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出國報告（出國類別：其他）

參加第二屆核科學與工程國際議

服務機關：核能研究所
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派赴國家：大陸西安
出國期間：105 年 8 月 23 日~105 年 8 月 27 日
報告日期：105 年 9 月 23 日

摘要

本次出差赴大陸之目的為參加 2016 年第二屆核科學與工程國際會議(2016 2nd International Conference on Nuclear Science and Engineering，NSE)，本研討會舉辦之目的，在於提供一個平台，供全球核科學與工程領域之學者專家進行技術面之交流討論，會議所探討之議題相當廣泛，包含有：核輻射偵測及防護、放射性與化學廢棄物處置及管理、除役、輻射屏蔽及應用、核化學、核物理及其它等環境科學技術。本所也發表了一篇論文，題目為：「HPGe and Scintillation Detectors Comparisons on Waste Drums Radioactivity Measurement.」，論文以全文方式發表於"Journal of Applied Mathematics and Physics" （ISSN:2327-4352）期刊中，藉由參加本會議，可以瞭解各國對於核科學與工程領域之最新研究發展現況，並蒐集相關資訊，可用來作為本所於研發之參考依據。

關鍵字：核科學、化學、物理

目次

一、目的

前往大陸西安參加「2016 年第二屆 NSE (2nd International Conference on Nuclear Science and Engineering)核科學與工程國際會議」此會議主要議題包含核輻射偵測及防護、放射性與化學廢棄物處置及管理、除役、輻射屏蔽及應用、核化學、核物理及其它等，匯集國際上核子科學及工程領域的科學家與工程師共同研討發表最新之研究成果與技術，參加此會議發表論文有助於提昇本所國際聲譽並與世界各國專家研討與學習最新的研究方法與技術，增進國內核子事故後偵測技術與放射性廢棄物處置管理之研發擴展，並促進國際交流，對本所技術發展與國際競爭力之提升皆有正面之助益。

而參與本會議本所也發表了一篇論文，題目為：「HPGe and Scintillation Detectors Comparisons on Waste Drums Radioactivity Measurement.」，論文以全文方式發表於"Journal of Applied Mathematics and Physics" （ISSN:2327-4352）期刊中，藉由參加本會議，可以瞭解各國對於核科學與工程領域之最新研究發展現況，並蒐集相關機構之研究發展成果與國際上最新技術資訊，可提供後續計畫執行之參考，有助於研究計畫的推展。

二、過程

(一) 行程概述

此次赴西安參加第二屆 NSE (2nd International Conference on Nuclear Science and Engineering)國際會議公差由 8 月 23 日至 8 月 27 日，共 5 天，行程如下：

8 月 23 日	由桃園機場搭機前往大陸西安
8 月 24 日	報到 NSE 研討會
8 月 25 日至 26 日	NSE 研討會，研討會的議程如表 1
8 月 27 日	由西安搭機返回台灣

表 1：第 2 屆核科學與工程國際會議議程

Date	Time	Location	
August 24	14:00-17:00	Registration (Lobby)	
Date	Time	Zhaoxing Room(昭行厅)	Jude Room（居德厅）
August 25	08:30-12:00	Invited Session 1: Physics Dr. Don Liu Prof. Lingai LUO Prof. Philipp Rudolf von Rohr Chair: Dr. Don Liu Coffee Break: 10:30-10:45	Invited Session 2: Agriculture Dr. Ekambaram Padmini Dr. Evgenia Dor Prof. Magdy Mohamed Gaber Prof. Wulf Diepenbrock Chair: TBD Coffee Break: 10:00-10:20
	12:00-13:30	Lunch	Lives Cafe 麗屋咖啡厅（西餐厅）, 2nd Floor
	14:00-18:00	Technical Session 1: Physics I Chair: Prof. Philipp Rudolf von Rohr Coffee Break: 16:00-16:15	Technical Session 2: Agriculture Chair: Prof. Rajinder Ranu Coffee Break: 15:45-16:00
	18:00-19:30	Dinner	Lives Cafe 麗屋咖啡厅（西餐厅）, 2nd Floor
Date	Time	Zhaoxing Room(昭行厅)	
August 26	09:00-12:00	Technical Session 3: Physics II Chair: Dr. David Le Hardy Coffee Break: 10:30-10:45	
	12:00-13:30	Lunch	Lives Cafe 麗屋咖啡厅（西餐厅）, 2nd Floor
August 27	07:00-18:00	One-day Tour (at own expense)	

本屆會議在中國陝西省西安市舉辦，主辦單位為工程資訊協會(Engineering Information Institute(Engii))，而本屆發表之論文，在會議現場依照內容概分為物理技術相關及農業等二大主題，本所發表之論文屬物理領域，故參加物理領域之場次，此場次之議題由美國路易斯安那理工大學 (Louisiana Tech University, USA) Don Liu 教授主持及並邀請法國國家科學研究中心（National Center for Scientific Research (CNRS)）Lingai LUO 教授及瑞士程序工程研究所(Institute of Process Engineering)Philipp Rudolf von Rohr 教授共同進行專題演說。會議論文發表方面，二大領域口頭發表論文總共 44 篇，海報論文為 4 篇，所有口頭發表論文議題詳見附錄一，另外參與本次會議之人員有法國、瑞士、中國、德國、俄羅斯、韓國、日本、印度、以色列、台灣等國家之專家學者，相關照片如圖 1 至**錯誤! 找不到參照來源。**所示。

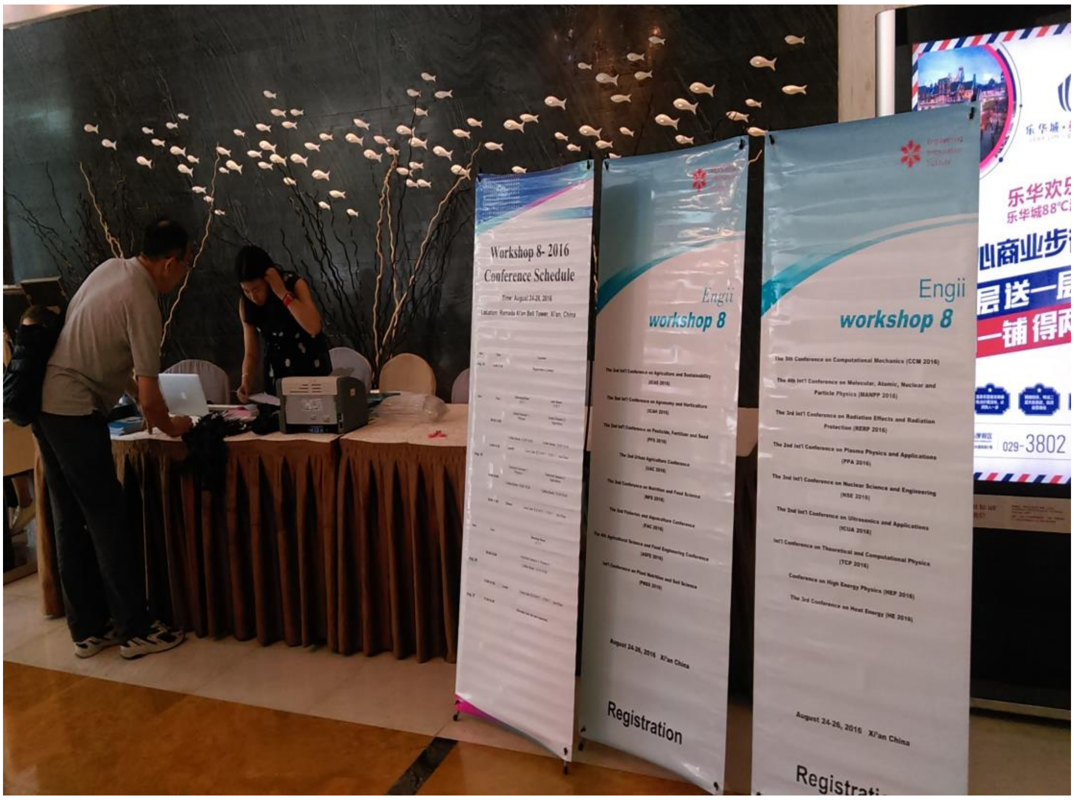


圖 1: 大會報到櫃臺

圖 2: 大會會場

圖 3: 大會會議廳 1

圖 4: 大會會議廳 2

(二) 本所投稿之論文

本所於此次研討會所發表的論文為 HPGe and Scintillation Detectors Comparisons on Waste Drums Radioactivity Measurement. 作者為本所保物組葉俊賢、袁明程、黃文治、李綉偉等人，論文以全文方式發表於" Journal of Applied Mathematics and Physics" （ISSN:2327-4352）期刊中，摘要及全文如附件二，論文內容概述如下：

研究使用 2 種做為執行放射性廢棄物桶活度量測作業與除役解除管制外釋的量測儀器，比較對於關鍵核種 Cs-137、 Mn-54 及 Co-60 活度量測結果的差異；此 2 種系統分別為由 3 部純鍺偵檢器所組合的量測系統與由 10 部閃爍偵檢器所組合的 4π 量測系統，前者系統特性為費用較高、可鑑別核種及量測所需時間較長(約 1000 秒)，後者系統特性為靈敏度較高、可鑑別熱點位置及量測時間較短(約 100 秒)。量測物質包含不同型式之廢棄物桶如參考物質廢棄物桶、均勻與非均勻分布之非金屬廢棄物桶與金屬廢棄物桶、材質緊密與鬆散分布之非金屬廢棄物桶與金屬廢棄物桶等，同時也改變整桶物質的填充率，比較二種不同偵檢系統量測不同填充物質廢物桶之 Cs-137、 Mn-54 及 Co-60 等關鍵核種的活度結果。

(三) 研討會論文討論

研討會進行的方式是分為二個場地分別進行不同主題的口頭報告，其一為物理相關，另一為農業相關的領域，二場次分別邀請相關主題之 3 位及 4 位學者專家進行專題演說。本次研討會論文涵蓋領域極為廣泛，由數值模擬、熱交換器、核化學、農業、土壤工程應用、材料開發等。其中，主要參與物理相關主題之議程，此議程之大會特邀演講及與本所發展趨勢較為契合之相關論文討論如下：

1. Spectral Element and Mesh-free Methods: Formulations and Applications

   此議題為大會邀請之美國路易斯安那理工大學 (Louisiana Tech University, USA) Don Liu 教授進行開場演講，Don Liu 教授也是本場次之主席。照片如圖 5 及圖 6。專題之內容主要在說明電腦數值模擬方法之光譜元素法(Spectral element methods，SEM)及自由網格方法之公式及應用，SEM 方法之精確度高於一般的有限元法（Finite element methods，FEM）。由於 SEM 正交擴張和測試功能，使其離散誤差可以減少並實現頻譜收斂，根據擴張和測試功能的具體選擇，SEM 可以是節點或模型方法，光譜收斂性解析度很高對於某些應用如在薄的邊界層捕捉急劇速度梯度的模擬特別理想。

   SEM 的應用如要在獲得數值解，如流體流動和傳熱問題。顆粒流動工程是廣泛存在工業和自然界的多相流體的一種形式，學術界和工業界研究人員特別感興趣的是大量粒子是顆粒流動，如在沿海地區夾帶泥沙。模擬顆粒流動現象的挑戰是如何追踪移動，及量化大量粒子和流體之間的相互作用的內部邊界。針對含有大量運動粒子的粒子流體已發展了一個經濟的物理計算模型，對於涉及大型區域變形的複雜的問題，如潑水和潰壩波浪的問題，可使用粒子的低階無網格離散方法可以有效地模擬。

