址，其包含放射性和化學廢棄物所污染的環境，在全美國約 100 多個場址，以清理所遺留下來受污染環境及已關閉之核能設施場，DOE/LM 介紹他們的任務，並確保人類健康和環境的未來保障，其目標是管理遺留下的場址，建築物及相關設施的保管，其功能是通過有效地長期監測以保護人類健康和環境，將過去經營的記錄和資料能被完整地保留與保護，以有效完成其使命，並實行讓場址原工作人員的養老金和醫療福利的政策延續，管理遺留下來設施的土地和資產，強調安全性、再利用和處置，積極聯絡和適當部門組織間協調所有政策問題。

圖 29.WCS 公司運送低放廢棄物的卡車與外包裝桶 Type B cask systems 具有 160m^3 容量

(7)參與人員交流與合影

在 WM2016 會議上，遇到幾位從台灣過去參加會議的同仁，林文聖博士任職於台大水工試驗所，擔任技士暨特約副研究員，其專業是放射性廢棄物處置、水文地質化學與土壤化學，其發表「Thermo-hydro Geochemical Evolution influence on the concrete cask in Long-term storage facility of spent fuel」針對以水熱地質化學對核一廠乾式貯存的混擬土護箱的影響評估。張仁坤先生與李柏叡先生是台電核能後端營運處最終處置組高放處置課人員，其對除役及低放射性處置場議題相關關注。朱銘博士是畢業於大陸清華大學，任職於美國能源部環境管理署辦公室之代理預算局局長，謝昀浩先生畢業於元智大學後，當完兵後就到英國 Imperial College(London)攻讀博士，從事有關處置的研究，李彥良先生是物管局的技士，吳全富博士是 ES&H Solutions 公司負責人。

圖 30.從台灣過去參加的人員與朱銘博士、吳全富博士合影，由左至右

(A)林文勝 副研究員 台大水工試驗所
(B)李彥良技士 物管局
(C)張仁坤先生 台電核能後端營運處最終處置組高放處置課
(D)朱銘博士 (代理預算局局長，美國能源部環境管理署辦公室)
(E) 吳全富博士 (ES&H Solutions 公司)
(F) 李柏叡先生 台電核能後端營運處最終處置組高放處置課
(G)作者
(H)謝昀浩先生在英國 Imperial College(London)攻讀博士

(三)拜訪 Waste Control Specialists LLC 低放處置場

核研所六氟化鈾運美安定化處理相關事宜，作者於會議後轉赴德州訪問 Waste Control Specialists LLC (以下簡稱 WCS 公司)。訪問時副總裁 Dr. Kelly D. Hunter, PE Senior Vice President 從達拉斯前來陪同，由廠長 Ms. Elicia Sanchez, Sr. VP/General Manager 陪同(圖 31 與圖 32)，WCS 公司是負責低放處置設施營運的廢棄物管理專家有限公司，主要處理聯邦與德州的低放射性廢棄物。拜訪 WCS 公司是為了詢問核研所六氟化鈾先運到 WCS 短期儲存，等美國 International Isotopes (INIS)六氧化鈾轉化廠開始營運，再送過去轉化，後運回 WCS 永久處置，Dr. Hunter 說明 WCS 目前的執照只允許接受低放廢料而不能接受鈾濃縮核物料。

圖 31. WCS 辦公室合影，由左至右 Kelly D. Hunter, Elicia Sanchez, 作者，吳全富博士

圖 32. 作者與廠長 Ms. Elicia Sanchez 合影

再來由廠長 Ms. Elicia Sanchez 親自以投影片解說低放射性放置場，並駕車親自解說與引導參觀。

Waste Control Specialists (WCS)位於德州西部安德魯(Andrews)的低放射性廢料(LLW)處置廠，擁有德州政府執照及聯邦許可接受、儲存、處理、處置美國境內各地來的低放射性廢料，已經商業營運多年，並與美國聯邦能源部環境管理署(Office of Environmental Management, EM)簽署長期合約，可接受能源部大量的低放射性廢料，包

括六氟化鈾轉化成的化性穩定的氧化鈾。WCS 擁有 14900 英畝的廠區包括 1338 英畝的放射性廢料處理/處置設施，分為四大部分(1) the Texas Compact Waste Facility, (2) the WCS Federal Waste Facility,(3) the Byproducts & Hazardous Waste Facility,及(4) Waste Treatment & Storage Facility。

此處置址特色包括：(1)地處德州偏遠且人煙稀少的西部邊陲；(2)最近的住宅約在西邊 3.5 英哩外的新墨西哥州境內；(3)場址鄰近地區缺少地表水以及適合飲用的地下水，加上土地所有權的問題，預期不會有人口成長的可能性；(4)場址平均的年降雨量約 16 英吋，遠遠低於每年超過 60 英吋的蒸發率。場址位置選在 Dockum 紅土質黏土層構成的山脊頂部，地表是單調的荒漠地形，氣候乾燥。

圖 33. WCS 低放射性廢棄物場的空照圖

圖 33.中 A 區屬德州，B 區屬新墨西哥州，A 區所挖的土壤現今都放置在 B 區內堆置成小土堆丘。其所接收主要分為兩類，一者屬於德州政府的廢棄物 CWF(Compact Waste Facility)，另一者屬於聯邦政府的廢棄物 FWF(Federal Waste Facility)。 CWF 接收 Texas Compact 的 Class A、B、C 類廢棄物，CWF 可運轉 35 年，接收 2.8 million ft^3，總活度 4.7 million curies，如果從其他州來的廢棄物，須先將帳轉為德州政府所擁有；

FWF 接收聯邦 DOE 的混合類廢棄物(Mixed Wastes) ，FWF 可運轉 35 年；接收 42 million ft^3；總活度 27 million curies。其處理過程中所產生污染的廢液，以蒸發處理方式，下層鋪上塑膠布，乾掉後再將塑膠布收集起來，紅色框位置即是水池，一者是有污染，另一者無污染。LSA pad：Low-Specific-Activity (LSA)低特定活度存儲區域，行政大樓和處理設施(Administration buildings and treatment facility)，副產物處理廠(Byproduct facility)，危險廢棄物填埋(Hazardous Waste Landfill)。

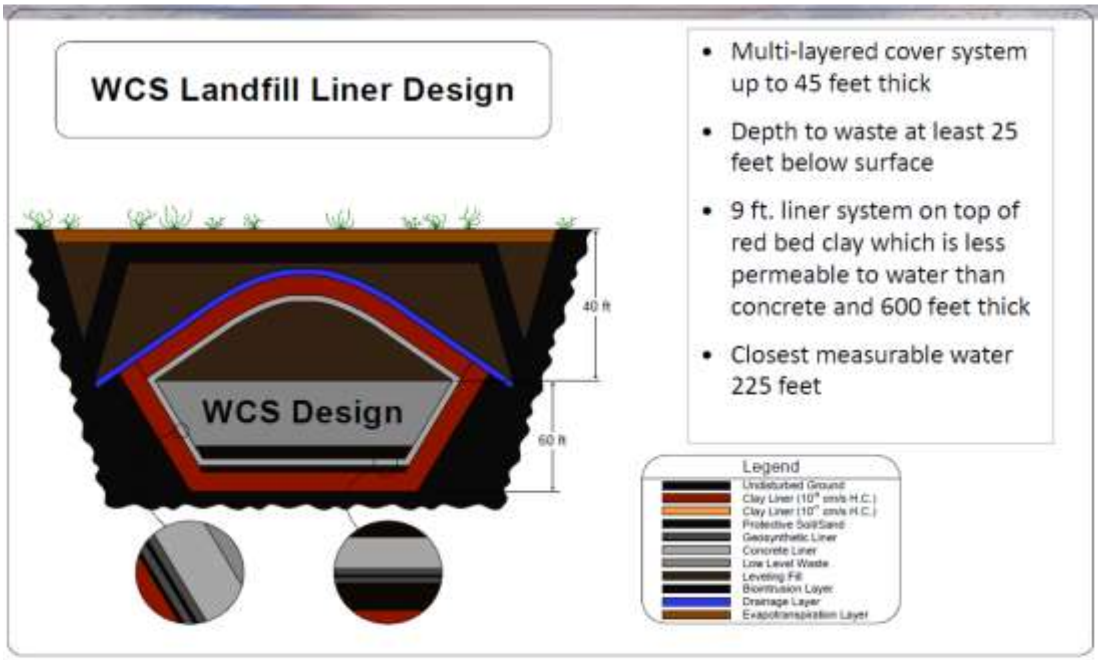


圖 34.WCS 低放射性廢棄物掩埋場的設計原理

多層覆蓋系統高達 45 英尺厚，表面到廢棄物的深度約 25 英尺，離地下可測得水層約 225 英尺。整個工程障壁設計有二個重點：一是處置設施的側向及底部與圍岩接觸面的襯砌設計；另一是廢棄物處置後，防止雨水入滲的覆蓋層設計。設施覆蓋層設施的功能主要是避免雨水入滲、防堵地下水流、減緩地表地質作用(geologic processes)或生物活動(biotic activity)導致的障壁功能退化，與一般近地表處置設施覆蓋層的功能目標大致相同。其設計主要分成三個部分：從最靠近廢棄物位置向上分別為功能障壁層(Performance Cover System) 、生物障壁層(Biobarrier Cover System)、蒸發蒸散層(Evapotranspiration Cover System)，各層設計的主要特色為，(1)功能障壁層：功能障壁

層的主要目的，就是要能符合處置設施的功能目標，是覆蓋層系統最重要的一環，其他蒸發蒸散層與生物障壁層都是為增強功能障壁層而設計。(2)生物障壁層：生物障壁層功能是防止不必要的動植物侵入，其最重要的組成是由經過篩選，直徑約在 4~12 英吋卵石所構成厚達 3 英呎的障壁，卵石間空隙回填以波特蘭水泥為主體的可控制性低強度回填材料(CLSM)。此障壁主要功能是保護設施避免受到風或水的侵蝕，以及阻擋植物根部、掘穴動物(burrowing animals)的侵入。(3)蒸發蒸散層：蒸發蒸散層的角色主要是透過植物作用，讓進入土壤空隙間的雨水蒸發或蒸散，此外，作為覆蓋層系統最上面的一層，蒸發蒸散層還要能夠維持場址長時期穩定性。其設計是利用植物生長蒸散土壤內多餘水分，同時利用植被維持場址長時期穩定性，依據 WCS 研究分析，位在半乾燥氣候環境的場址，使用蒸發蒸散層最為有利，要讓蒸發蒸散層發揮預期作用，地表植物的栽植是重要一環，植物生長需要水與肥料等，但由於場址的乾燥氣候很難維持植物正常生長，因此在蒸發蒸散層表面以平均直徑約 0.25 英吋的卵石鋪設一層厚 1 英吋的覆蓋層，在人工植被發芽初期的季節，此覆蓋層可以降低水分喪失、抵抗風與土壤侵蝕、避免植物種子遺失。從圖 36 至圖 38，掩埋場開挖後再經鋪設防水層及鋼筋混泥土層，廢棄物至廠內會先於處理廠整理後再裝入模塊化混凝土罐內 Modular Concrete Canister (MCC)，再依序擺入掩埋場後覆蓋沙土。

