台灣電力公司
用過核子燃料最終處置計畫

我國用過核子燃料最終處置初步安全論證報告
— 選址前安全論證之初步發展

(Preliminary Development of Pre-siting Safety Case)

國際同儕審查報告
(中譯版)

國際審查小組委員
Patrik Vidstrand (召集人)
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中華民國111年10月

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簽名頁

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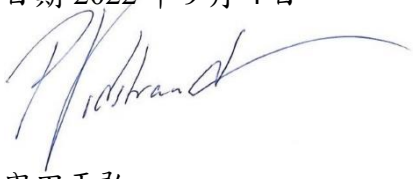

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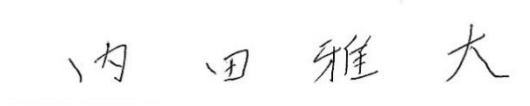

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1. 前言

1.1 背景

台灣自 1978 年以來即使用核能發電，預計產生約 5,000 噸(MTU)用過核子燃料(Spent Nuclear Fuel)，其中分別包括 17,890 束沸水式反應器(BWR)用過核子燃料與 4,320 束壓水式反應器(PWR)用過核子燃料。

管理用過核子燃料等放射性廢棄物需要在很長一段時間內將其隔離於人類及生活環境之外。地質處置系統可為放射性廢棄物提供獨特的保護能力與長時間的隔離。深層地質處置場概念即利用地質與工程材料與解決方案的能力來實現安全功能；這些措施可協力達成隔離與圍阻功能，並在必要時延緩放射性廢棄物的放射性核種遷移。跟全球普遍採用地質處置場概念進行高放射性廢棄物管理的方式一樣，台灣亦採取在穩定地質構造中處置用過核子燃料以進行長期管理的策略。在現行的管制制度下，核能電廠的所有者與經營者，台灣電力公司(Taiwan Power Company, TPC)應負責其核能電廠產生的所有用過核子燃料之最終處置。

行政院原子能委員會(Atomic Energy Council, AEC)為台灣放射性廢棄物管理體系中的核能安全主管機關。

台灣自 1986 年以來即持續推動用過核子燃料處置的相關研發與驗證研究。發展地質處置系統的長期作業係由台灣電力公司於 2006 年提報用過核子燃料最終處置計畫，並經原子能委員會核定實施。該計畫每四年應檢討修正，目前最新版次為 2018 年修訂版。

台灣的用過核子燃料最終處置計畫採用國際共通的階段式發展作法與決策理念，並循序推動管理計畫，以尋求設置高放射性廢棄物地質處置場。

台灣的用過核子燃料最終處置計畫定義五個不同的階段，包括：1.潛在的母岩特性調查與評估；2.候選場址與核定；3、場址詳細調查與試驗；4.處置場設計與安全分析評估；5.處置場建造。目前五個階段的計畫規劃與重要里程碑如圖 1-1。

圖 1-1：台灣用過核子燃料最終處置計畫目前五個階段的計畫規劃與重要里程碑

第一階段潛在處置母岩特性調查與評估，在台灣電力公司提交SNFD2017 報告後已完成階段任務，並經由國際審查小組與原子能委員會完成審查。第一階段的目的是評估、研究與場址調查技術的發展，同時發展台灣電力公司在處置場工程及性能與安全評估能力。第一階段未涉及任何處置設施的選址程序，但在台灣的幾個地點進行場址調查技術的測試與發展未來的選址能力。

2018 年正式展開第二階段的候選場址評選與核定工作，此即為當前的階段。

台灣原子能委員會對 SNFD2017 報告的審查結論，要求台灣電力公司應提交 SNFD2021 初步安全論證報告，及 SNFD2025 安全論證報告，以封閉後安全評估為重點。

1.2 SNFD2021 報告的目的

管制機關原子能委員會在審查 SNFD2017 報告時，要求台灣電力公司在提交SNFD2025報告之前，應先提交初步安全論證報告。SNFD2021報告即為履行此一管制要求。

此外，SNFD2021 報告的主要目的是持續強化自主能力，參照國際原子能總署(IAEA)與經濟合作暨發展組織核能署(OECD/NEA)發布的相關導則，擬定封閉後安全評估的方法。另一個目的是更加理解應如何組織系統與彙整未來用過核子燃料處置場的完整安全論證，以及如何有效開展相關工作。

最後，藉由直接審閱 SNFD2021 報告內容或在審查過程中確定知識、技術與方法方面的不足之處，為後續研發與驗證計畫以及工程障壁發展計畫之建立與發展，提供有價值的意見回饋，為工程設計、場址調查、場址建模、處置場工程與處置計畫管理等需求建立國家團隊。