圖 5: 主席 Don Liu 教授

圖 6: 主席 Don Liu 教授之演講

2. Recent progress in compact heat exchanger and their functionality integration.

此議題為大會邀請之法國國家科學研究中心（National Center for Scientific Research (CNRS)）Lingai LUO 教授進行演講，如圖 7。此專題主要在研究高性能緻密的熱交換器，包括其設計、製作、模型和實驗研究。熱交換器是將熱從一種介質傳遞到另一個介質的裝置。在化學工程與工業界是不可少的單元要件，也常應用於電力生產過程，化學和食品工業，電子，環境工程，餘熱回收，製造行業、空調、製冷和空間應用等。在這些應用中，熱及水力平衡和能量使用發揮主導作用。提高熱交換器的效率預計將節約能源和材料。

本研究工作提出了微型的(mini-scale)熱交換器的幾個創新設計概念，與其他方法不同，不看超細渠道尺寸(extra fine channel size)的大小，而注重的是對於如何有效地管理流體動力學方面和加強傳熱表面的幾何組織在可接受的總壓降上增加熱的傳遞。如使用內部（chaotic）混合、多通道(multi-passage)結構、和多尺寸形狀(multi-scale geometries)。

另外研究發展多功能熱交換反應器。提出樹狀的(tree-like)分配和採集反應器，有平行的 16 個小通道與 T-mixers。經由熱性能的實驗測試和得到高的總傳熱係數從 2000 到 5000 $W{\cdot}m^{-2}{\cdot}K^{-1}$。顯示出具有高的熱交換能力。使用酸性和鹼性溶液之間的中和典型的快速放熱反應，進行測試研究熱交換器反應器的熱控制能力。結果表明等溫條件可以通過穿過熱交換器循環的冷卻劑的適當流速來實現。熱交換器反應器中的具有樹枝狀分配器和收集器的設計是多通道系統的應用。

圖 7 : Lingai LUO 教授之演講

3. Plasma-assisted surface modifications of powders and granular particles

此議題為大會邀請之瑞士程序工程研究所(Institute of Process Engineering) Philipp Rudolf von Rohr 教授進行演講，如圖 8。此專題主要在研究使用電漿技術來進行粉末或顆粒粒子表面的改質，非熱電漿處理是用於溫度敏感的材料表面處理有力的工具。它允許基底物質表面有益地特性像潤濕性，溶出行為，抵抗力，流動性，電化學特性或微生物污染的影響。

由於存在於電漿中的高能電子，使得即使需要高反應焓的化學反也可以被

有效地執行，由於低能量的重粒子（離子、中子）使得處理同時的總體溫度可以保持在低溫的狀態。反應性氣體的電漿（如含有電漿的氧）可通過將極性氧基團引入到基板表面而增加粉末的潤濕性和溶解行為。本研究成功地應用在低壓狀態下之感應耦合管狀電漿反應器通過電漿在 0.1 秒內處理 HDPE 粉末和水楊酸粉末。同時也研究將此程序轉移到大氣壓力下執行。

非熱電漿處理也可以應用於降低微生物的活性，目前正在調查發芽種子微生物的活消滅。同時也研究使用低壓電漿循環流體化床反應器技術應用於麥粒的去污。

圖 8: Philipp Rudolf von Rohr 教授之演講

4. Measurement of Gamma-Rays Induced Luminescence Generated in a Sapphire Based Fiber-Optic Radiation Sensor

本篇作者為韓國 Young Beom Song, Kyoung Won Jang, Hye Jin Kim, Dong Eun Lee, Mingeon Kim1,Sang Hun Shin, Wook Jae Yoo, Bongsoo Lee 等人。論文以全文方式發表於" Journal of Applied Mathematics and Physics" （ISSN:2327-4352）期刊中。本研究建置了使用藍寶石晶體為感測物質的光纖輻射感測器(Fiber-Optic Radiation Sensor (FORS) ，以下簡稱 FORS)。為了評估其性能，以 Co-60 之加馬射線為射源照射並量測光纖輻射感測器所產生之發光光譜與強度，結果也與使用朗伯 - 比爾(Lamber-Beer)公式計算出的值進行比較。實驗系統如圖 9。

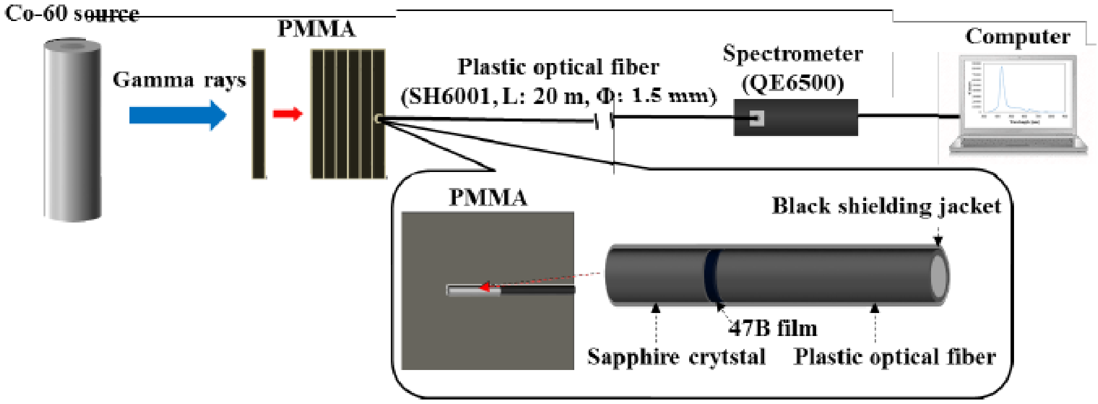


圖 9： FORS 量測加馬輻射照射產生之光譜實驗裝置

圖 9 為使用 FORS 測量加馬射線實驗裝置，其中包括有使用藍寶石晶體製造的 FORS、塑料光纖（Plastic Optical Fiber，POF）和一個帶通濾波器（band pass filter，47B film）。圓柱形藍寶石晶體（氧化鋁）被用作感測物質。藍寶石晶體直徑及長度分別為 1 毫米和 3 公分，折射率為 1.75 其密度 3.97 克/立方公分。塑料光纖用於發送生成的發光信號從藍寶石水晶到光譜儀。POF 的芯和包覆層的組成分別是聚甲基丙烯酸甲酯(polymethylmethacrylate ，PMMA)和氟化聚合物(fluorinated polymer)，這種纖維的外徑是 1.5mm 且芯部的折射率為 1.49，長度為 20 微米。帶通濾波器被用來從在塑料光學纖維產生的干擾信號中分離出藍寶石的發光來傳輸。

使用光譜儀(型號 QE65000, Ocean Optics）測量 FORS 的發光，可測量光譜的範圍為 200nm 至 1100nm。這項研究中所使用的加馬射線源 Co-60 活度為 1047 TBq。 Co-60 射源和 FORS 之間的距離為 14 公分，PMMA 幾何尺寸為 20 公分× 20 公分×1 公分，另外也改變 PMMA 厚度來檢測加馬射線作並分析結果。加馬射線照射在 FORS 產生的發光經由 20 公尺長的塑料光纖傳送到光譜儀，進行量測分析。

圖 10 顯示出從 FORS 產生的發光光譜量測結果。觀察到的發光波長範圍從 400 nm 到 480 nm，光峰值約在 420 nm 處。

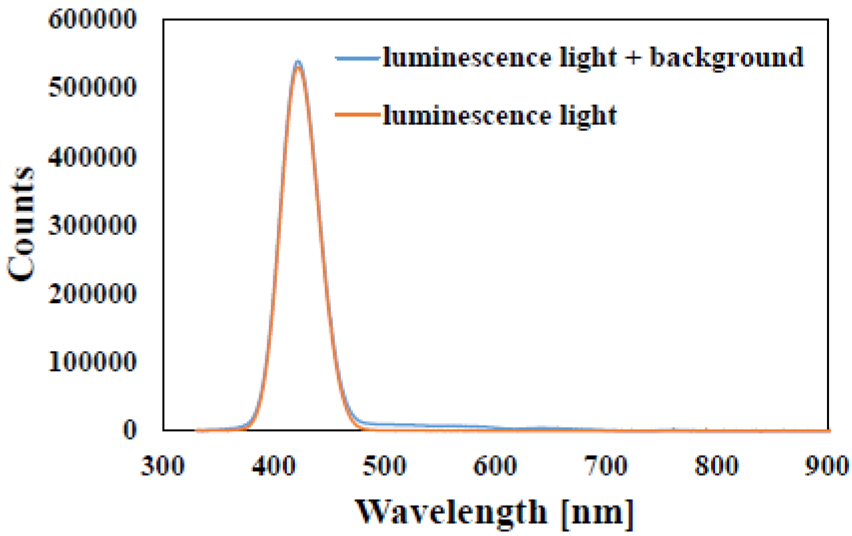


圖 10：使用 FORS 產生之發光訊號光譜

圖 11 顯示 FORS 的再現性。其結果為使用同樣的實驗裝置在一樣的位置分別測定 10 次發光信號。由圖可看出發光的測量計數範圍在±0.065%線內，獲得的相對標準偏差為 0.03%。

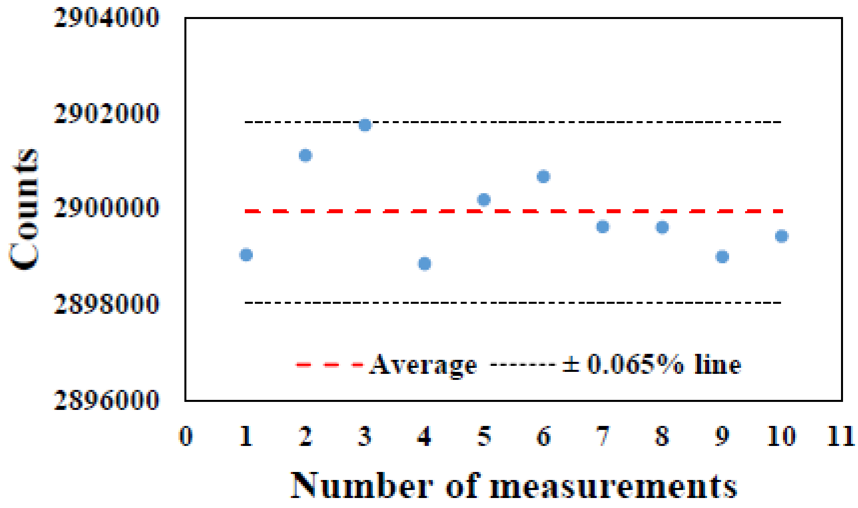


圖 11：FORS 量測發光訊號之再現性

圖 12 顯示改變不同 PMMA 厚度來量測 FORS 發光光譜之結果，在此實驗中可看出將發光峰的計數隨著 PMMA 的厚度增加而減小，因為初級或二次電子由於加馬相互作用的數量減少。