圖 35.WCS 掩埋場事前準備工作，圖右綠色為鋪上的鋼筋材質

圖 36.MCC 模塊化混凝土罐內部先裝入 55 加侖桶後再以水泥封裝

圖 37.從 LANL 國家實驗室來的大型廢棄物放置在水泥外套內，後再加入水泥後處置；MCC 桶依循擺放於底層後再覆蓋沙土。

(四) 拜訪 URENCO 鈾濃縮公司

URENCO 鈾濃縮公司其經營範圍主要是提供核燃料供應鏈之鈾濃縮服務，以採用世界領先的離心分離技術進行鈾濃縮，為核電事業提供燃料，URENCO 公司分別在英國、德國、荷蘭與美國皆有設置工廠。美國 URENCO 鈾濃縮廠是位於新墨西哥州東南部 Eunice 六氟化鈾濃縮廠，其總公司在華盛頓特區，擁有美國 NRC 執照，已經商業運轉多年。

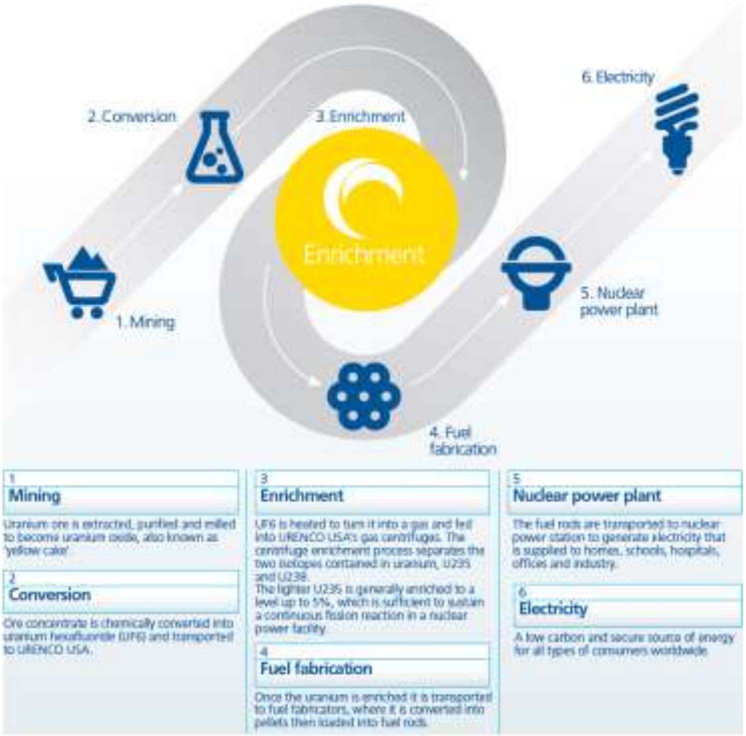


圖 38.核燃料供應鏈

圖 38.為核燃料供應鏈，分成四個主要流程：開採(mining)、轉換(conversion)、濃縮(enrichment)和製造(fabrication)。URENCO 鈾濃縮公司主要負責六氟化鈾(UF_6)以離心技術將鈾 238 與鈾 235 分離與濃縮後，再運送至燃料製造公司(fuel fabrication)，剩下的乏鈾填裝於 48Y 桶貯存於廠區(需取得貯存執照)，其程序如圖 39。

Heating to vaporize UF6

UF6 is a solid at room temperature. Once in the enrichment facility, the transport cylinder holding UF6 is connected to the facility's feed system. It is then heated up to approximately 136F, in order to vaporize the UF6 and turn it into gas at sub-atmospheric pressure.

Uranium is delivered to us in secure, internationally standardized transport cylinders by approved suppliers. Our suppliers are audited on a regular basis to ensure standards are maintained and new, improved processes applied.

Separation of uranium isotopes

Gaseous UF6 is fed into a centrifuge containing a cylindrical rotor. This spins at high speed, separating uranium's two isotopes. The heavier isotope, U238, is forced closer to the wall of the rotor than the lighter U235, making the gas closer to the wall depleted in U235. The gas nearer the rotor axis becomes slightly enriched in U235. To achieve the desired levels of enrichment, the process is repeated over and over again in a series of centrifuges operating in parallel, known as a 'cascade'.

Enriched uranium is compressed and cooled

Enriched uranium (UF6 containing up to 5% of the U235 isotope) is fed from centrifuge cascades into a compressor before entering a cooling box. During the cooling process the UF6 vapor solidifies in the cylinder. The cylinders are homogenized and sampled to check the enrichment level before leaving our facility.

All cylinders are accurately weighed and analyzed to comply with the requirements of the US Department of Transportation and the International Atomic Energy Agency (IAEA). All UF6 shipments from our facility are made in approved cylinders which are transported in a licensed protective casing which meets international standards.

Depleted uranium is stored

The uranium gas closer to the wall in the centrifuge is depleted in U235 and this depleted UF6 is collected and cooled in sub-atmospheric cylinders and weighed to ensure all material can be accounted for. Depleted UF6 still contains 30-50% of the natural U235 concentration and has the potential for re-enrichment.

The cylinders containing the depleted UF6 are stored at our facility in internationally approved cylinders pending future re-enrichment or conversion to a more chemically stable form for long-term storage or disposal e.g. U308.

圖 39.URENCO 公司鈾濃縮處理程序

作者拜訪 URENCO 公司(圖 40)與美國地區執行長 Ms. Melissa Mann 及 Mr. Clint Williamson (公關部副執行長)，說明核研所貯存六氟化鈾事宜，將之前與國務院、能源部接洽情形向他們說明與討論，會後執行長 Ms. Mann 表示其可以接受 30B 與 48 桶，迄今持續與執行長 Ms. Mann 連繫並提供本所相關現貯存桶的檢驗及現況，以利其接收前所需的檢查。

圖 40.　拜訪 URENCO 公司，作者於公司前留影

本次公差遇到邱鴻誠(Hung-Cheng Chiou)博士(圖 41)其為化學博士，也是保健物理的專家，現派駐在 WIPP 的 DOE/EM 官員，負責 WIPP 輻射防護的工作，與邱博士見面時贈送作者 WIPP 在建造挖掘時所得之岩石(圖 42)以作為紀念，邱博士是核研所前魏副所長元勳的女婿，回來後與邱博士聯繫，提供相關 WIPP 資料 (http://www.wipp.energy.gov/wipprecovery/recovery.html) 此網頁裡面有許多 WIPP 每日更新的資料可供參考，未來作者會再繼續與邱博士聯繫，希望邱博士能提供本所相關重要的技術與資訊，以作為與美方之間重要的橋樑。

圖 41. 邱鴻誠博士

圖 42. WIPP 岩石

三、心得

(一)「國際放射性廢棄物管理研討會(WM symposium)」是世界各核能工業相關國家之工程技術研發應用於放射性廢棄物處理及處置等技術交流的國際研討會，是一個官、商、研交流的平台、其中能源部相關人等參與甚多。本次國內參加單位物管局、台灣電力公司及核研所，會場中更是核能機構藉機推銷本身技術的最佳場所，藉發表相關研究論文與探討放射性廢棄物處理新技術，彼此之經驗得以直接溝通與交流。

(二)因六氟化鈾相關事宜任務，到德州WCS公司拜訪與參觀，副執行長Dr. Kelly D. Hunter事前熱心地協助安排及廠長Ms. Elicia Sanchez用心解說與帶導，也說明WCS主要是處理低放射性廢棄物的處置場。

(三)拜訪新墨西哥州URENCO公司，與美國地區負責人Ms. Melissa Mann及公關部副執行長Mr. Clint Williamson洽談核研所六氟化鈾事宜，會後執行長Ms. Mann表示其可以接受30B與48桶，迄今持續與執行長Ms. Mann連繫並提供本所相關現貯存桶的檢驗及現況，以利其接收前所需的檢查。

(四)核能廢棄物處理技術發展腳步不斷邁進，未來我國核一廠與核二廠相繼面臨除役，其相關及周邊處理技術與處置事宜，須與時並進及與國際接軌，透過國際間的交流研討及刺激，更能促進本所年輕研發人力具有國際觀之培養。

四、建議事項

(一)「國際放射性廢棄物管理研討會(WM symposium)」是促進世界各國之核能合作與技術交流的重要管道，與會專家學者涵蓋有關核能中不同的研究領域，均能提出豐碩的研究成果，且是技術推銷的大好時機。透過參與相關之國際研討會議，可以吸取國外最新之經驗與資訊，有助於解決各項研究發展計畫上所遭遇的實際問題。此研討會又有吳全富博士在其中為籌備委員之一，更能藉由其穿針引線使我們受益良多，建議本所同仁把握機會參與此研討會。鼓勵本所同仁參與各項國際學術研討會並發表所內最新成果來提升我國的學術地位，增進本所的國際聲譽。

(二)此次大會特別提供了在學學生獎學金能夠一起來參與，由Roy G. Post Foundation提供交通費、報名費、住宿費與生活費，讓5個國家與22位研究生，來參與此次會議並報告其研究成果，建議我國的學術研究單位能夠鼓勵研究生積極爭取這難得的機會，以開拓國際研究的視野與能見度。

(三)本次公差認識派駐在WIPP廠的DOE/EM官員邱鴻誠博士，作者持續與其聯繫，若邱博士回國時，建議邀請邱博士來本所參訪與演講，希望邱博士能提供本所相關重要的技術與資訊，以作為與美方之間重要的橋樑。

五、附件 會議議程、各組會議名稱與作者發表資料

附件1. 會議議程

WM2016 SCHEDULE OF EVENTS

All sessions will take place at the Phoenix Convention Center (PCC) West Building unless noted otherwise.
**All buses for off-site events & tours will load from the Hyatt Regency Phoenix Monroe Street exit.

SATURDAY, MARCH 5, 2016

0700 – 2000 - Guest/Attendee Tour: Grand Canyon Tour** – Buses load at 0645
1100 – 1700 - Registration Open – Lower Level, Exhibit Hall 4
1100 – 1700 - Satellite Registration Desk Open – Marriott Renaissance Lobby
1100 – 1900 - Satellite Registration Desk Open - Hyatt Regency Lobby
1630 – 1800 - Track Co-Chair Meeting – Hyatt Regency AB
1800 – 2130 - PAC Meeting and Dinner – Hyatt Regency CD

SUNDAY, MARCH 6, 2016

0800 – 2000 - Registration Open – Lower Level, Exhibit Hall 4
0800 – 1500 - WMS Board of Directors Meeting – Hyatt Regency
0800 – 1700 - Workshop - "US EPA Superfund Radiation Risk Assessment Calculator Training"* - Level One, 106B
0800 – 1630 - Roy G. Post Foundation Benefit Golf Tournament* – The Legacy Golf Club
0900 – 1700 - Satellite Registration Desk Open - Marriott Renaissance Lobby
0900 – 1700 - Satellite Registration Desk Open - Hyatt Regency Lobby
1000 – 1400 - Guest/Attendee Tour: Desert Hike Tour** – Buses load at 0945
1100 – 1700 - Workshop – "Critical Decisions (and Tools) for First-Time and Experienced Managers"* Level One, 106C
1500 – 1600 - First Time Attendee/PAC Orientation – Level One, 101B
1600 – 1645 - IPAC Meeting – Level One, 102A
1600 – 1645 - Technical Student Assistant Training – Level One, 101C
1700 – 2000 - Welcome Reception & Show Floor Open – Lower Level, Exhibit Hall 4

MONDAY, MARCH 7, 2016

0700 – 0800 - Presenter's Breakfast – Level Three, 301A
0700 – 1800 - Registration Open – Lower Level, Exhibit Hall 4
0730 – 1100 - ASME Radwaste System Committee Meeting – Hyatt Regency Phoenix, Cowboy Artist's Room
0800 – 0945 - Opening Plenary Session – Level Three, 301CD
0930 – 1830 - Show Floor Open – Lower Level, Exhibit Hall 4
0945 – 1030 - Refreshment Break - Lower Level, Show Floor, Exhibit Hall 4
1000 – 1700 - Technical Sessions – Level One & Show Floor, Exhibit Hall 4
1045 – 1115 - Demonstration in Demo Zone - Lower Level, Show Floor, Exhibit Hall 4
1200 – 1315 - Keynote Luncheon – Level Three, 301CD
1330 – 1400 - Demonstration in Demo Zone - Lower Level, Show Floor, Exhibit Hall 4
1330 – 1700 - Student Poster Competition – Lower Level, Show Floor, Exhibit Hall 4
1415 – 1445 - Demonstration in Demo Zone - Lower Level, Show Floor, Exhibit Hall 4
1445 – 1530 - Refreshment Break - Lower Level, Show Floor, Exhibit Hall 4
1700 – 1830 - WMS Networking Reception – Lower Level, Show Floor, Exhibit Hall 4
1800 – 1930 - Students & Young Professionals Networking Reception – Lower Level, Show Floor, Exhibit Hall 4 (Near Student Poster Session)

TUESDAY, MARCH 8, 2016

0700 – 0800 - Presenter's Breakfast – Level Three, 301A
0700 – 1800 - Registration Open – Lower Level, Exhibit Hall 4
0830 – 1700 - Technical Sessions – Level One & Show Floor, Exhibit Hall 4
0930 – 1830 - Show Floor Open – Lower Level, Exhibit Hall 4
0945 – 1030 - Refreshment Break - Lower Level, Show Floor, Exhibit Hall 4
1045 – 1115 - Demonstration in Demo Zone - Lower Level, Show Floor, Exhibit Hall 4
1200 – 1315 - Honors & Awards Luncheon – Level Three, 301CD
1415 – 1445 - Demonstration in Demo Zone - Lower Level, Show Floor, Exhibit Hall 4
1445 – 1530 - Refreshment Break - Lower Level, Show Floor, Exhibit Hall 4
1700 – 1830 - WMS Evening Reception – Lower Level, Exhibit Hall 4
1800 – 2000 - Women of Waste Management (WoWM) Panel & Networking Reception – Level Two, 212ABC

WM2016 SCHEDULE OF EVENTS

All sessions will take place at the Phoenix Convention Center (PCC) West Building unless noted otherwise.
**All buses for off-site events & tours will load from the Hyatt Regency Phoenix Monroe Street exit.

WEDNESDAY, MARCH 9, 2016

0700 – 0800 - Presenter's Breakfast – Level Three, 301A
0700 – 1800 - Registration Open – Lower Level, Exhibit Hall 4
0830 – 1700 - Technical Sessions – Level One & Show Floor, Exhibit Hall 4
0930 – 1330 - Show Floor Open – Lower Level, Exhibit Hall 4
0945 – 1030 - Refreshment Break - Lower Level, Show Floor, Exhibit Hall 4
1445 – 1530 - Refreshment Break - Level One, Foyer
1800 – 2100 - Phoenix Art Museum Networking Reception & Dinner** – Buses load at 1745

THURSDAY, MARCH 10, 2016

0700 – 0800 - Presenter's Breakfast – Level Three, 301A
0700 – 0815 - PAC Meeting - Part 1 - Level Three, 301A
0700 – 1700 - Registration Open – Level One, 101A
0800 – 0845 - Refreshment Break - Level One, Foyer
0830 – 1700 - Technical Sessions – Level One
1200 – 1315 - Thursday Luncheon – Level Three, 301A
1200 – 1315 - PAC Meeting - Part 2 - Level Three, 301A
1330 – 1700 - Topical Session - International Nuclear Plant Decommissioning: Time for Awareness and Planning – Level One, 102BC
1445 – 1530 - Refreshment Break - Level One, Foyer
1700 – 1800 - Closing Reception – Level One Foyer
1800 – 1930 - Optional PAC Meeting - Part 3 – Hyatt Regency, Curtis AB

***Separate Registration Fees Apply; Schedule Subject to Change**

附件2. 各組會議名稱

#	**Technical Program - Schedule at a Glance -** **Annotated Session Titles** *(for full session titles, please see individual listing)*	Time	Room	1: Policies/Programs	2: HLW/SNF/TRU	3: L/ILW, NORM	4: Nuclear Power Pl.	5: Packag./Trans.	6: D&D	7: Environ. Rem.	8: Commun., E & T	9: Special Topics	United Kingdom	D&D of NPP
	Monday Morning, March 7		**The 9 WM Tracks for Subject Reference**											
1	Waste Management Symposium 2016 Plenary Session	8:00	301CD	X										
2	Panel: Hot Topics in US DOE Environmental Management	10:00	102BC	X										
3	Panel: Featured Country - United Kingdom	10:00	105AB	X									X	
4	Panel: LANL Recovery - Re-Treatment of Problem TRU Waste Stream	10:00	103AB		X									
5	HLW, SNF/UNF and Long-lived Alpha/TRU Programs and Policies	10:00	101B		X									
6	Structural Integrity and Wear in Nuclear Process Equipment	10:00	101C		X									
7	Panel: Managing Safety Culture During Transitions	10:00	104AB									X		
8	Assessments of Disposal Systems, Facilities and Sites for LLW/ILW	10:00	102A			X								
9	Tools for Packaging and Transportation Policies	10:00	106A					X						
10	Groundwater Remediation Projects, Worldwide Experiences	10:00	106B							X				
11	Environmental Remediation in Urban and Suburban Environments	10:00	106C							X				
12	The Effectiveness of Advisory Boards; the US DOE EM Site Specific Experience	10:00	105C								X			
	Monday Afternoon, March 7													
13	Panel: Featured Country: United Kingdom	13:30	105AB	X									X	
14	Panel: Featured Country: United Kingdom	15:15	105AB	X									X	
15	Panel: US DOE WIPP: Lessons Learned and Return to Operations	13:30	102BC		X									
16	Panel: Hot Topics in US Commercial LLW Management	13:30	103AB			X								
17	Selected Key Topics in US Commercial LLW Management	15:15	106A			X								
18	Development and Use of Gamma and Neutron Waste Characterization Methods	13:30	102A			X								
19	US DOE EM Risk-Informed Performance Based Decision Making	13:30	104AB							X				
20	Panel: Implementing Technically-Based Cleanup; Balancing Regulatory & Fiscal	15:15	104AB							X				
21	Panel: Interim Storage of Used Nuclear Fuel in the US – What are the Options?	13:30	Ex Hall		X									
22	Panel: US DOE - Excess Facilities D&D Implementation Plans	15:15	Ex Hall	X										
23	Experience in Salt Waste Processing, Worldwide Examples	13:30	106A		X									
24	Panel/Papers: Getting a Handle on D&D Costs - a Global Perspective	15:15	103AB						X					X
25	Application of Innovative D&D Technologies - Part 1 of 2 – Global Experience	13:30	106B						X					
26	Development of Novel Waste Forms and Processes for TRU and HLW	13:30	105C		X									
27	ER Post Closure Challenges and Long Term Stewardship/Legacy Management	13:30	101C							X				
28	Innovations and Performance Solutions in Workplace Management	13:30	106C								X			
29	Developments in Deep Borehole Disposal Around the World	13:30	101B									X		
30	Posters: HLW, SNF/UNF and Long-Lived Alpha/TRU Waste	13:30	1-Foyer		X									
31	Student Posters: The Next Generation - Industry Leaders of Tomorrow	13:30	Ex Hall	X										
	Tuesday Morning, March 8													
32	Panel: US DOE Featured Site: Oak Ridge - Partnering for Success – Part 1 of 4	08:30	102BC	X										
33	Panel: US DOE Site: Oak Ridge - Responding to Current Challenges – Part 2 of 4	10:15	102BC	X										
34	Panel: UK NDA – US DOE Perspective on Contracting Approaches	10:15	Ex Hall	X									X	
35	Panel: DOE Hanford - Direct Feed Low Activity Waste - Update - Part 1 of 4	08:30	105AB		X									
36	DOE Hanford - Direct Feed Low Activity Waste - Program Overview - Part 2 of 4	10:15	106C		X									
37	Worldwide Regulatory and Oversight for Waste Management and Disposal	08:30	106C	X										
38	Panel: Emerging Issues that Challenge Contractors at Federal Sites Worldwide	10:15	105AB	X										
39	Panel: Consent Based Siting–Opportunities and Challenges for Disposal Facilities	08:30	104AB		X									
40	Storage and Retrieval of Spent/Used Nuclear Fuel - Part 1 of 2	08:30	105C		X									
41	Storage and Retrieval of TRU	10:15	106A		X									
42	Panel: Graduates: Wants and Needs – Does it Differ Between Countries?	08:30	103AB								X		X	
43	Panel: Young Professionals in Nuclear Science and Engineering	10:15	103AB								X		X	
44	Assessments of Performance of Disposal Systems, Facilities & Sites for LLW/ILW	08:30	102A			X								
45	Perspectives on Management of Nuclear Power Plant Liquid and Wet Waste	08:30	106B				X							
46	D&D of Nuclear and Non-Power Generating Facilities Both Large and Small	08:30	101C						X					
47	Technical Innovations in Environmental Remediation and Site Closure	08:30	101B							X				
48	Experience with ER Challenges – Alternative Approaches to Achieving End State	10:15	101B							X				
49	A Global Perspective on Advances in Nuclear Safety Management	08:30	106A									X		
50	Posters: L/ILW	08:30	1-Foyer			X								
51	Posters: Nuclear Power Plant (NPP) Waste Management	08:30	1-Foyer				X							