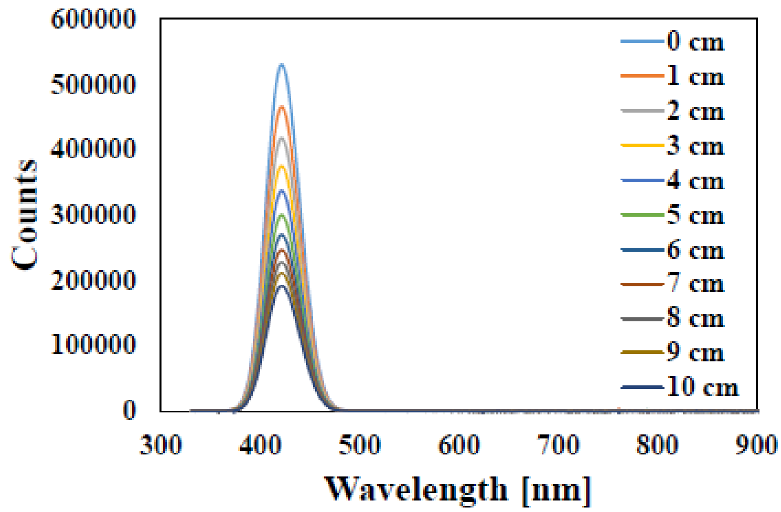


圖 12：在不同 PMMA 厚度使用 FORS 量測之發光能譜

圖 13 顯示根據 PMMA 厚度量測 FORS 發光強度的值與從朗伯 - 比爾公式計算得到的值比較結果，由圖可看出實驗量測 FORS 發光強度的值與朗伯 - 比爾公式計算結果有很好的一致性。

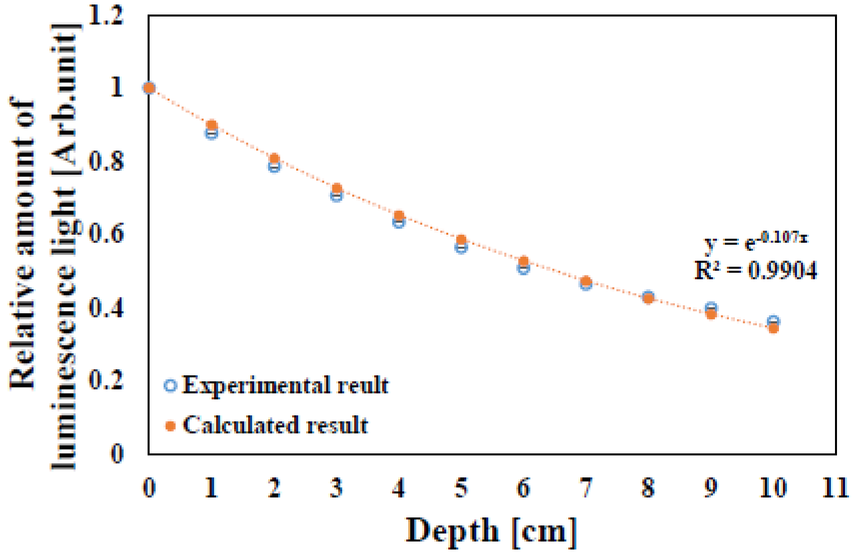


圖 13：使用 FORS 量測發光強度與使用 Lamber-Beer 公式計算結果之比較

光纖輻射感測器（FORS）有許多優點，如良好的柔韌性和不受壓力、濕度和電磁場干擾，空間解析度高等，同時因其尺寸小故可被用於狹小的空間中，由於這些優點，應用 FORSs 可檢測有害輻射場游離輻射。如用過核子燃料的儲存廠中輻射致發光（RIL）如謝倫可夫輻射和熒光經常產生，可通過本研究建置之光纖輻射感測器來測量 RIL。應用本研究於危險環境條件下之游離輻射檢測。

5. Comparison of Depth Dose Distributions Using Cerenkov Fiber-Optic Dosimeter and Monte Carlo Simulation for HDR Brachytherapy

本篇作者為韓國 Sang Hun Shin, Young Beom Song, Mingeon Kim, Hye Jin Kim, Wook Jae Yoo,Kyoung Won Jang, Bongsoo Lee 等人，論文以全文方式發表於 " Journal of Applied Mathematics and Physics" （ISSN:2327-4352）。在這項研究中，建置了沒有使用任何閃爍體的謝倫可夫光纖劑量計（Cerenkov Fiber-Optic Dosimeter，CFOD）用以測量由於加馬射線產生的謝倫可夫輻射信號。應用於量測使用 Ir-192 為射源的高劑量率（High-Dose-Rate，HDR）近距離放射性治療源的相對深度劑量（Relative Depth Dose，RDD）分佈。並將實驗量測的 RDD 分佈曲線和蒙特卡羅模擬程式（Monte Carlo N-particle extended transport code，MCNPX）計算結果比較。

高劑量率（HDR）近距離治療應用幾百 Kev 中間能量的各種輻射源，其作用也可能產生謝倫可夫輻射。對於閃爍體的光纖劑量計（fiber-optic dosimeters，FODs）而言，謝倫可夫輻射是一額外的光信號，因此在使用閃爍體的光纖劑量計要精確測量劑量時會被視為不要的光信號干擾量測。但謝倫可夫光對於量測劑量也是實用的，因為它也是輻射在 FODs 的感測器區域相互作用所產生的各個光信號中的一個。輻射誘發的光信號包括謝倫可夫光可以簡單地使用沒有任何閃爍材料製成光纖而得到。在這項研究中，製造一種新穎的謝倫可夫光纖劑量計，使用塑料光導纖維(plastic optical fibers，POFs）與光電倍增管(Photomultiplier Tube ，PMT)及一光子計數元件(photon-counting unit)，來測量通過加馬射線誘導的謝倫可夫放射的光強度。

本研究之 CFOD 的感測器探頭由兩個材質相同但不同長度的塑料光導纖維(POF)組成如圖 14。感測探頭 1 和 2 相差 10 毫米，POF 的芯和包覆層的組成分別是聚甲基丙烯酸甲酯(polymethylmethacrylate，PMMA)和氟化聚合物(fluorinated polymer)，芯直徑為 0.98 毫米，包層厚度為 0.01 毫米。使用差減法方法來量測的感測器兩者之間信號。HDR 近距離治療所使用之射源為 Ir-192，放射性活度為 8.14 Ci。Ir-192 的直徑和長度分別為 0.6 毫米和 3.5 毫米。Ir-192 發射的加馬射線能量範圍從 50 到 800 keV，能量峰值在 316 和 468 keV。放置在密封的不銹鋼中的 Ir-192 發出的伽瑪射線的平均能量約 397 keV。

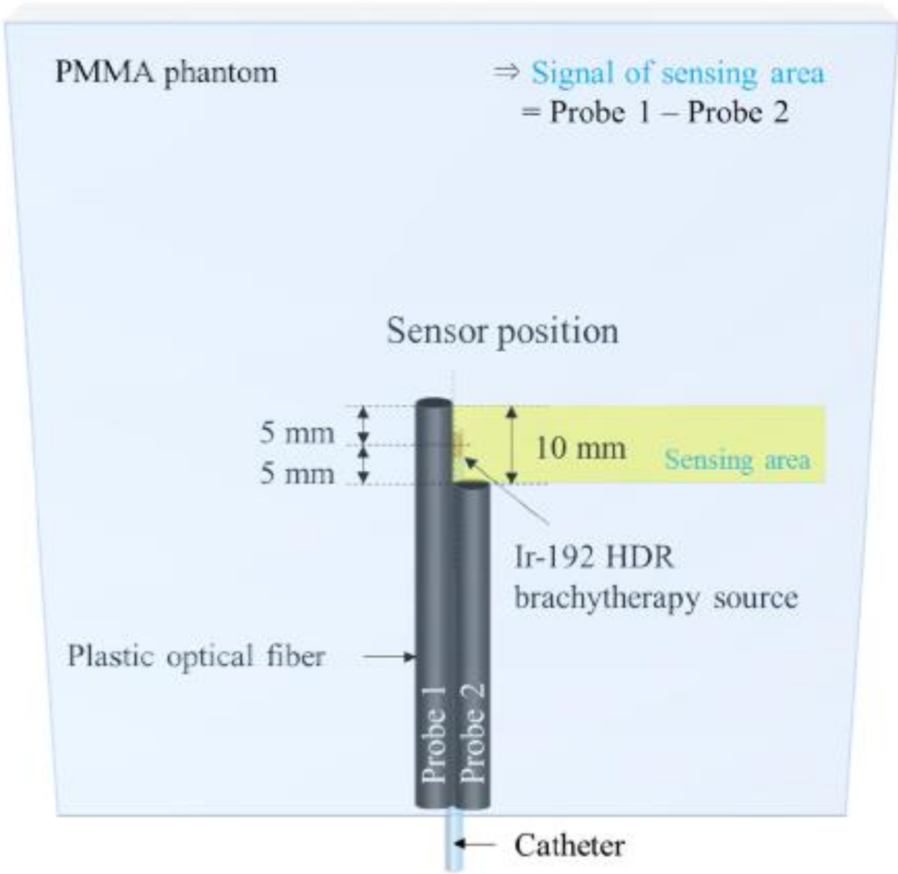


圖 14：沒有任何閃爍體的 CFOD 之感測探頭示意圖

圖 15 顯示用於測量在 CFOD 的感測器探頭產生的謝倫可夫輻射的實驗裝置。感測器探頭位於 HDR 近距離治療 Ir-192 放射性射源的中心。當感測器探頭由伽瑪射線照射，2 個具有不同的光強度的謝倫可夫輻射信號可分別從感測器探頭 1 和 2 被生成，然後由 10m 長的光纖傳送到光電倍增管進行計測。

圖 16 顯示出了從感測器探頭所產生的謝倫可夫輻射信號的光強度，由圖可看出 CFOD 在同樣的伽瑪射線照射期間探頭 1 的輸出信號是比探頭 2 高，因為這兩個探頭具有不同的輻射照射長度。在這研究中的實際劑量，通過測量探頭 1 和 2 中的謝倫可夫輻射信號強度的差而獲得如圖 16 中所示。