#	**Technical Program - Schedule at a Glance -** **Annotated Session Titles** *(for full session titles, please see individual listing)*	Time	Room	1: Policies/Programs	2: HLW/SNF/TRU	3: L/ILW, NORM	4: Nuclear Power Pl.	5: Packag./Trans.	6: D&D	7: Environ. Rem.	8: Commun., E & T	9: Special Topics	United Kingdom	D&D of NPP
	Tuesday Afternoon, March 8													
52	Panel: US DOE Site: Oak Ridge- Improving Performance in the Field-Part 3 of 4	13:30	102BC	X										
53	Panel: US DOE Site: Oak Ridge-Transitioning from Cleanup to Reuse-Part 4 of 4	15:15	102BC	X										
54	Panel: UK/USA /Canada Partnering - Accomplishments and Lessons Learned	13:30	105AB	X									X	
55	Panel: Small Business Contracting Opportunities with DOE & Prime Contractors	13:30	Ex Hall	X										
56	Panel: Addressing the Small Business Barriers in Contracting with the US DOE	15:15	Ex Hall	X										
57	Worldwide Perspectives of Radioactive WM - Challenges and Solutions	13:30	102A	X										
58	Panel: Progress on Deep Repository Programmes Around the World	13:30	103AB		X									
59	Global Advances in HLW Retrieval Equipment	15:15	105C		X									
60	DOE Hanford - Direct Feed Low Activity Waste - Program Execution-Part 3 of 4	13:30	106C		X									
61	DOE Hanford - Direct Feed Low Activity Waste-Technology Maturation-Part 4 of 4	15:15	106C		X									
62	Panel: US Nuclear Power Plant Waste Management - US LLW Disposal Issues	13:30	104AB				X							
63	Panel: Nuclear Power Plant Waste Management - LLW Processor Issues	15:15	104AB				X							
64	Type B Cask Packaging Design	13:30	105C					X						
65	Panel: Worldwide Challenges in Radioactive Material Packaging	15:15	103AB					X						
66	Operating Experience in the Treatment and Storage of LLW/ILW	13:30	101B			X								
67	D&D of US DOE Facilities	13:30	101C						X					
68	Communication of Technical Issues; Worldwide Experiences	13:30	106B								X			
69	Decision Making Tools & Frameworks for ER that Enhance Communication	15:15	106B								X			
70	Integrated Performance & Risk Assessments, Decision Analyses & Risk Mgmt	13:30	106A									X		
71	Posters: Environmental Remediation	13:30	1-Foyer							X				
72	Posters : Communications, Involvement, Education and Training	13:30	1-Foyer								X			
	Wednesday Morning, March 9													
73	Panel: Cleanup of Fukushima NPP – D&D and Waste Management - Part 1 of 2	08:30	102BC	X										X
74	Panel: WM from Remediation of Legacy Sites or Unplanned Releases	08:30	105AB	X										
75	Panel: Problematic US DOE Mixed Waste Streams & Policy Changes	08:30	103AB			X								
76	Panel: Industry and Public Feedback Site-Specific PA - US NRC Rulemaking	10:15	103AB			X								
77	Global Use of Cementitious Waste Forms for LLW/ILW	08:30	102A			X								
78	Panel: US DOE Procurement and Contracting Opportunities	10:15	Ex Hall	X										
79	Panel: UK Featured Site - Sellafield Legacy Ponds and Silos	08:30	104AB	X									X	
80	Lessons Learned from the Safety Pause of Operations at SRNS, September 2015	10:15	104AB	X										
81	International Experience in Complex Site Characterization and ER Technologies	08:30	105C							X				
82	FUSRAP and US Army Corp of Engineers Projects	08:30	106A							X				
83	Records, Knowledge and Memory (RK&M) Nuclear Waste Geologic Repositories	08:30	106B								X			
84	Plans For and Experience in Transitioning to Decommissioning, World Examples	08:30	106C						X					X
85	Geologic Disposal of HLW, SNF/UNF and Long-lived Alpha/TRU - Status & Plans	08:30	101C	X										
86	Experience in Waste Treatment & Process Updates, an International Perspective	08:30	101B	X										
87	Posters: D&D	08:30	1-Foyer						X					X
88	Posters: Packaging and Transportation	08:30	1-Foyer					X						
89	Posters: Special Topics and Track Crosscutting Technology Topics	08:30	1-Foyer	X								X		
	Wednesday Afternoon, March 9													
90	Panel: US DOE Featured Site: Sandia National Laboratories	13:30	105AB	X										
91	Panel: Cleanup of Fukushima -Offsite Cleanup and Int'l Collaboration -Part 2 of 2	13:30	102BC	X										X
92	ESPRC DISTINCTIVE Research Programme	13:30	106C	X									X	
93	Panel: ER Projects in Eastern Europe & Central Asia, IAEA TC Project RER 9121	13:30	104AB							X				
94	Panel: Challenges in US DOE HLW Tank Management	13:30	103AB		X									
95	Novel Inspection – Tools and Equipment to Support Tank Storage	15:15	102A		X									
96	Technical Advancements in HLW/SNF Disposal - Part 1 of 2	13:30	101C		X									
97	Storage and Retrieval of Spent/Used Nuclear Fuel - Part 2 of 2	13:30	101B		X									
98	Advances Around the World in the Management of NPP Dry Waste	15:15	101B				X							
99	Regulatory and Programmatic Issues and Solutions for LLW/ILW	13:30	106B			X								
100	Packaging and Transportation of Radioactive & Hazardous Materials and Wastes	13:30	106A					X						
101	D&D of Nuclear Power Plants - Part 1 of 2	13:30	105C						X					X
102	Experience in Waste Optimization/Minimization and Harmonization During D&D	15:15	105C						X					X
103	International Experience in Community Involvement and Education Initiates	13:30	102A								X			
104	Panel: Approaches to Risk-Informed Regulations for Radwaste Management	15:15	103AB								X			
105	Non-Paper Posters: Emerging Issues and Late Abstracts	13:30	1-Foyer	X										

#	**Technical Program** **- Schedule at a Glance -** **Annotated Session Titles** *(for full session titles, please see individual listing)*	Time	Room	1: Policies/Programs	2: HLW/SNF/TRU	3: LL/ILW, NORM	4: Nuclear Power Pl.	5: Packag./Trans.	6: D&D	7: Environ. Rem.	8: Commun., E & T	9: Special Topics	United Kingdom	D&D of NPP
	Thursday Morning, March 10													
106	Panel: Transition to GoCO at Canadian Nuclear Laboratories	08:30	102BC	X										
107	Panel: Emerging Middle East Nuclear States' Status and Plans - WITHDRAWN													
108	Panel: International Collaboration for Safe WM and D&D- WITHDRAWN													
108A	Application of Innovative D&D Technologies - Part 2 of 2 (Merged with 129)	13:30	103AB						X					
109	Panel: US DOE Lexington, KY Office (Portsmouth & Paducah Sites)	10:15	103AB	X										
110	Roundtable: WM Energy Facilities Contractor Operating Group (EFCOG)	08:30	105C			X								
111	Approaches to Fast Track Technology Development and Demonstration	08:30	106A						X					
112	Panel: The Richland Operations Office Cleanup Mission - Beyond the 2015 Vision	08:30	105AB	X						X				
113	Experience of Records, Knowledge and Memory for Waste Geologic Repositories	10:15	104AB								X			
114	Investigations of Problematic Wastes and New Candidates for Immobilization	08:30	106B		X									
115	Issues in Tank Chemistry, Are There Worldwide Similarities?	10:15	106B		X								X	
116	Advances in Nuclear Facility Operation and Optimization	08:30	106C		X									
117	Future Alternate Fuel Cycle HLW Management, Worldwide Experiences	10:15	106C		X									
118	D&D of Nuclear Power Plants - Part 2 of 2	08:30	101B						X					X
119	Sustainable Remediation Processes - Global Insights or Applications	08:30	102A							X				
120	Panel: Interagency Community of Practice in Risk and Performance Assessment.	08:30	104AB									X		
121	Global Insights into Disposal Site Selection	10:15	106A	X										
122	Experience with Waste Certification, Acceptance and Disposal for LLW/ILW	08:30	101C			X								
	Thursday Afternoon, March 10													
123	Topical Session - International NPP D&D: Time for Awareness and Planning	13:30	102BC						X					X
124	Integration of Human Development with Modeling for Disposal or ER Decisions	13:30	105AB								X			
125	Panel: Lessons Learned from Yucca Mountain License Application Process	13:30	103AB		X									
126	Experience with Closure & Monitoring of HLW, SNF/UNF & Alpha/TRU Facilities	13:30	102A		X									
127	Technical Advancements in HLW/SNF Disposal - Part 2 of 2	15:15	102A		X									
128	Radioactive Material Packaging and Transportation Regulatory Issues	13:30	101C					X						
129	Merged with Session 108A													
130	Innovative Field Monitoring for Environmental Remediation	13:30	106A							X				
131	ER Progress towards Closure of Contaminated Sites Around the World	13:30	106B							X				
132	Global Management of Used Radioactive Sealed Sources & Orphan Materials	13:30	106C									X		
133	Social Sciences as a Resource for Improving Public Involvement - WITHDRAWN													
134	Emerging Treatment Technologies for LLW/ILW	13:30	101B			X								
135	Panel: Russian Technologies Update -WITHDRAWN													

附件3. 作者發表論文資料

Development of Treatment Process for Radioactive Wastewater Generated from Molybdenum-99 Study

Authors: ***Chang-Liang Hu***, Hsien-Ming Hsiao

Waste Management Symposia 2016, Phoenix, *AZ*
Date: 2015.03.07

Institute of Nuclear Energy Research

INER

Outline

- Introduction
- Treatment procedures
- Results & Lesson-learned
- Conclusions

INER 1

Introduction

- Radiopharmaceutical:Tc-99m
  decay chain: Mo-99 (66h)→ Tc-99m (6h)→Tc-99 (211,000 y)
- Application:Mo-99/Tc-99m generators
- Production of Mo-99 isotope at INER **in 1986-88**
  - Neutron activation of natural UO_2:
    fission product U-235/Mo-99 dissolved in 10N HNO_3
  - Separation of Mo-99 and U-235:
    extract Mo-99 from nitric acid 5% D_2EHPA/Kerosene, followed by 2% H_2O_2 in 0.1N HNO_3 solution extracting Mo-99 to inorganic phase
  - Mo-99 purified

INER 2

Introduction

- Radioactivity analysis

Nuclides	Co-60	Cs-137	Sr-90	Gross α	Gross β
Radioactivity (Bq/ml) (in 1994)	20.4~318	2E+4~2E+5	<LLD~9E+5	1E+1~2E+3	5E+4~1E+6
Radioactivity (Bq/ml) (in 2006)	<LLD	2E+4~1.5E+5	<LLD~7E+4	1E+1~1.3E+3	5E+3~3E+5

- Urgency for Treatment
  - ✓ pressure of storage tanks is as high as 5 kg/cm^2
  - ✓ containers corroded
  - ✓ high concentrated nitric acid

INER 3

Introduction

-Specifications of storage tanks for Mo-99 waste solution

(a) lead-shielded storage tank

(b) heavy sand-shielded storage tank

Waste solution	Capacity (liter)	Storage volume (liter)	Shielding & Thickness(cm)	Dimension (cm)	Dose rate µSv/h/ml
Raffinate	18	11	Lead, 16t	62Φ×120	15
Washing	50	33	Concrete, 12.5t	94Φ×120	10

INER 4

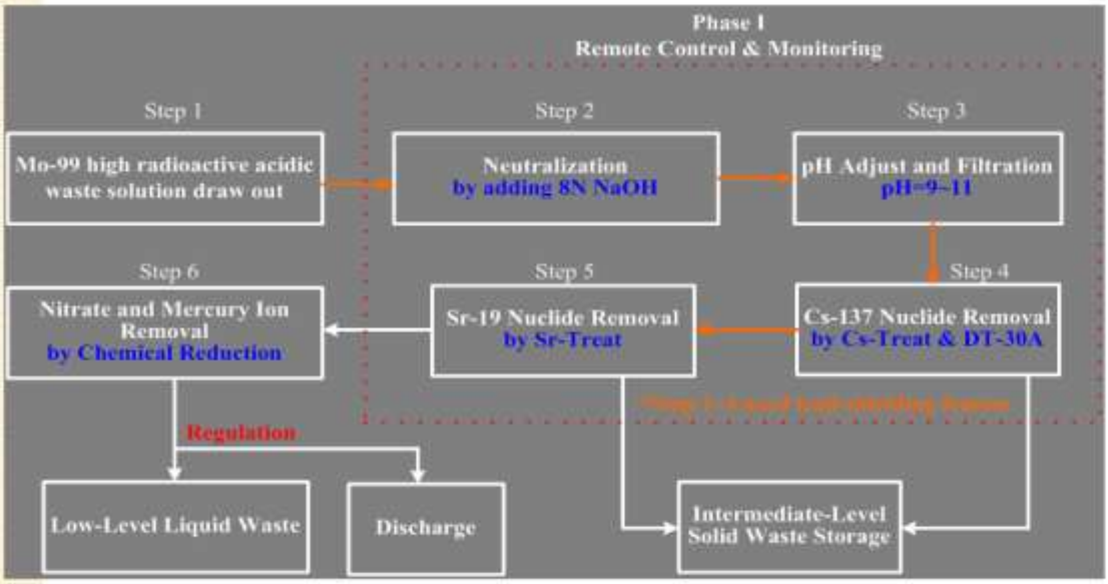
Introduction-Reviews about treatment methods

Country	Canada	Belgium	Netherlands	South Arfica	Russian	Australia	Germany	ANL /USA	Argentina	Taiwan
Materials	HEU(≥20% 235U)					LEU(<20% 235U)				natural UO2 targets.
Laboratory	CRL	IRE	ECN	AEC	IPPE	ANSTO	Karlsruhe	Argonne	CNEA	INER
Type	HLW (acid)	ILLW (base)	ILLW (base)	ILLW (base)	HLW (acid)	ILLW (acid)	Not Available	Not Available	ILLW (base)	HLW (acid)

International Atomic Energy Agency, "Management of radioactive waste from ^{99}Mo production", IAEA-TECDOC-1051, 1998.

INER 5

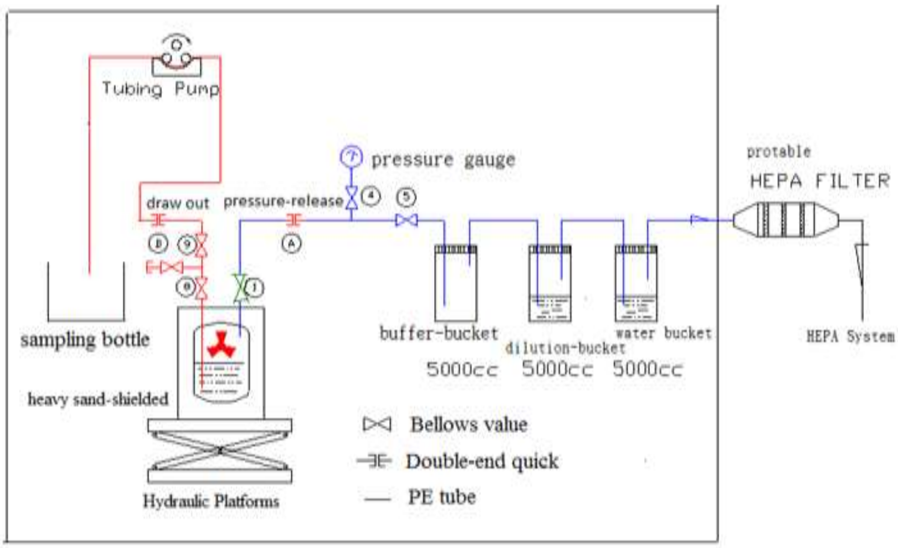
Treatment procedures—
Flow diagram for the treatment of Mo-99 liquid waste



INER

6

Treatment procedures—
Procedure of waste solution draw-out and pressure-release



INER

7

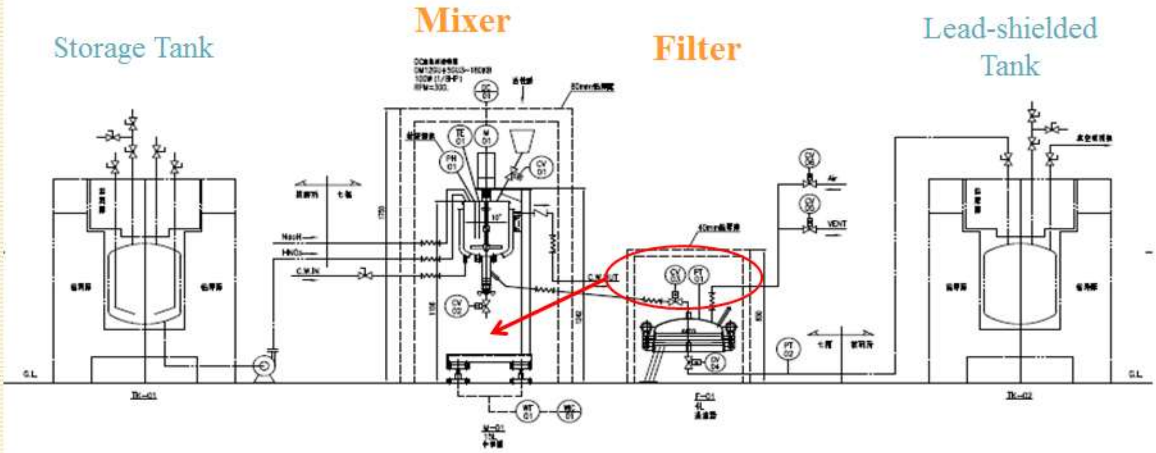
Treatment procedures- Neutralization and Filtration