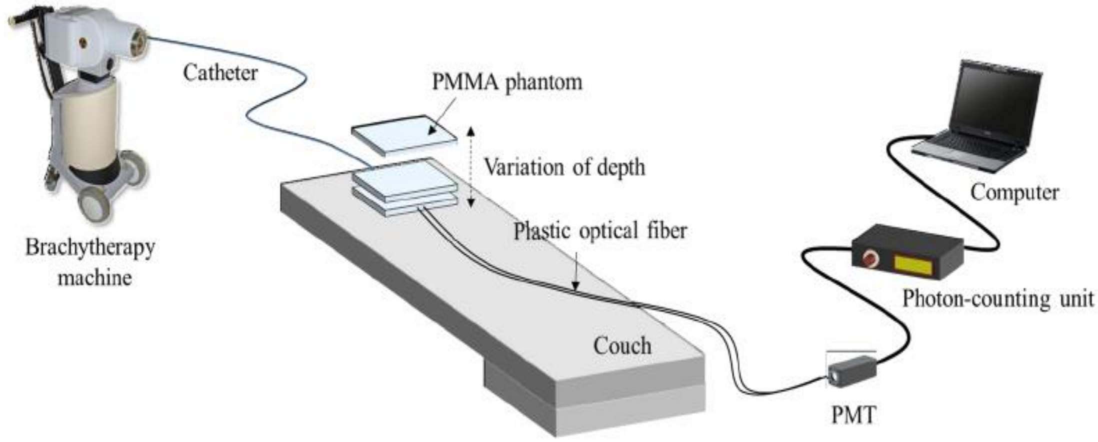


圖 15：CFOD 量測謝倫可夫輻射之實驗裝置及 Ir-192 HDR 近接治射療射源

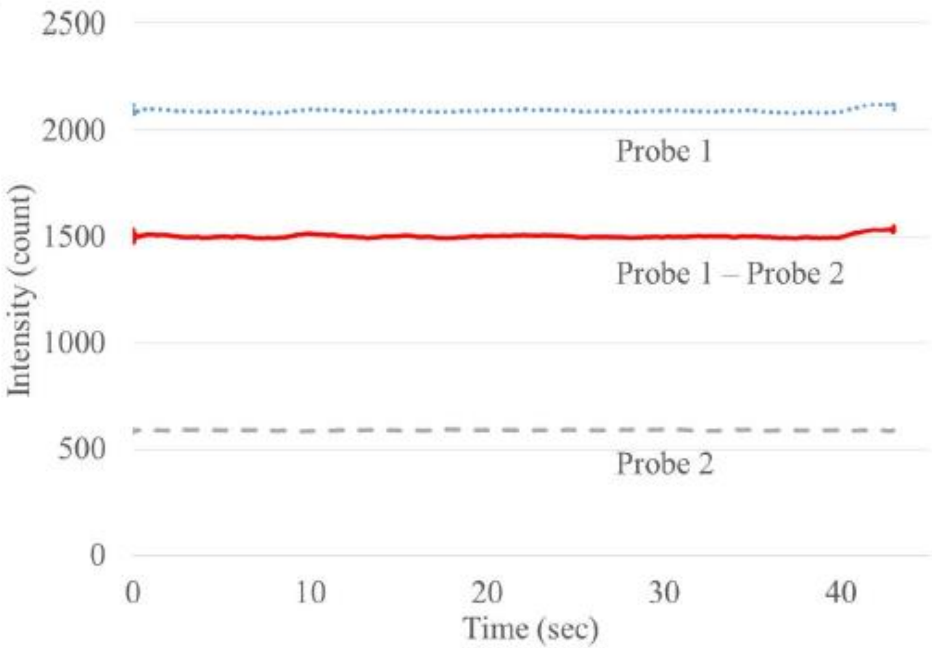


圖 16：感測探頭 1 號及 2 號量測之謝倫可夫輻射訊號與減算法

使用減算法法，從探頭 1 的輸出信號的扣除探頭 2 的輸出信號，並變化不同的 PMMA 深度量測獲得了 RDD 曲線，如圖 17，在 PMMA 中的 RDD 曲線急劇掉落在 20 毫米的深度，超過 20 毫米深度則輕微的減小。

使用 CFOD 測量的 RDD 曲線也與 MCNPX 的模擬結果相比較，用來驗證 CFOD 的劑量。由圖可看出 CFOD 實驗結果所獲得的 RDD 曲線類似於使用 MCNPX 程式計算的分佈。

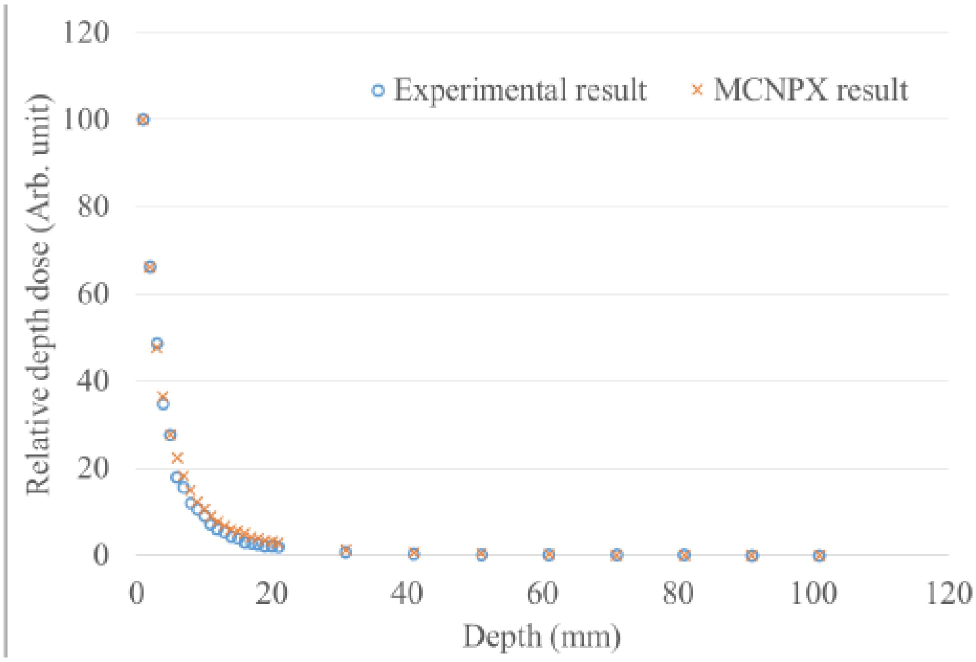


圖 17：CFOD 實驗量測之 RDD 結果與 MCNPX 計算結果之比較

總結在這項研究中，製造了 CFOD 使用兩個沒有任何閃爍晶體的 POF 來測量 HDR 近距離放射治療的劑量。通過使用 CFOD 的感測探頭成功測量來自 Ir-192 發射的伽瑪射線產生的謝倫可夫輻射信號。使用減算方法獲得深度劑量分佈，然後比較 RDD 曲線與 MCNPX 模擬計算出的結果，最後證明了本研究所提出的 CFOD 可以用來測量劑量與 RDD 分佈。根據這項研究的結果，可以預期 CFOD 能為 HDR 近距離放射治療獲得有用的劑量資訊，其有許多優點，包括高空間解析度，即時監控，遠程操作，以及具有水或組織等效性。

6. A Study of the Thermal Decomposition of $CH_3{}^{131}I$ in a Gas Flow in the Presence of "Fizkhmin" ^{TM} Granulated Materials

本篇作者為俄羅斯 Alexey A. Bessonov, Sergey A. Kulyukhin, Lubov V. Mizina, Igor A. Rumer 等人。

核電廠核燃料再處理或核子事故可能會產生揮發性放射性碘，如何將揮發性放射性碘的化合物通過各種吸附劑從蒸氣或氣體介質中測定對於環境保護是非常關重要的，揮發性有機放射性碘中最難以測定的是甲基碘（CH_3-^{131}I）。活性炭，矽膠，氧化鋁等吸附劑目前已廣泛地用於甲基碘測位。文獻顯示在緊急狀況下使用無機吸附劑含有 8－12 wt%的銀離子從氣相吸附甲基碘是最有效。但是銀的成本高，需開發更便宜的 CH_3-^{131}I 測定系統。

目前已有很多種方法被用於將 CH_3-^{131}I 轉換為容易測定的形式，如在紫外線輻射的作用下放射性甲基碘分解成化學活性原子碘，同時也產生細小分散的 IxOy 氣溶膠。也有使用電荷場的臭氧分解甲基碘的方法，此作用的主要產物是氣溶膠形式的 I_2O_5 會沉積在放電室的壁上。這些程序主要缺點在於 CH_3-^{131}I 分解會產生具有不同顆粒尺寸的放射性氣溶膠，包括奈米尺寸，奈米粒子的測定需要使用特殊的過濾系統。要轉換甲基碘而不形成放射性氣溶膠的替代途徑之一是熱分解，過去的研究中發現 97.9%的 CH_3-^{131}I 分解僅在 800℃下才觀察得到，在較低溫度下，CH_3-^{131}I 分解度低如在 500℃下為 13%，在 600℃為 83%。根據研究數據顯示允許 CH_3-^{131}I 在較低溫度下高效率地進行熱分解的材料是缺乏的，因此，本研究的目標是開發和研究存在氣流中甲基碘的熱分解材料，研究使用不同的"Fizkhmin" ^{TM} 的粒狀材料以矽膠為基礎浸漬 d-元素。

圖 18 為本實驗之流程及裝置圖。其中:1 為 CH_3-^{131}I 的產生器；2 為水洗滌器；3 為礦型的加熱爐；4 為本研究所用的複合材料；5 為一個含 SiO_2-Cu^0 的管柱；6 為熱電偶；7 為洗滌用 0.05M 亞硫酸鈉溶液；8 為圓筒型的加熱爐；9 為包覆 10 材料的的管柱；10 為 SiO_2-$AgNO_3$。

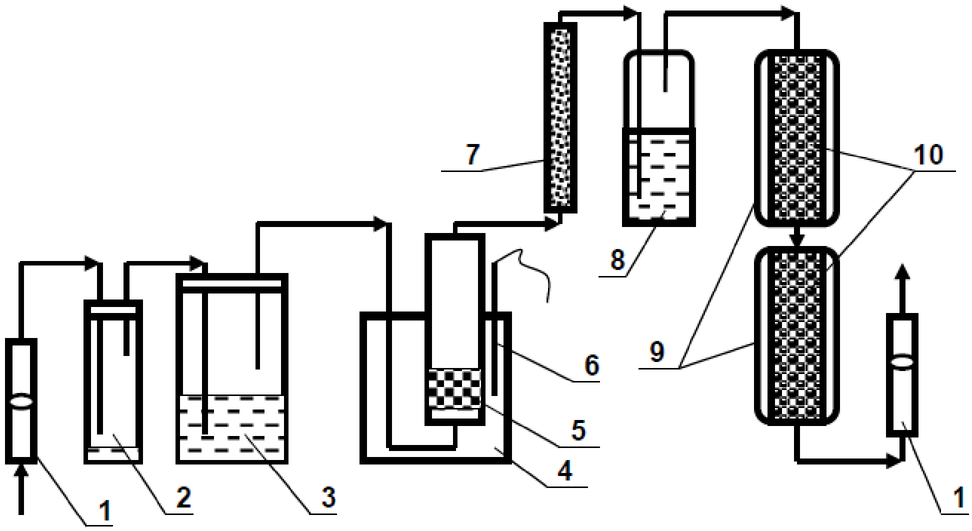


圖 18：研究氣流中甲基碘的熱分解的流程及裝置

本研究所使用矽膠及“Fizkhmin”TM複合材料介紹如下:

(1) 矽膠為基礎的複合材料，浸漬 2M 的 NH_4OH 溶液，儲存 24 小時，進行乾燥，乾燥程序以 20 度/分鐘的升溫速率從室溫增加至 300℃，並維持 4 小時。

(2) 矽膠為基礎的複合材料，浸漬 0.13 M 的 NH_4NO_3 溶液，在相同條件下存儲、乾燥。

(3) 矽膠為基礎的複合材料，浸漬 Cu 以 Cu(II)硝酸鹽形式處理，接著 110℃乾燥複合材料，用氨處理該乾燥的前體 24 小時，並在 300℃空氣中放置 4 小時。Cu 含量為 8 wt%（定名為:KKM-Cu）

(4) 矽膠為基礎的複合材料，浸漬 Ni 和 Cu 以 Ni(II)和 Cu(II)硝酸鹽形式處理，隨後處理如 KKM-Cu。 Cu 和 Ni 的總含量為 10 wt%，Cu：Ni 重量比為 1：1 和 1：4（定名為:KKM-CuNi）;