(a)Neutralization of waste solution (b) Filtered cake

(c) Add the camera (d) Add the lead-shielding (e) To know the inner reaction

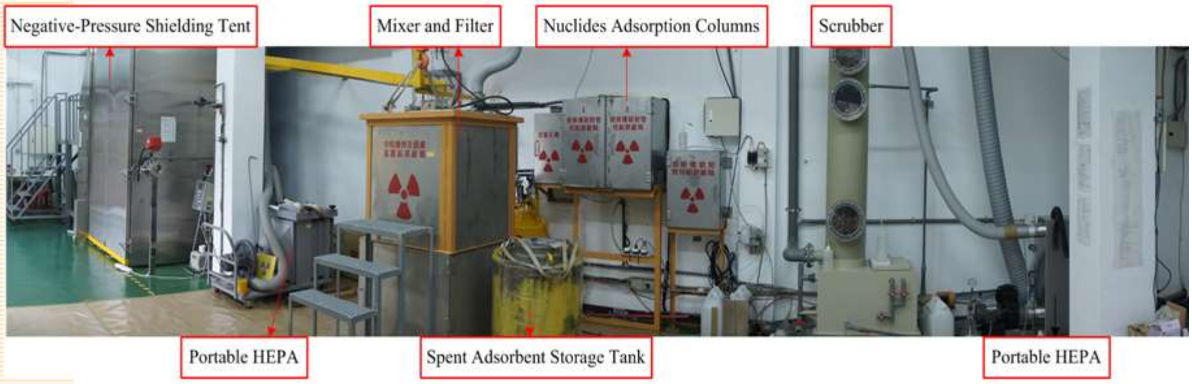
INER 8

Treatment procedures -design & build



INER 9

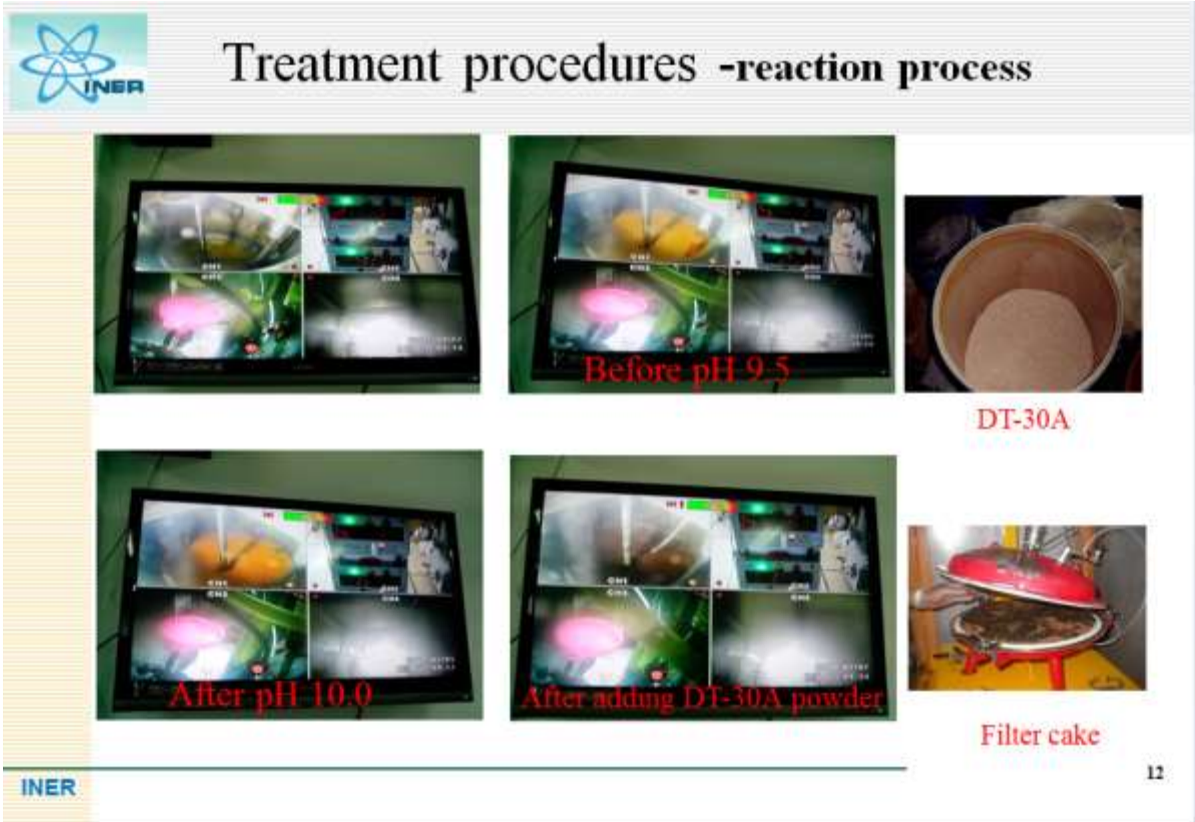
Treatment procedures – Treatment facilities for Mo-99 waste solution at INER



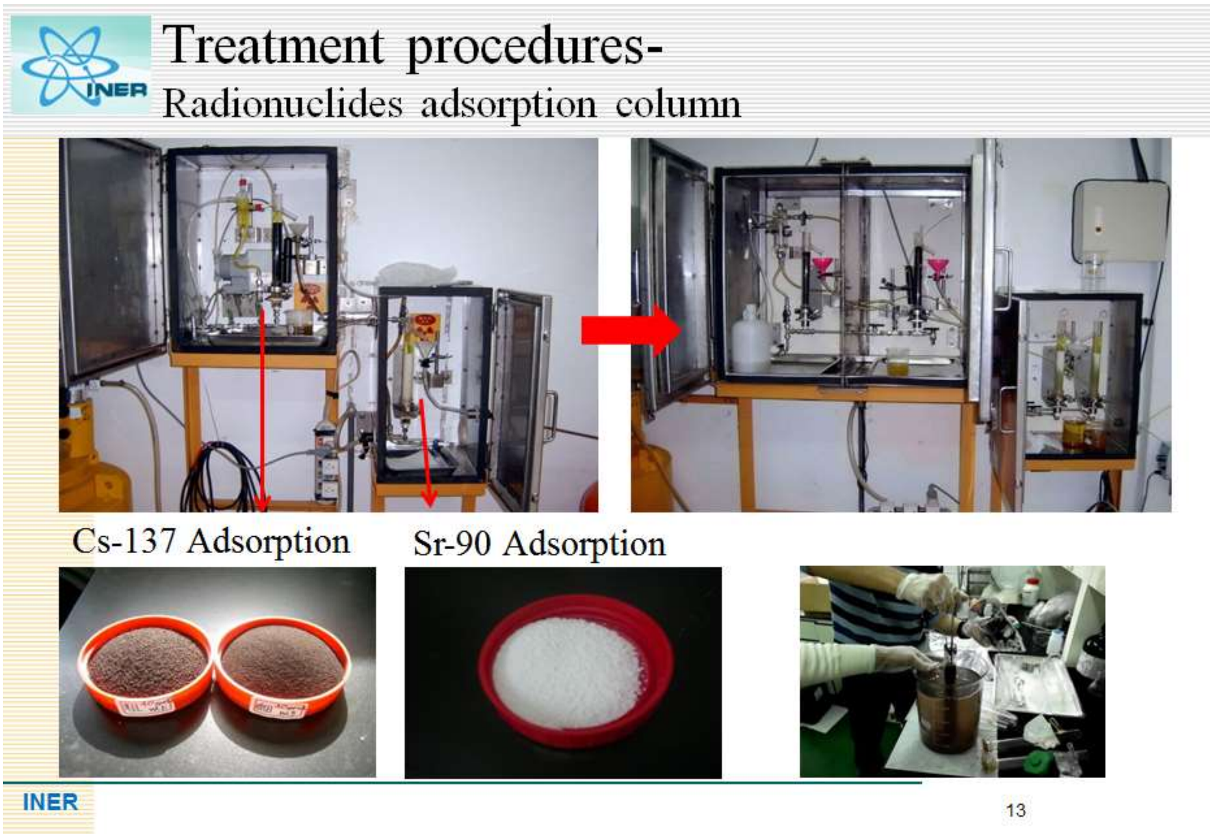
INER 10

Treatment procedures –Delivery of storage tank from store to negative-pressure shielding box

INER 11



Treatment procedures -reaction process
Before pH 9.5
DT-30A
After pH 10.0
After adding DT-30A powder
Filter cake
INER
12



Treatment procedures-
Radionuclides adsorption column
Cs-137 Adsorption
Sr-90 Adsorption
INER
13

Treatment procedures

Ion exchanger selection

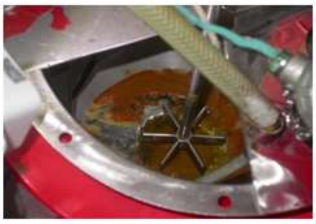
- Cs-Treat：Finland
  - ✓Total ion exchange capacity：0.3~0.4 meq/g
  - ✓Particle size：0.25～0.85 mm
  - ✓Operating pH range：1～13
  - ✓Selectivity Factor：$K_{Cs/Na}$=1,500,000，$K_{Cs/K}$ =50,000
- Sr-Treat：Finland
  - ✓Total ion exchange capacity：4.5~5.5 meq/g
  - ✓Particle size：0.30～0.85 mm
  - ✓Operating pH range：9～13
- DT-30A：USA

INER

14

Results & Lesson-learned

- **pH meter**
- **Filtration is the most difficult part .**
- **Adsorption by Cs-Treat is too expensive, alternative DT-30A is applied.**
- **Radionuclides Adsorption Problem**



INER

15

Results & Lesson-learned

- Treatment results of Mo-99 waste water (WC-103)

Radioactivity Analysis	Before Treatment	After Treatment
Gross α	<1.07E-2 Bq/ml	<1.07E-2 Bq/ml
Gross β	2.49E+1 Bq/ml	3.8 Bq/ml
Radioactivity of Cs-137	3.99 Bq/ml	0.287 Bq/ml
Radioactivity of Sr-90	6.39E+2 Bq/ml	<1.64E-2 Bq/ml

INER

16

Results & Lesson-learned

- Treatment results of Mo-99 waste water (WC-103)

Concentration(after radionuclides removal)		Regulation of EPA
Nitrate(NO_3^-)	93400 mg/L	50 mg/L
Mercury(Hg)	646 mg/L	0.005 mg/L
COD	536 mg/L	200 mg/L
TOC	284.2 mg/L	100 mg/L
ABS	4686 mg/L	10 mg/L

INER

17

Conclusions

- The acidic Mo-99 radioactive waste liquid was treated by a compacted process, and facilities which were simple, feasible and easy to operate.
- After the neutralization, filtration and nuclides adsorption processes, the treated Mo-99 inorganic waste solution met the criteria for discharge. The Cs-137 and Sr-90 nuclide adsorption columns were in parallel, which shortened the treatment time
- The process generated a small amount of filter cake and spent adsorbents, and they were categorized as low-level waste..

INER 18

Acknowledgements

We would like to acknowledge the help from Dr. Pen Ben-Li, Mr. Lee Shih-Yi and Mr. Tsao Kuo-Hao for the treatment process concept, construction of facilities and instrument operation.

INER 19

WM2016 Conference, March 6 – 10, 2016, Phoenix, Arizona, USA

Development of Treatment Process for Radioactive Wastewater Generated from Molybdenum-99 Study – 16415

Chang-Liang Hu, Hsien-Ming Hsiao
Chemical Engineering Division, Institute of Nuclear Energy Research
1000 Wenhua Rd. Jiaan Village, Longtan District, Taoyuan City , Taiwan (ROC)
Email: clhu@iner.gov.tw, hmhsiao@iner.gov.tw

ABSTRACT

Molybdenum-99 (Mo-99) high acidic waste solution was securely stored at INER for numerous years. Until 2004, the procedures of waste solution draw-out and pressure-release were accompanied, along with construction of treatment facilities. In 2009, after simulated solution and small volume Mo-99 waste solution tests, the treatment procedure was determined. Then batch-scale treatment facilities were set up. The waste solution was preserved using the instrument, along with modification of some facilities simultaneously. Ultimately all of 12 tanks of Mo-99 inorganic waste solution stored in Building 014 were finished on July, 2012. And residential 5 tanks of those solution served in Building 015B were also completed on September, 2014.

A practicable process has been developed for treating radioactive waste generated from Mo-99 study, and it can effectively remove radionuclides from a nitric acid solution. At first, after the waste was sucked from the bucket, the pH value was adjusted to about 10.0 through acid-alkali neutralization. Then, an adsorbent of natural zeolite powder was added to adsorb nuclides, and two adsorption columns filled with Cs-treat and Sr-treat adsorbents were used for removing nuclear species of Cs-137 and Sr-90. In this step, the nuclear species of Cs-137 and Sr-90 contained in the liquid waste are significantly reduced to a degree for manual operation allowable. Then, nitrate ion and mercury ion were removed through another procedure.

As a result, the operations were safer and more efficient than other conventional methods. Additionally, the hazard of accidental leakage caused by corrosion of the bucket after long period of storage can be effectively prevented and potential pollution threats are also eliminated.

INTRODUCTION

About 400 liters highly radioactive acidic liquid waste originating from Mo-99 production was stowed at INER over many years. In 2007, an examination of the waste solution showed that:

- The activity of Co-60 was decayed to a very low level,
- Significant Cs-137 and Sr-90 nuclides still exist,
- A risk of a spill exists due to the storage tank corrosion in the case of high pressure (as high as 5 kg/cm^2),
- The pH value of solution is negative.

A study on the treatment of the radioactive acidic liquid waste was conducted to solve the above problems, and allow for discharge of the liquid waste while avoiding environmental pollution. The first step of treatment is to neutralize the acidic liquid waste followed by nuclides removal (Phase I). Therefore, in the subsequent operation, the use of radiation shielding can be avoided. The above solution will then be treated to remove nitrate and mercury ions. Before discharging the liquid waste, the nitrate and mercury ions must be removed in the next step.