(5) 矽膠為基礎的複合材料，浸漬 Ni 以 Ni (II)硝酸鹽形式處理，隨後處理如 KKM-Cu。Ni 含量為 8wt%（定名為:KKMNi）。

在沒有複合材料的氣流中 10 毫克 CH_3-^{131}I 的熱分解數據如表 1，可以看到 CH3I131 分解程度隨溫度增加並在～760℃達到一最大。如隨著溫度 540℃增加 760℃的分解程度從 9.5%增至 98.0%。

氣流中 10 毫克 CH_3-^{131}I 在矽膠及部分“Fizkhmin”TM複合的矽膠中的熱分解數據如表 2，由表中可以看出，存在矽膠 CH_3-^{131}I 的分解程度在 540℃即有 96.8

%，分解程度急劇隨溫度的降低而降低，如溫度從～540℃下降到～240℃，CH_3-[131]I 分解從 96.8～降低到～0.03%。

氣流中 10 毫克 CH_3-[131]I 在浸漬 Cu 和 Ni 化合物的“Fizkhmin” TM 複合材料中的熱分解數據如表 3，從表 3 中可見使用含有 d-元素“Fizkhmin” TM 複合材料允許 CH_3-[131]I 的分解溫度可以從～540℃降低到～450℃，即幾乎降 100℃。例如使用 KKM-8Ni 材料 CH_3-[131]I 分解程度從～39%增加至～92%在溫度從 340℃增加到 450C。 用含有 Cu 和 Ni 化合物的其他複合材料觀察到類似的效果。

因此，本研究所使用被具有 d-元素浸漬的矽膠“Fizkhmin” TM 複合材料允許 CH_3-[131]I 分解溫度降低 300℃以上，可用於精進現有的放射性碘的熱分解系統，應用於核能產業環境保護之放射性碘處理。

表 1：氣流中甲基碘的熱分解結果

Material	T, °C	Degree of ^{131}I sorption, %			The total degree of ^{131}I sorption, %	
		Column with material	Column with SiO_2-Cu^0	Scrubber with 0.05 M Na_2SO_3	Without accounting of thermal decomposition	With accounting of thermal decomposition
-*	540	-	~7.49	~0.004	~0	~7.50
	550	-	~9.45	~0.004	~0	~9.50
-	640	-	~74.97	~0.004	~0	~75.00
	760	-	~97.95	~0.004	~0	~98.00
Glass cylinders	550	~0.004	~19.51	~0.003	~0	~19.51
	660	~0.03	~73.94	~0.015	~0	~73.99

*-linear rate of gas flow~8.9 cm/s, time of the air flow presence in the heating zone with length 5.2 cm - 0.6 s.

表 2：氣流中甲基碘的在矽膠中熱分解結果

Material under study	T, °C	Degree of ^{131}I sorption, %			The total degree of ^{131}I sorption, %	
		Column with material under study	Column with SiO_2-Cu^0	Scrubber with 0.05 M Na_2SO_3	Without accounting of thermal decomposition	With accounting of thermal decomposition
Silica gel	240	~2.12	~0.03	~0.006	~2.12	~2.16
	350	~1.15	~8.99	~0.007	~1.15	~10.15
	460	~0.54	~76.20	~0.009	~0.54	~76.74
	540	~0.31	~96.75	~0.012	~0.31	~97.07
Silica gel-NH_4OH	340	~0.45	~7.99	~0.002	~0.45	~8.44
Silica gel-NH_4NO_3	340	~0.23	~3.09	~0.002	~0.23	~3.32

表 3：氣流中甲基碘的在複合材料 “Fizkhmin” TM 中熱分解結果

Composite "Fizkhimin"TM	T, °C	Degree of ^{131}I sorption, %			The total degree of ^{131}I sorption, %	
		Column with composite Fizkhimin"TM	Column with SiO_2-Cu^0	Scrubber with 0.05 M Na_2SO_3	Without accounting of thermal decomposition	With accounting of thermal decomposition
KKM-8Cu	240	~9.31	~4.40	~0.002	~9.31	~13.72
	340	~3.96	~58.14	~0.002	~3.96	~62.10
	450	~1.33	~91.80	~0.013	~1.33	~93.15
KKM-5Cu5Ni	235	~6.93	~1.60	~0.002	~6.93	~8.52
	345	~15.97	~51.19	~0.003	~15.97	~67.15
	445	~2.89	~94.96	~0.009	~2.89	~97.85
KKM-2Cu8Ni	250	~12.48	~7.15	~0.006	~12.48	~19.64
	350	~37.59	~51.62	~0.026	~37.59	~89.24
	480	~2.26	~96.45	~0.039	~2.26	~98.75
KKM-8Ni	260	~15.86	~12.68	~0.016	~15.86	~28.56
	340	~48.75	~38.88	~0.016	~48.75	~87.79
	450	~7.63	~91.82	~0.026	~7.63	~99.48

7. Gas-Phase Conversion of the U(VI), Sr, Mo,and Zr Oxides in Nitrating Atmosphere

本篇作者為俄羅斯 Sergey A. Kulyukhin, Yurii M. Nevoin, Natalya A. Konovalova,Andrey V. Gordeev, Alexey A. Bessonov, Margarita P. Gorbacheva, Andrey Yu. Shadrin2, Konstantin N. Dvoeglazov 等人。

用過核子燃料(Spent Nuclear Fuel，SNF)再處理的技術主要目的是要回收蘊含於用過核子燃料中的可用能源，並利用此能源供應未來進步型快中子反應器使用，以減低核子廢棄物的總量和有害物質，目前典型的再處理技術為做鈽鈾萃取回收（Plutonium andUraniumRecovery byExtraction，PUREX）技術。鈽鈾萃取回收法是將用過核子燃料研碎後用強酸溶解，然後用有機溶劑（比如磷酸三丁酯）萃取，最後用離子交換方法分離。而另外也再找替代 PUREX 的 SFN 再處理技術，其中是一個技術是對於 SNF 和鋯合金燃料包殼進行 voloxidation(volume oxidation) ，隨後再以含有 NOx 氣的氣體中處理 voloxidation 的產物，此技術在俄羅斯和其他國家正在發展。

Voloxidation 允許揮發性成分（如 ^{3}H，^{14}C，^{129}I，放射性惰性氣體）在開始進行燃料的放射化學再處理前先移除，鋯燃料包層轉化為 ZrO_2，UO_2 轉化為 U_3O_8。然而 SNF 溶解於硝酸的步驟中經常形成膠體的問題，較好的方式是不以

硝酸溶解而以氮氧化物(nitrogen oxides)處理 SNF 經 voloxidation 的產物，以得到弱水合水溶性鈾化合物。

本研究的目的是確認 U_3O_8（模擬 SNF 氧化的 voloxidation 的產物），MoO_3、SrO（模擬裂變元素的氧化物），ZrO_2（模擬燃料棒包層氧化產物），以及它們的混合物，在含（NOX +蒸汽 H_2O）或 HNO_3（蒸氣）的氣體中氣相轉化為水溶性化合物的可能性。

本研究之 U_3O_8 在硝化氣體的氣相轉化形成水溶性化合物的反應方程式描述如下：由實驗證明了 U_3O_8 會在硝化氣體中氣相轉換形成水溶性硝酸鹽化合物。U_3O_8 在含 NOX - H_2O(蒸汽）的氣相轉化產物之紅外線光譜圖如圖 19。

$$U_3O_8 + 6NO_2 + 2O_2 + 3nH_2O = 3UO_2(NO_3)_2{\cdot}nH_2O \ (n = 0, 1, 3 \text{ or } 6) \tag{1}$$

$$U_3O_8 + 3H_2O + 3NO_2 + 1/2O_2 = 3UO_2(OH)(NO_3) \tag{2}$$

$$U_3O_8 + 8HNO_3 = 3UO_2(NO_3)_2{\cdot}nH_2O + 2NO_2 + 4H_2O \ (n = 0, 1, 3 \text{ or } 6) \tag{3}$$

$$U_3O_8 + 5HNO_3 = 3UO_2(OH)(NO_3) + 2NO_2 + H_2O. \tag{4}$$

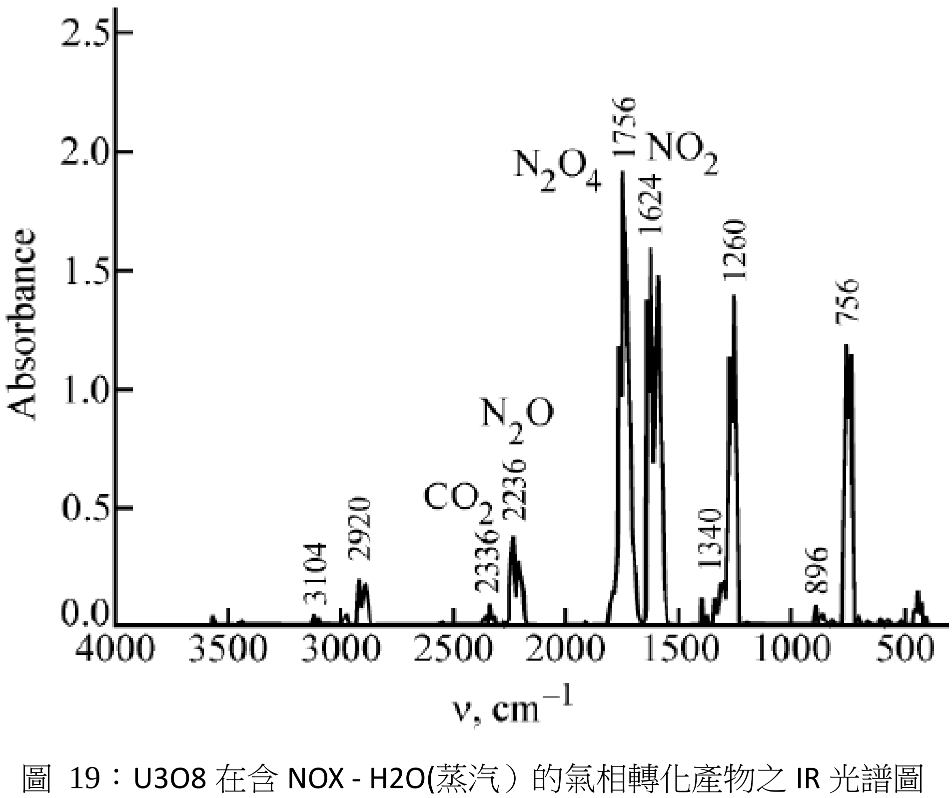


圖 19：U3O8 在含 NOX - H2O(蒸汽）的氣相轉化產物之 IR 光譜圖

本研究之 SrO 在硝化氣體的氣相轉化形成水溶性化合物的反應方程式描述如下：由實驗結果證明了 SrO 會在硝化氣體中氣相轉換形成水溶性硝酸鹽化合物。

$$SrO + 2NO_2 + 1/2O_2 = Sr(NO_3)_2, \tag{6}$$
$$2SrO + 2NO_2 + H_2O + 1/2O_2 = 2Sr(NO_3)OH \tag{7}$$
$$SrO + 2HNO_3 = Sr(NO_3)_2 + H_2O \tag{8}$$
$$SrO + HNO_3 = Sr(OH)NO_3 \tag{9}$$

$$SrO + H_2O = Sr(OH)_2 \tag{10}$$
$$Sr(OH)_2 + HNO_3 = Sr(OH)NO_3 + H_2O \tag{11}$$
$$Sr(OH)_2 + 2HNO_3 = Sr(NO_3)_2 + 2H_2O \tag{12}$$