In Phase I of the treatment process, the bench tests were carried out by using simulated solutions, followed by real waste solutions. The results revealed that NaOH is the preferred solution to neutralize the high acidic waste solution and the pH of solution must be adjusted to 9~11 prior to the removal of nuclides. After pH adjustment and the separation of precipitate by filtration, the waste solution was ready for radionuclide removal. Two kinds of adsorbents were employed for Cs-137 removal, and a third was used for Sr-90 removal. Expensive inorganic selective ion exchange materials, Cs-Treat and Sr-Treat, can remove specific nuclides effectively. Another ion exchange material, DT-30A, is less effective than Cs-Treat for the removal of Cs-137, but much less expensive than Cs-Treat. Use of the three adsorbents in sequence significantly reduced the cost of the treatment process.

A 5-liter treatment system was set up to treat the radioactive liquid waste. This system includes a stirring reaction tank, a vacuum filter and adsorption columns. For personnel radiation protection, the reaction tank and filter were covered by lead frame with thickness of 30 mm and 5 mm respectively. Remote control and monitoring systems were adopted based on the previous operation experience. In 2012, this treatment system has successfully treated all of the Mo-99 liquid waste, and reduced the activity of Cs-137 and Sr-90 from 2E+5 and 9E+5Bq/ml to 2 Bq/ml and less than LLD (Lower Limit of Detection) respectively.

WASTE SOLUTION PROPERTIES

Mo-99 is the mother nuclide of Tc-99m, which is often used as a nuclear medicine for organ analysis in cancer diagnosis. Several countries, such as Canada, Belgium, Netherlands, South Africa, Australia and the United States, have developed Mo-99 production technology.[1] Among them, Netherlands classified Mo-99 liquid waste into two categories, namely intermediate and low level, and then temporarily stored them in COVRA (Centrale Organisatie Voor Radioactief Afval), which is the central organization for the management of radioactive waste in the Netherlands.[2] A majority of countries have adopted this long-term storage approach for handling Mo-99 waste solutions.

The Mo-99 produced at INER in 1986 was from neutron irradiation of U-235. The process has been implemented 21 times, and each time produced 20 curies of Mo-99 products. After this process, the inorganic acidic and organic extracting solutions, which had been classified as GTCC (Greater-Than-Class-C) waste, were stored in lead-shielded tanks and heavy sand-shielded containers. The inorganic wastewater consisted of 10N nitric acid, mercury ion, and radioactive nuclides due to the nature of the production process. Chemical and radioactive analysis of the Mo-99 waste solution was performed in 1994 and the results are shown in Table I.

Table I. Chemical and radioactive analysis of Mo-99 waste solution in 1994

Solution	Co-60[a]	Cs-137[a]	Sr-90[a]	Gross α[a]	Gross β[a]
Inorganic	20.4~318[b]	2E+4~2E+5	<LLD[c]~9E+5	1E+1~2E+3	5E+4~1E+6
Organic	<LLD[c]~22	1E+2~1E	<LLD[c]~4E+	<LLD[c]	1E+3~2E

	.2	+3	3	~6E+3	+4

a. Unit : Bq/ml

b. Co-60 decayed to below LLD in 2006

c. LLD = lower limit of detection

All these Mo-99 waste solutions have been temporarily stored at INER for almost 20 years. During the storage period, the pressure of storage tanks increased to as large as 5kg/cm^2, which creates the risk of spill due to the corrosion of valves and tubes. [3] For long-term safe storage, the pressure must be released. In hope of releasing the pressure safely, analysis of the operational procedures, equipment design, radiation protection and operator's exposure dose must be conducted. During the pressure release and sampling process performed in 2005, it was noticed that the steel material of containers was corroded for those containing high concentration acids, but not for those containing washing water or organics. [4]

After long storage, the radioactivity of Co-60 nuclide in inorganic waste water was decayed significantly; however, the radioactivity of long half-life nuclides, such as Cs-137 and Sr-90, was still very high. In consideration of safe storage of wastewater, the inorganic waste solution, especially the one with high acidity, needs to be neutralized and the nuclides within it must be removed for the decommissioning of storage building and remediation of storage drums. Therefore, this article will focus on the treatment of acidic Mo-99 inorganic wastewater.

PROCESS FOR THE TREATMENT OF MO-99 INORGANIC WASTE SOLUTION

The flow diagram for the treatment Mo-99 inorganic liquid wastewater is shown in Fig. 1 Step 1 to 5 will be discussed in detail in the following paragraphs, and the Phase I is the most important part of this treatment process. Step 6 is the final step of the treatment process in which the wastewater can be completely discharged, however, this step is not the emphasis of this article. Before discharging the liquid waste, removal of nitrate and mercury is essential to comply with EPA regulations in Taiwan. In Step 1 to 4, the radioactivity of the wastewater was very high. Therefore, personnel need to be shielded by a lead frame for safe operation. After several operational trials and adjustment of the treatment facilities, a remote control and monitoring system was incorporated to carry out the treatment process accurately. [5]

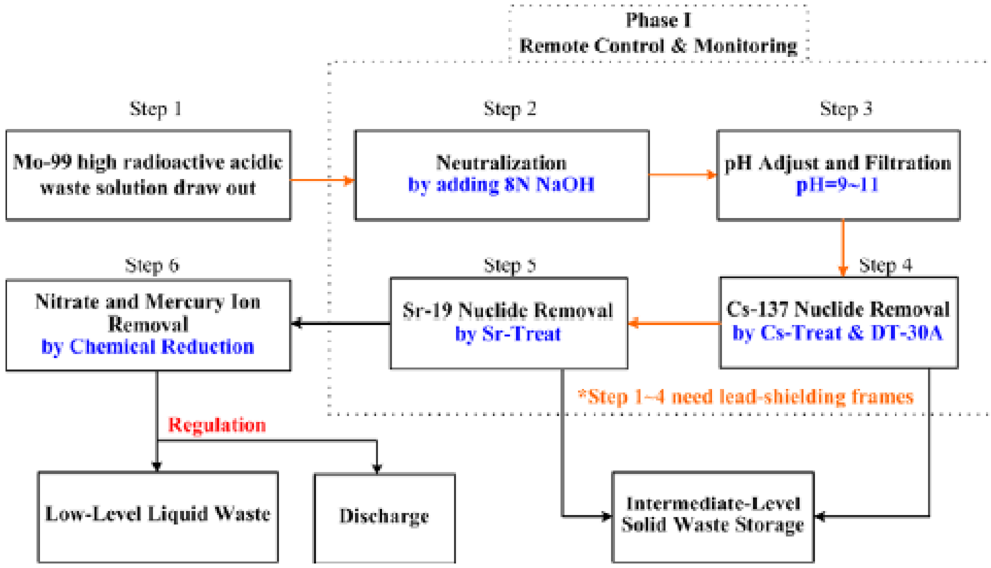
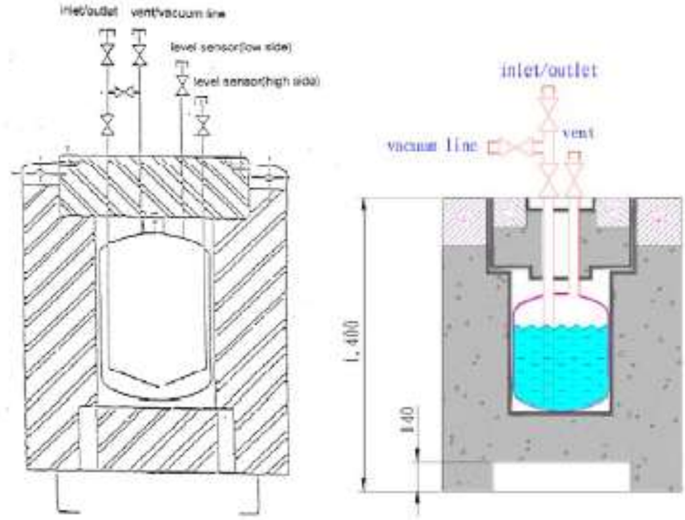


Fig. 1. Flow diagram for the treatment of Mo-99 liquid waste

Delivery from Storage Tank to Reaction Tank

Fig. 2 shows the structure of lead-shielded and heavy sand-shielded storage tanks, with a thickness of more than 16cm and 12.5cm, respectively. There were two kinds of inorganic waste water stored in the storage tanks, namely the raffinate and washing solution. Table II shows the specifications of these two kinds of storage tanks. By completing the connection between the storage tank and the reaction tank, as shown in Fig. 2 marked with "inlet/outlet", the Mo-99 waste solution was pumped out by a diaphragm pump. The entire pipeline for connecting between the storage tank and the reaction tank was encased in a lead pipe with a thickness of 1.5 cm, which shielded the radioactivity of the waste solution.

The reaction tank was equipped with a mixer and was held in a steel framework with a load cell below. The load cell allowed the amount of waste solution entering the reaction tank to be accurately controlled. There was one level alarm detector attached at the top of the reaction tank to prevent overflow of the waste solution. The volume of the reaction tank is about 15 liters and three stainless baffles were attached inside the reaction tank, with equal distance between each other. A valve for the discharge of waste solution was set at the bottom of the reaction tank and was controlled by high-pressure air. The mixer in the reaction tank was a flat bade turbine made of stainless steel, same as the reaction tank. The mixer has a maximum rotation speed of 300 rpm. A thermometer, pH meter and liquid level sensor were also installed in the reaction tank to monitor the temperature, pH, and level of waste solution.



(a) (b)

Fig. 2. Schematics of (a) lead-shielded and (b)heavy sand-shielded storage tanks

Table II. Specifications of storage tanks for Mo-99 waste solution

Waste solution	Capacity (liter)	Storage volume (liter)	Shielding & Thickness(cm)	Dimension (cm)	Dose rate μSv/h/ml
Raffinate	18	11	Lead, 16t	62Φ×120	15
Washing	50	33	Concrete, 12.5t	94Φ×120	10

Neutralization and Filtration

Once acid waste solution entered the reaction tank, 8 N sodium hydroxide solution was added into the tank to increase the pH of waste solution to around 9 to 11. The pH of solution was controlled carefully in order to match with the operation pH of the adsorbents. Since the acidic waste solution was 10N HNO_3, significant fume was generated by this process. To prevent overheating during the neutralization process, a water cooling system was employed to keep the temperature of waste solution in the range of 30~35℃.