而 MoO_3 在硝化氣體的氣相轉化形成水溶性化合物的反應可用下列假設之方程式描述。由實際的實驗結果顯示了 MoO_3 在硝化氣體中氣相轉換形成水溶性化合物並不會顯著的發生。

$$MoO_3 + 2NO_2 + 1/2O_2 = MoO_2(NO_3)_2 \tag{13}$$
$$MoO_3 + 4NO_2 + O_2 = MoO(NO_3)_4 \tag{14}$$
$$MoO_3 + 2HNO_3 = MoO_2(NO_3)_2 + H_2O \tag{15}$$
$$MoO_3 + 4HNO_3 = MoO(NO_3)_4 + 2H_2O \tag{16}$$

同樣的 ZrO_2 在硝化氣體的氣相轉化形成水溶性化合物的反應可用下列假設之方程式描述。經由實驗結果發現 ZrO_2 的反應類似於 MoO_3 的反應，在硝化氣體中氣相轉化 ZrO_2 為水溶性化合物不會顯著的發生。

$$ZrO_2 + 2NO_2 + 1/2O_2 = ZrO(NO_3)_2, \tag{17}$$
$$ZrO_2 + 4NO_2 + O_2 = Zr(NO_3)_4, \tag{18}$$
$$ZrO_2 + 2HNO_3 = ZrO(NO_3)_2 + H_2O, \tag{19}$$
$$ZrO_2 + 4HNO_3 = Zr(NO_3)_4 + 2H_2O. \tag{20}$$

三、心得

2016 第二屆核科學與工程研討會所討論之議題相當廣泛，本次參與報告之研究人員除了幾位年紀較大之學者，大部分皆為年輕之研究人員，積極的發表研究成果，展現出對所屬研究領域的熱誠，透過本次會議中，大幅感受到不同領域研發工作之應用與蓬勃發展，舉凡電腦程式計算模擬在各項物質、熱交換器、偵檢器設計、材料特性研發、核化學領域等等，國際間各領域之研究皆致力開發新方法與技術及推展應用，相關成果皆可供國內各項研究工作參考。

對於核子事故或用過核燃料處理可能產生之放射性揮發物質如 I-131，在此會議中有相關論文提出新的材料物質來處理放射性的 CH_3-^{131}I，其結果可效率的將熱分解之溫度降低，此材料技術應可應用於國內在核子事故、除役或處理高放射性廢物的過程中對於可能產生之放射性揮發物質處理。

四、建議事項

(一) 本會議在大陸西安主辦，同時結合了 The 5th Conference on Computational Mechanics (CCM 2016)、The 4th Int'l Conference on Molecular, Atomic, Nuclear and Particle Physics (MANPP 2016)、 The 3rd Int'l Conference on Radiation Effects and Radiation Protection (RERP 2016)、 The 2nd Int'l Conference on Ultrasonics and Applications (ICUA 2016)、 The 2nd Int'l Conference on Plasma Physics and Applications (PPA 2016)、 Conference on High Energy Physics (HEP 2016)、 Int'l Conference on Theoretical and Computational Physics (TCP 2016)、 The 3rd Conference on Heat Energy (HE 2016)等研討會，非單一學術領域，被接受之會議論文發表於 Journal of Applied Mathematics and Physics (ISSN: 2327-4352)期刊，同時也有其他領域期刊文獻在與會中邀稿。建議本所同仁可藉由參與類似會議得到文獻發表之機會，藉機彰顯本所研究成果。

(二) 本會議所包含之領域眾多，與會人員所學專長均不相同，因此會議參與人員可在短時間內接觸到非常多不同的研究應用領域，了解不同領域專家之間思考模式差異，對於研究人員可增廣見識。建議與會人員可透過會議後的討論聚焦於相關研究領域，結識與本所發展契合的國際學者，可有效加速國內在相關領域之研發進程。

(三) 國際研討會提供一個技術交流的平台，讓各界專家學者進行討論及經驗分享，藉由參加研討會可吸取來自國際各專家之實務作法與未來發展趨勢，大幅減少研究人員的摸索時間，同時並可認識該領域之專家，拓展人脈以及視野。因此建議本所應持續派員出國參加類似之研討會，積極參與國際會議使研究人員可即時掌握研究發展之最新趨勢。

五、附錄

附件一、本會議現場發表論文

Technical Session 1: Physics I

Session Chair: Prof. Philipp Rudolf von Rohr, Institute of Process Engineering, Switzerland
Zhaoxing Room(昭行厅), 3rd Floor 14:00-18:00, Thursday Afternoon, August 25, 2016

ID	Paper Title	Author	Affiliation
1-1	Unstructured grid convergence study	Ganbo Deng	CNRS
1-2	CFD simulation of magnetorheological fluid Pin-Bushings	Peng Zhang	INHA University
1-3	Boundary element analysis of two dimensional structure water entry based on attached water quality	Zou Li	State Key Laboratory of Structural Analysis for Industrial Equipment
1-4	Solving the direct and inverse problems of the Helmhotz equation for a multiply connected domain using the multiple-source, multiple-scales Trefftz method	Weichung Yeih	National Taiwan Ocean University
1-5	Numerical Analysis on the Oscillator of External Stimulation and Self-excited	Li Junlong	School of Chemical Machinery and Safety, Dalian University of Technology
1-6	Simulation of crack propagation in fiber reinforced concrete using embedded zero-thickness cohesive elements	S. Tarasovs	University of Latvia
1-7	A Study on Prediction of Building Load using Building Characteristic Coefficient	Seong-Yeon Yoo	Chungnam National University
1-8	Experimental Investigation of Loop Heat Pipe with Two Evaporators/Two Condensers under Thermal Vacuum Condition	XInyu Chang	Nagoya University Japan
16:00-16:20	**Coffee Break**		

1-9	Closed/open-cell Photoacoustic Imaging for Spectroscopic Measurements	Tsutomu Hoshimiya	Tohoku gakuin University
1-10	Prediction of Residual Stress of U-Bending Heat Transfer Tube of Steam Generator	Ok-gyu Kwak	R&D Center, BHI Co., LTD, Haman, South Korea
1-11	Measurement of the neutron field on the surface of QUINTA setup under 660 MeV protons irradiation	Jindrich Adam	Joint Institute for Nuclear Research
1-12	Prediction of golden time using CFNN for recovering SIS under severe accidents in NPPs	Kwae Hwan Yoo	Chosun University
1-13	Estimation Uncertainty of Break Size of Loss-of-Coolant Accident Using Cascaded Fuzzy Neural Networks	Geon Pil Choi	Department of Nuclear Engineering, Chosun University
1-14	FACTORS AFFECTING IN FORMATION OF NEUTRON FIELDS FROM RADIONUCLIDE NEUTRON SOURCES FOR DOSIMETRY	Sergey Fedorov	FSUE "VNIIFTRI"

Technical Session 2: Agriculture

Session Chair: Prof. Rajinder Ranu, Colorado State University, USA

Jude Room(居德厅) 3rd Floor 14:00-18:00, Thursday Afternoon, August 25, 2016

ID	Paper Title	Author	Affiliation
1-1	Rhizobia biological characteristic valorization and input rationalization for sustainable agriculture and environment preservation	Sifi Bouaziz	Agronomy INRAT
1-2	Application of Inflow Model for Weir Irrigation System without Upstream Dam	Sombat Chuenchooklin	Naresuan University
1-3	Role of an algaecidal compound in mediating the expression of immune-related genes in shellfish	Cheng Chi	Laboratory of Aquatic Biomedicine, College of Veterinary Medicine and Research Institute for Veterinary Science, Seoul National University

1-4	Isolation of bacteriophage (pVsp-14) against *Vibrio splendidus* as the causative agent of bacillary necrosis of Pacific oyster (*Crassostrea gigas*) larvae	Hyoun Joong Kim	Laboratory of Aquatic Biomedicine, College of Veterinary Medicine and Research Institute for Veterinary Science, Seoul National University
1-5	Study the changes of serum protein electrophoretic pattern induced by metronidazole and levamisole in common carp	Mohammad Razi Jalali	Shahid Chamran University of Ahvaz
1-6	Total Replacement of Fish Meal With Poultry Offal Meal Enhances The Growth Performance and Feed Utilizatin In Snakehead, Channa striata Juvenile	NURUL NADIAH MUSTAPAR	Universiti Sains Malaysia
1-7	GALACTOOLIGOSACCHARIDE (GOS) AND COMBINATION OF YEAST + β GLUCAN (YBG) ENHANCES GROWTH AND IMPROVES INTESTINAL CONDITION IN STRIPED CATFISH (Pangasianodon hypophthalmus) FED SOYBEAN MEAL DIETS	Amalia Sutriana	Universiti Sains Malaysia
1-8	The impact of heat stress on lodging resistance in canola	Wei Wu	Ottawa Research and Development Centre, Agriculture and Agri-Food Canada
1-9	Influence of cultivars on the development of fungal pathogens in carrot and onion plants	Martin Koudela	Czech University of Life Sciences Prague
1-10	Influence of seed thermal treatment on development of fungal pathogens in carrot and onion plants	Cenek Novotny	Institute of Microbiology CAS, Prague, Czech Republic
1-11	The Structural Proteins of Bdellovibrio bacteriovorus Bacteriophage MAC-1.	Rajinder Ranu	Colorado State University
1-12	Soil Moisture Content of Date Palm Varieties (Phoenix dactylifera L) as Affected by Water Harvesting Methods and NP-fertilizer Rates	Mohammed Sani Isiyaku	Federal University

1-13	Role of pectin-esterase to improve the storage life of Kinnow fruit during cold storage	Ayesha Maryam	University of Agriculture
1-14	Development of a new fermented pumpkin-based beverage inoculated with water kefir grains by response surface methodology (RSM)	Wee Yin Koh	Universiti Sains Malaysia
1-15	CIPA: a new epidemiological tool to assess retrospective occupational exposure to pesticides in France	Johan Spinosi	French institute for public health surveillance
1-16	Quantification of Nutrient Uptake and Absorption in Vanilla xtahitensis cv Tahiti and Haapape to Optimize Vanilla Production	Johan Perret	Soil Science and Plant Nutrition, EARTH University
1-17	IMPLICATIONS OF APPLYING SUPERPHOSPHATE-P, ROCK-P, COMPOST AND SULPHER SINGLY OR IN COMBINATIONS TO MAIZE (Zea mays) ON YIELD AND NPK CONTENT	Haythum Salem	Benha University, Egypt
1-18	Selenium Mobility in Some Egyptian Soils	Abdou Soaud	Cairo University
1-19	Canola Plant Yield As Influenced By Treated Rock Phosphate With Different Amendments	Mohamed ElSayed Ali	Benha University, Egypt
1-20	STUDY ON THE NITROGEN NUTRITION IN SOYBEAN USING 15N ISOTOPE TRACER TECHNOLOGY IN MOLLISOL	Jun Yan	Northeast Institute of Geography and Agricultural Ecology, Chinese Academy of Sciences
1-21	Effect of different rates of nitrogen and phosphorous on growth and nodulation of Glycine max in the Eastern region of Sri Lanka	Somasundaram Sutharsan	Eastern University Sri Lanka
1-22 **Poster**	EFFECT OF DIFFERENT SALINITY CONCENTRATION ON GILL OF BENNI Barbus sharpeyi	Hassan Morovvati	Department of Basic Science, Faculty of Veterinary Medicine, University of Tehran