If too much NaOH solution is added, significant yellow-brown foam will be formed on the surface of the mixture, making it difficult to determine the volume of either NaOH or waste solution and the measurement of solution pH will be meaningless. In this case, it would take several hours to mix the solution until the foam disappeared. When the pH of solution was below 1.2, there would be no precipitate formed. However, when the value of pH exceeded 2, lots of fine precipitates were formed in the solution. If the pH value was controlled perfectly in the range of 9~11, the color of the waste solution would be green or brown, depending on the source of Mo-99 waste solution. Fig. 3(a) shows the reaction condition in the reaction tank. When the pH was too low, the waste solution would become transparent with less precipitate.

After mixing completely, the releasing valve at the bottom of the tank can be opened by using compressed air to allow the waste solution to go into the negative-pressure filter. The filter was equipped with a filter paper that has diameter of 40cm, and pore size of approximately 3μm. To prevent the spill of high radioactive waste solution, the filtration process was carried out under negative pressure of higher than 30in-Hg (i.e.76 cm-Hg), so that the waste solution could be sucked into the 18 liter lead storage tank. Fig. 3(b) shows the precipitate in the negative-pressure filter and the radioactivity was about 7.15μSv/hr. The most common problem in the filtration process is the blocking of pipe by coarse DT-30A particles. However, if DT-30A were grinded too fine, the filtered waste solution will contain those fine particulates with size smaller than 3μm. Therefore, the adsorption column would be blocked during the subsequent nuclides adsorption process.

(a) (b)

Fig. 3. (a)Neutralization of waste solution and (b) the filtered cake

Nuclide Adsorption

After pH adjustment and the separation of precipitate by filtration, the waste solution was ready for radionuclides removal. Several nuclide removal methods from the literature were assessed and the method of using inorganic adsorbents was selected for this purpose. [6-11] During nuclide adsorption, the waste solution was pumped from the lead storage tank to the fixed adsorption columns for Cs-137 and Sr-90 removal. The inorganic selective ion adsorbents, Cs-Treat and Sr-Treat, were employed for Cs-137 and Sr-90 removal, respectively. They were both commercial products purchased from Fortum Nuclear Services Ltd, Finland. The operating environment and characteristics of these adsorbents are shown in Table III.

Table III. Properties of Cs-Treat and Sr-Treat

Item	Cs-Treat	Sr-Treat
Operating pH	1~13	>10

Selectivity	$K_{Cs/Na}$=1,500,000	-
Total Ion Exchange Capacity	0.3~0.4 meq/g	4.5~5.5 meq/g
Color	Dark Brown/Black	White

The pH of waste solution must be adjusted in advance to meet the working pH of adsorbents. The selectivity of Cs-Treat was very high. Therefore, the adsorption efficiency of Cs-137 in the high-salt environment was very good. However, due to the high cost of Cs-Treat, an alternative, DT-30A, was selected for the preliminary treatment of waste solution. About 400 grams of DT-30A were added in the reaction tank, which held 12litersof waste solution, right after neutralization and filtration step. DT-30A was mixed thoroughly with waste solution and then filtrated by the same negative-pressure filter.

After three to four batch operations of DT-30A mentioned above, the radioactivity of the Mo-99 wastewater was reduced to 25μSv/hr per 100ml of solution. Afterward, the waste solution was pumped into the adsorption column filled with Cs-Treat and Sr-Treat adsorbents to further lower the radioactivity of wastewater contributing from Cs-137 and Sr-90 nuclides. When the radioactivity of Cs-137 adsorption column reached nearly 2000μSv/hr, the adsorption process was stopped and the column was refilled with fresh Cs-Treat adsorbent. The operators were shielded during the entire replacement procedure to comply with the radiation protection regulations. The spent Cs-Treat adsorbent was then stored in a reformed lead-shielded tank.

Remote Operation

Remote control and monitoring systems were adopted by learning from previous operating experience. The remote control system, including neutralization stirring unit and pump control for reagent feeding, was customized for the process. The monitoring system mainly improved the accuracy of neutralization process and prevented the overflow of waste solution. The monitoring system comprised radiation detectors and CCD cameras to overlook the progress of neutralization and adsorption. The remote control and monitoring systems were very useful for reducing personnel's exposure to radioactivity.

Fig. 4. Monitoring system of waste solution treatment facilities

Off-Gas System

Since the Mo-99 inorganic waste solutions contained high concentrations of nitric acid, the system needed to be ventilated and equipped with HEPA (High-Efficiency Particulate Air) filters to capture radioactive nuclides during treatment. The lead-shielded frame was connected to a scrubber through a two-inch outlet nozzle, and then to a movable HEPA filter as well as the building's HEPA filters for off-gas preliminary and final treatment. The scrubber was 180 cm in height, 30 cm in diameter and has a gas flow rate of 280 L/min. Weak NaOH solution was cycled in the scrubber for washing nitric acid gas, and used NaOH solution was employed as the base for neutralization. The scrubbed gas was then pumped into HEPAs with filter efficiency higher than 99.97% to capture nuclides.

Facilities

A 5-liter per batch system was set up for the treatment of Mo-99 radioactive waste solution. This system includes a stirring reaction tank, a vacuum filter, adsorption columns and off-gas HEPA etc. For personnel radiation protection, the reaction tank, filter and adsorption columns were covered by lead frame with the thickness of 30 mm, 5 mm and 3mm, respectively. All facilities were tested by pure water and simulation solution before real sample was treated. Fig.5. shows the panoramic view of whole treatment facilities at INER. The tank named WC-103contained that waste solution that was the first treated due to its lowest radioactivity and acidity. The treatment results of WC-103 are shown in Table IV. The COD in the waste solution was reduced by using active charcoal powder in batch operation to the concentration of 76 mg/L. However, the remaining substance, such as nitrate, mercury, TOC and ABS, needs to be treated by other methods.

In 2012, this treatment system has successfully treated all of the Mo-99 liquid waste, and reduced the activity of Cs-137 and Sr-90 from 2E+5 and 9E+5Bq/ml to 2Bq/ml and less than LLD respectively.

Fig. 5. Treatment facilities for Mo-99 waste solution at INER

Table IV. Treatment results for WC-103 liquid waste

Radioactivity Analysis	Before Treatment	After Treatment
Gross α	<1.07E-2 Bq/ml	<1.07E-2 Bq/ml
Gross β	2.49E+1 Bq/ml	3.8 Bq/ml
Radioactivity of Cs-137	3.99 Bq/ml	0.287 Bq/ml
Radioactivity of Sr-90	6.39E+2 Bq/ml	<1.64E-2 Bq/ml
Concentration(after radionuclides removal)		Regulation of EPA
Nitrate(NO_3^-)	93400 mg/L	50 mg/L
Mercury(Hg)	646 mg/L	0.005 mg/L
COD	536 mg/L	200 mg/L

TOC	284.2 mg/L	100 mg/L
ABS	4686 mg/L	10 mg/L

LESSON LEARNED

Fine precipitate particles still existed in filtered waste solution, and those particles would block the adsorption column, therefore, the Cs-137 adsorption treatment can't be operated effectively. High acidity would also lower the efficiency of Cs-Treat and made the adsorbent to dissolve. By using self-developed treatment process and equipment, the treatment costs were significantly reduced, particularly when DT-30A batch adsorption was adopted prior to Cs-Treat column operation. Most of the radioactivity of Mo-99 waste solution was removed, however, the contaminants such as nitrate, mercury, as well as α nuclide in solution still need to be treated, which could be removed by chemical reaction and membrane filtration. In such operation, lead shielding is not required any more.

CONCLUSIONS

The acidic Mo-99 radioactive waste liquid was treated by a compacted process, and facilities which were simple, feasible and easy to operate. After the neutralization, filtration and nuclides adsorption processes, the treated Mo-99 inorganic waste solution met the criteria for discharge. The Cs-137 and Sr-90 nuclide adsorption columns were in parallel, which shortened the treatment time. The expensive Cs-Treat and cheap DT-30A adsorbents were used in turn to lower the operational cost. Treatment capacity is limited to about 5 liters, which is safe for operators from a radiation protection perspective. The process generated a small amount of filter cake and spent adsorbents, and they were categorized as low-level waste. The solid waste was stored in the reformed, empty shielded tanks which were originally used to store the Mo-99 solutions.

REFERENCES

1. IAEA, Management of radioactive waste from ^{99}Mo production, IAEA-TECDOC-1051, November, 1998.

2. Rozé.M. van Kleef, COVRA NV, Radioactive waste treatment from Mo-99 production facility in the Netherlands, WM'01 Conference, February 25-March 1, 2001, Tucson, USA.
3. Pen Ben-Li, Ma Yung-Kuang, Chiu Chin-Lee, Tsao Kuo-Hoa, Safety analysis of pressure releasing and sampling of the shielded Mo-99 liquid waste drums at INER, INER-OM-0711R, 2005, Taiwan (In Chinese).
4. Pen Ben-Li, Tsao Kuo-Hao, Chu Yeong-Ton, The pressure discharge and sampling of 014B's Mo-99 drums, INER-SOP-0050, 2006, Taiwan (In Chinese).
5. Pen Ben-Li, Tsao Kuo-Hao, Shih-Yi Lee, Hsiao Hsien-Ming, Chemical equipment design and performance test for Mo-99 waste treatment, INER-7489R, 2010, Taiwan (In Chinese).
6. L.I. Rudenko and V.E. Khan; "Membrane methods for treating liquid radioactive wastes from the shelter to remove transuranic elements" Radiochemistry, Vol.47, No.1, pp.89-92, Russia, 2005.
7. V.N.Kosyakov, I. E. Veleshko,N. G. Yakovlev,V. N. Chernetskii, and N. E. Nifant'ev, Water-soluble chitosans as flocculants for deactivation of liquid radioactive, Radiochemistry, Vol.45, No.4, pp.403-407, Russia, 2003.
8. J. Kamenik and F Sebesta, Comparison of some commercial and laboratory prepared cesium ion-exchangers, Czech Technical University in Prague, Department of Nuclear Chemistry, Czechoslovak Journal of Physics, Vol. 53, Supplement 1, pp. A571-A576, Czech Republic, 2003.
9. Dmitry V Marinina and Garrett N Brownb, Studies of sorbent/ion-exchange materials for the removal of radioactive strontium from liquid radioactive waste and high hardness ground waters, Waste Management, Vol. 20, Issue 7, pp. 545–553, USA, 2000.
10. Paul Sylvester and Abraham Clearfield, The removal of strontium and cesium from simulated Hanford groundwater using inorganic ion exchange materials, Solvent Extraction and Ion Exchange, Vol. 16, Issue 6, pp. 1527 – 1539, USA, 1998.
11. E. Tusa, Use of nuclide removal system (NURES) for clean-up of different waste liquids, Fortum Engineering Ltd, Finland.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help from Dr. Pen Ben-Li, Mr. Lee Shih-Yi and Mr. Tsao Kuo-Hao for the construction of facilities and instrument operation. The authors would also like to thank Mr. Kan Shih-Min for his instruction in radiation protection.