1-23 Poster	A histo-anatomical study on the spleens of a silky shark, Carcharhinus menisorrah	Hassan Morovvati	Department of Basic Science, Faculty of Veterinary Medicine, University of Tehran

Technical Session 3: Physics II

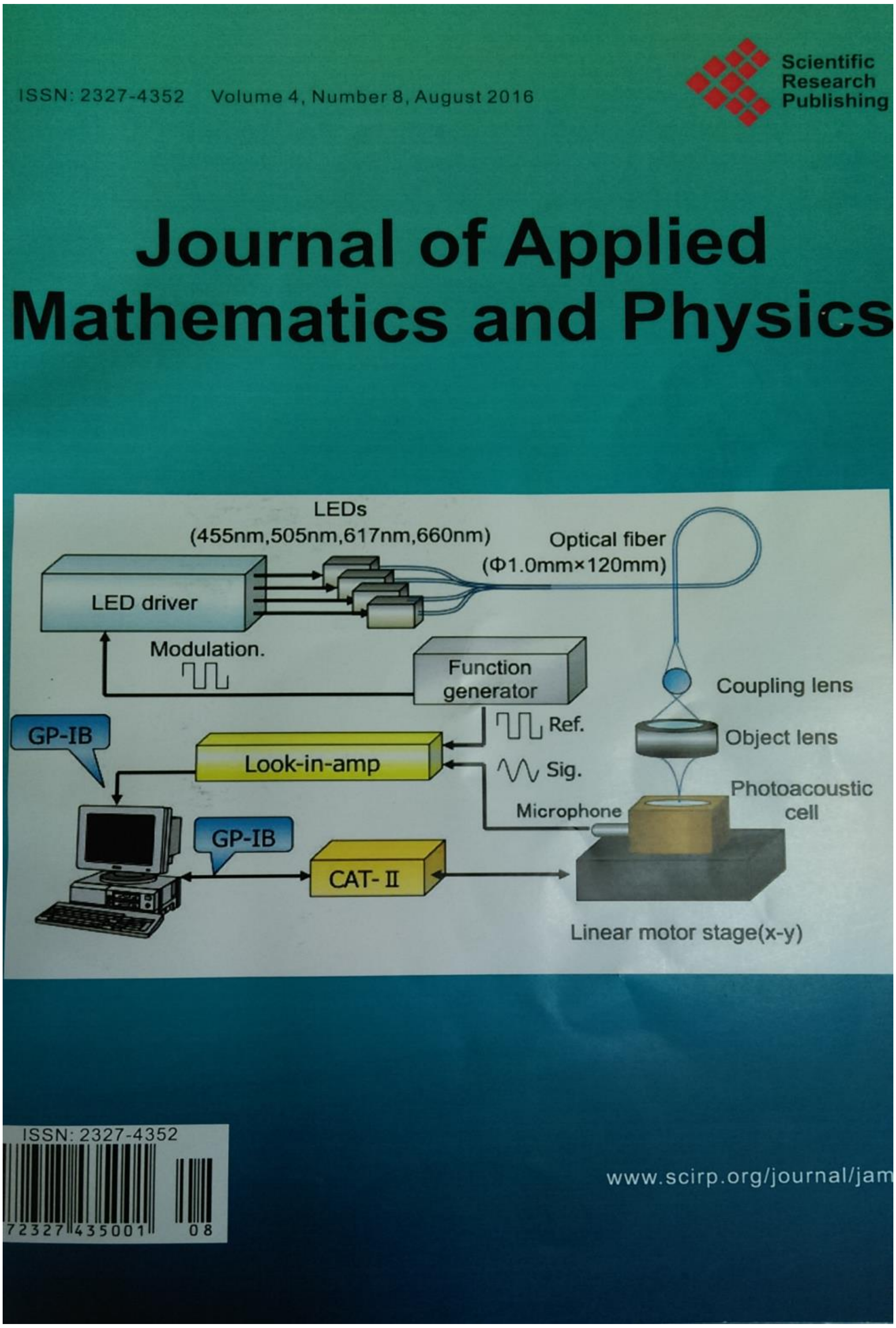
Session Chair: Dr. David Le Hardy, University of Nantes, France

Zhaoxing Room(昭行厅), 3rd Floor 09:00-12:00, Friday Morning, August 26, 2016

ID	Paper Title	Author	Affiliation
1-1	Grid Deformation for Multi-Body Geometry by Potential Flow Solution	Byoungsoo Kim	Chungnam National University
1-2	Dynamical Traps as Stationary Point Generalization for Systems with Fuzzy Rationality	Ihor Lubashevsky	University of Aizu
1-3	3D radiative transfer equation coupled with heat conduction equation with realistic boundary conditions applied on complex geometries	c	University of Nantes
1-4	MODELING LIGHT PROPAGATION THROUGH TURBID MEDIA VIA NUMERICAL SOLUTION OF MAXWELL'S EQUATIONS	Snow Tseng	National Taiwan University
1-5	Asymptotic Solutions of the Kinetic Boltzmann Equation and Multicomponent Non-equilibrium Gas Dynamics	Sergey Serov	Fundamental Researches Department, RFNC-VNIIEF
1-6	A study on numerical calculation method of small cluster density in percolation model	Xucheng Wang	Jiangsu Tianyi High School
1-7	Protein contact prediction based on information theory	Julian Lee	Soongsil University
1-8	Optical spectroscopic investigation of TiO2-like polymerization processes by inductively cou-pled plasma	Zhiling Li	Guizhou Institute of Technology

1-9	Expanding Space-Time and Variable Vacuum Energy	Claudio Parmeggiani	University of Milano-Bicocca, Italy
1-10 **Poster**	Gas-phase conversion of the U(VI), Sr, Mo, and Zr oxides in nitrating atmosphere	Sergey Kulyukhin	IPCE RAS
1-11 **Poster**	A Study of the Thermal Decomposition of CH3131I in A Gas Flow in the Presence of "Fizkhmin"TM Granulated Materials	Alexey Bessonov	IPCE RAS

附件二、投稿論文期刊發表



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HPGe and Scintillation Detectors Comparisons on Waste Drums Radioactivity Measurement

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Abstract

Two measurement systems, one being comprised of three HPGe detectors and the other being a 4π measurement system of the assembly of 10 sets of scintillation detectors, were compared for their measurement performance in operations of radioactive waste drum radioactivity measurement and clearance and release operation of decommissioning. The system features of the former were high costs, capable of identifying radionuclides, a measurement time of about 1000 sec. The system features of the latter were high sensibility, capable of identifying hotspots, a measurement time of about 100 sec. Various comparisons were made for the differences of the two systems on reference drums, whole-drum homogeneous and non-homogeneous metal drums and non-metal drums, whole-drums of different filling rates. The aim was to compare the differences of the two measurement systems in measuring radioactivity of critical radionuclides of ^{137}Cs, ^{54}Mn and ^{60}Co.

Keywords

HPGe Detector, Scintillation Detector, Clearance

1. Introduction

For nuclear facilities decommissioning, HPGe detectors and highly sensible scintillation detectors which are capable of identifying energies and usually placed inside lead shields are used to measure the very low radioactivity (IAEA ≤ 0.1 Bq/g) of radioactive waste for clearance operations. The Institute of Nuclear Energy Research (INER) established two gamma radioactivity measurement systems which were respectively comprised of three HPGe detectors and 10 sets of scintillation detectors (4πmeasurement system) [1] [2]. The main critical radionuclides measured by the two systems are ^{137}Cs, ^{54}Mn and ^{60}Co. These two systems passed comparison programs on radioactive waste radioactivity measurements organized in Taiwan in 2009 and 2015 [3] [4]. The aim of this article is to discuss the difference of radioactivity analyses in various scenarios containing reference drums with homogeneous radioactivity distribution, waste drums with radioactivity similar to non-metal drums with homogeneous radioactivity distribution and metal drums with non-homogeneous radioactivity distribution, different filling ratios of whole-drum materials by using these two measurement systems.

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http://dx.doi.org/10.4236/jamp.2016.48154

2. Materials and Methods

Two measurement systems, one being comprised of three HPGe detectors (Canberra Q2) and the other being a 4π measurement system of the assembly of 10 sets of scintillation detectors (INER SWAM2) are illustrated as **Figure 1**. These two measurement systems were put to use under the assumption of using drums of homogeneous distribution, simulation of point radioactive source theory calculation and establishment of multiple-density reference drums to come out with counting efficiencies as given in **Figure 2**. The HPGe detectors measurement system and the scintillation detectors measurement system had respective standard combined uncertainties of 9% and 7%. For the uncertainty evaluation of radioactivity measurement, decommissioning wastes were measured following the guideline from ISO. The performance differences of both measurement systems were listed in **Table 1**.

In this article, the concerned critical radionuclides were ^{137}Cs, ^{60}Co and ^{54}Mn. These sources used were traceable to the national radiation standards with a standard uncertainty of less than 1%. These critical radionuclides were used to make 40 cm diameter large-area source slice and1.5 cm diameter 60 cm long rod-shaped liquid

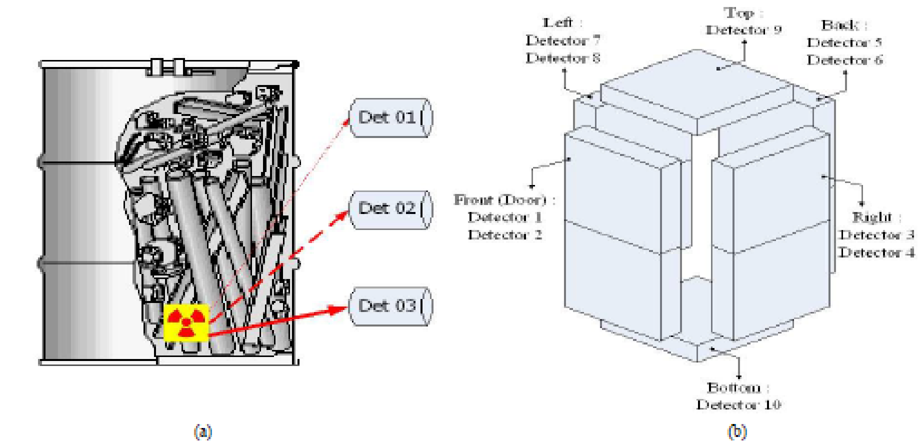

Figure 1. Measurement system of (a) three HPGe detectors and (b) 4πscintillation detectors.

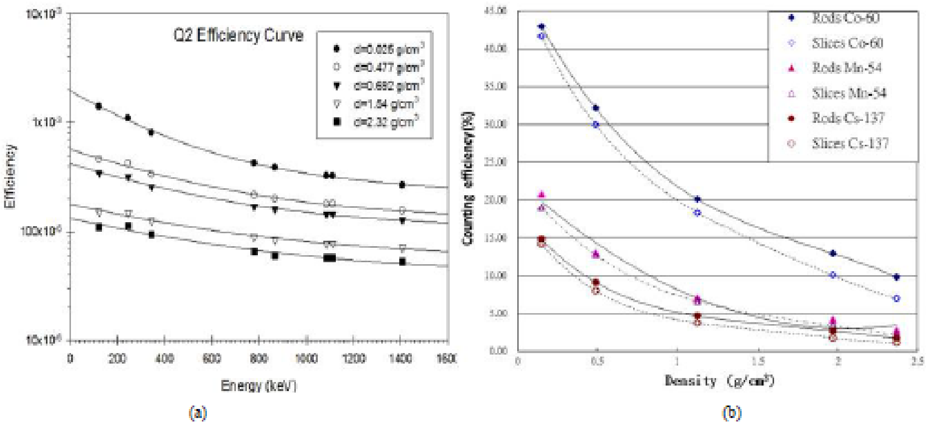

Figure 2. Efficiency of (a) three HPGe detectors and (b) 4π scintillation detectors.

Table 1. Characteristic of test drums for activity measurement.

Matrix	Density (g/cm³)	Totalactives (Bq)	Source distr.
Water	1.0	~10E3	uniform
Concrete	1.9	~10E3	near uniform
Carbon	1.0	~10E7	near uniform
Plastic	1.1	~10E5	near uniform
Resin	0.9	~10E5	near uniform
Concrete	1.8 - 2.1	~10E5	near uniform
Aluminium plate	0.4 - 0.9	~10E2	non uniform
Iron plate	0.7 - 0.9	~10E5	non uniform
Iron tube	0.5 - 0.9	~10E5	non uniform

source with homogeneous distribution. The radioactivities of the source slice and source rod were about 30 kBq and the uncertainties were less than1.5% (k = 2). For simulations of decommission wastes, test drums were made for various energies, matrix, densities, radioactivities and source distribution. Furthermore, single and mixed source containing ^{137}Cs, ^{60}Co and ^{54}Mn of water solution test drum and 16 source rods of concrete test drum were constructed with a homogeneous radioactivity distribution. Five metal test drums were made for different radiation hotspots positions on the upper, middle and lower horizontal levels of the iron plate of the drum, on the vertical center and on the tilting side with non-homogeneous radioactivity distribution. Three kinds of non-metal drums of different materials (resin, plastics, carbon) with homogeneous radioactivity distribution, 20 drums of aluminum plate with non-homogeneous radioactivity distribution, 16 drums of concrete with homogeneous radioactivity distribution and four drums with different filling ratios of plastic matrix were constructed. The homogeneity of radioactivity distribution was the ratio of the maximum cps from the individual scintillation detector to the average cps of all the scintillation detectors. The homogeneity of the water solution of the 10 detectors was lower than 1.5.

3. Result and Discussions

Five simulations of 55 gallon drums with source distribution under different geometrical conditions were performed to compare the measurement results of these two measurement systems for the radioactivities of critical radionuclides of ^{137}Cs, ^{54}Mn and ^{60}Co as the following:

Reference drum

The reference drums used were traceable to the national radiation standards. Two types of reference drums containing water solution were constructed, one being made with a single radionuclide, the other being made with mixed radionuclides of ^{137}Cs, ^{54}Mn and ^{60}Co. The measurement results of the two measurement systems are given in the **Table 2**. The maximum difference among the reference drums using single radionuclides and mixed radionuclides were 19%and 20%, respectively.

Hot-spot test

The measurement results of the metal drum of non-homogeneous radioactivity distribution are given in the **Figure 3** when the hot-spot lies in the upper, middle and lower levels of the horizontal axial or lies in the center or tilting part of the vertical axial of the whole drum. It showed that the radioactivity differences of the five hotspot positions of the scintillation detectors were larger than those of the HPGe detectors. The4πmeasurement system can identify the locations of the hotspots. However, the total radioactivity measurement of this system is obtained by adding up all the radioactivity results of every detector. It lacks of the weighting factors of individual detector for radioactivity corrections. In addition, both systems have their largest difference in the measurement results as the hotspots lying in the vertical axial center in the drums with non-homogenous distribution. Since the hotspots of ^{137}Cs and ^{60}Co are farthest away from the detectors, the self-absorption effect will also be the maximum.

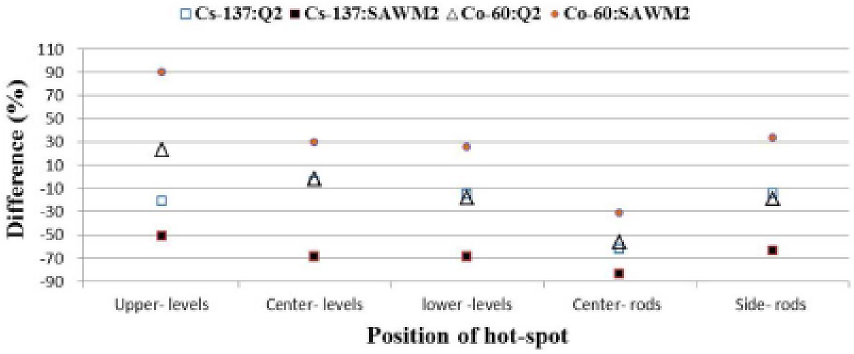

Figure 3. Comparison radioactivity of hot spots at different position of whole drum.

Table 2. Comparison activities of reference material drum..

Nuclide	Activity (Bq)	Difference (%)	
		Q2	SWAM2
^{137}Cs	4000	1.2	7.8
^{54}Mn	3660	16.0	−4.5
^{60}Co	3957	5.0	19.2
Mix-^{137}Cs	2000	−20.0	18.8
Mix-^{54}Mn	1830	11.8	9.4
Mix-^{60}Co	1980	11.2	17.6

Non-metal drums of homogeneous distribution

For the non-metal drums of homogeneous radioactivity distribution made of plastics, concrete, resin and carbon whose radioactivity in carbon was about 10E7, the measurement results of the two systems are given in **Figure 4**. When compared with the measurement average values obtained by the HPGe detectors for the four non-metal drums with homogeneous radioactivity distribution, the differences of these two measurement systems are all less than 12%. One thing noteworthy is that the differences obtained by the HPGe detectors for high radioactivity carbon in ^{60}Co were about 33% and the differences obtained by the scintillation detectors for concrete radionuclides were about 26% in ^{137}Cs.In addition, based on the measurement of HPGe system, the comparison of measurement results of ^{137}Cs between two systems was given in **Figure 5**, the differences were about −8.7% to −16.3%.

Metal drums of non-homogeneous distribution

For the clearance measurement operation of decommissioning in nuclear research institutes, the judgment of the compliance of the low radioactivity waste with the IAEA clearance standards (≤0.1 Bq/g) were carried out. Sampling twenty metal drums of non-homogeneous distribution containing aluminum waste were measured for the residualradioactivity. Comparison of measurement difference between two systems is given in **Figure 6**. The maximum difference in ^{137}Cs was 0.2% - 39%. The measurement results of the five of the 20 drums were lower than the MDA value and the measurement values obtained by the HPGe detectors were about 0.002 Bq/g.

Filling ratio of drum matrix

Test drums with the same density of plastic matrix ofwhole-drum and respective filling ratios of 25%, 50%, 75% and 100% were prepared. In the above drums, large-area reference area sources were evenly placed inside. The differences of both systems in measurement radioactivities are given in **Figure 7**. When the matrix filling ratio was higher than 75%, the radioactivity differences of the critical radionuclides of ^{137}Cs, ^{54}Mn and ^{60}Co were less than 20%. When the matrix filling ratios were between 25% and 50%, there were few radionuclides whose differences were higher than 20% for critical radionuclides.

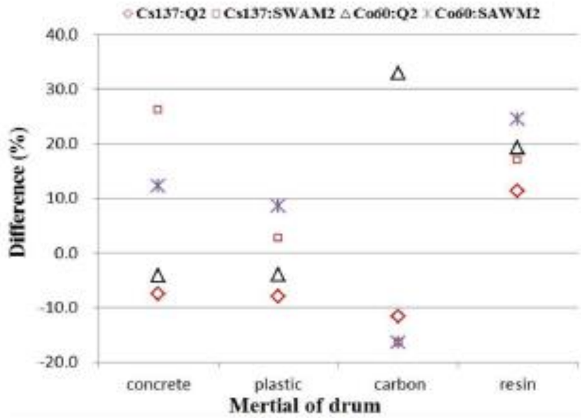

Figure 4. Comparison the measurement of non-metal drums with homogeneous radioactivity distribution.

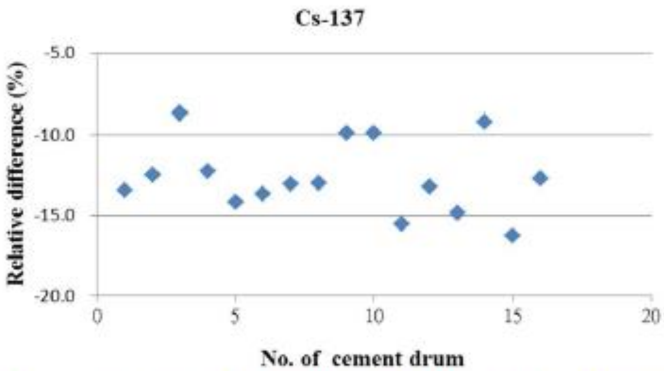

Figure 5. Comparison measurement of concrete drums with homogeneous radioactivity distribution.

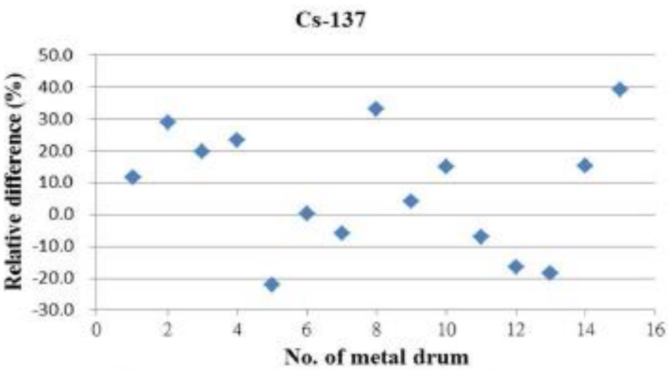

Figure 6. Comparison the measurement of waste metal drums with non-homogeneous radioactivity distribution.

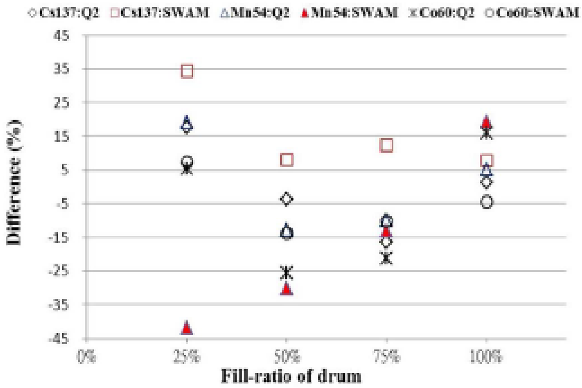

Figure 7. Comparison the difference of radionuclides activity of plastic drums with different filling rate.

4. Conclusion

According to the characteristics and the radioactivity measurement results of these two systems, it appeared that the measurement result of scintillation detectors system is suitable for the determination of the long half-life radionuclides for clearance and the release for very low activity wastes. HPGe detectors systemis suitable for establishing historical radiation data of inventory drums in storage sites such as complicated radionuclides and measurements for classification of matrices and low level radioactivity standards. The measurement time consumed by scintillation detectors is much lower than HPGe detectors. However, for the drums which have hotspots and non-homogeneous radioactivity distribution, scintillation detectors have greater measurement differences and MDA than HPGe detectors. In the measurement process of release, it seems obviously that scintillation detectors system is appropriate for a pre-screening process and then verified by HPGe system for sampling.

References

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