1.3 國際同儕審查

依據原子能委員會的管制要求，台灣電力公司辦理 SNFD2021 報告的獨立國際專家同儕審查。

為進行同儕審查，由第三方審查協調單位財團法人核能資訊中心(Nuclear Information Center, NIC)組建一個國際審查小組，獨立於台灣電力公司或其他參與編寫 SNFD2021 報告的機構之外。

國際審查小組的所有成員都具有先進的地質處置系統經驗，並且正在或曾經參與過先進核能國家的高放射性廢棄物地質處置計畫。

國際審查小組的所有成員均無利益衝突，且未參與任何與編寫 SNFD2021 報告相關的活動。台灣電力公司或核能研究所(INER)工作人員與國際審查小組的所有書面交流均由審查協調單位負責籌劃與管理。

國際審查小組成員如下(簡歷詳附件一)：

(1) 帕特里克·維斯特蘭德(Patrik Vidstrand)(瑞典)(召集人)

(2) 內田雅大(Masahiro Uchida)(日本)

(3) 河西基(Motoi Kawanishi)(日本)

(4) 西蒙·諾里斯(Simon Norris)(英國)

(5) 佩卡·庫皮亞寧(Pekka Kupiainen)(芬蘭)

上述國際審查小組委員對本次審查中的所有陳述負責。委員意見僅代表個人觀點，而與其現職或曾任職的機構無涉。

1.4 國際同儕審查報告

國際同儕審查報告中的陳述係基於台灣電力公司所提供的英文檔案，包括 SNFD2017 報告(TPC，2017)，簡報檔中提供的其他資訊，以及台灣電力公司、核能研究所及工業技術研究院工作人員在審查期間的直接答詢。

此外，國際同儕審查報告中的陳述受到以下理解的影響：SNFD2021 報告是一份初步安全論證報告，台灣現為逐步發展處置系統的初步階段。

國際同儕審查報告中的意見陳述、建言與建議通常遵循國際原子能總署(IAEA)發布的專業術語，例如參考 SSG-23 導則。

國際審查小組認同台灣電力公司已經準備許多文件與技術報告來支持 SNFD2021 報告；但是，由於時間有限，且其他佐證文件與報告大多未譯為英文。因此，根據 6 月 23 日視訊會議，以及 8 月 2 日至 8 月 5 日

在台灣電力公司總部(台北市)舉行審查會議中，台灣電力公司在第一天為審查小組所做的簡報，本次審查的重點，主要是針對台灣提出的四項議題(摘述如下)，及其具有高度相關性的問題。

(1) 請國際審查小組評估 SNFD2021 報告是否已達成建立初步安全論證的能力。

(2) 請國際審查小組評估 SNFD2021 報告中顯示的能力與努力，是否已可做為發展 SNFD2025 報告的基礎。

(3) 請國際審查小組協助判定 SNFD2021 報告的闕漏。

(4) 國際審查的總體目標是強化並促進 SNFD2025 報告的準備工作。

因此，國際審查小組對於評估的各項主題的審查與詳細程度會有所不同。具體而言，對用於安全評估的資料、計算及模式並不會進行任何詳細的檢視。

國際審查小組係利用其成員的專業知識及其對國際典範實務的集體理解來評估台灣電力公司所提供的資訊。

2. 總結性說明

國際審查小組共同負責選擇其認為與審查目標相關的主題，並希望台灣電力公司確認提供足夠的資訊，以便能夠因應審查需求。國際同儕審查係基於台灣電力公司所提供的書面資訊，以及在視訊會議期間及舉行同儕審查會議期間，台灣處置計畫團隊對於問題的詳盡且禮貌的解釋與熱情的回答。值得注意的是，台灣電力公司所提供的所有的專業知識都來自台灣本土的處置計畫、大學與研究機構。

鑒於國際審查小組具有的廣泛國際經驗，審查報告中提出的許多觀察結果與發現可利於計畫發展，或有益於未來的 SNFD2025 安全論證報告，該報告將隨著台灣處置計畫的安全論證而持續的發展。

本國際同儕審查報告係呈現國際審查小組的共同觀點，根據 OECD/NEA 的獨立審查程序，被審查者有機會檢視審查報告的事實正確性。因財團法人核能資訊中心與台灣電力公司並無異議，故國際同儕審查報告未進行修正。

SNFD2021 報告是目前在用過核子燃料最終處置前期準備階段，研擬封閉後安全評估報告的初步彙編。該報告以 SNFD2017 技術可行性評估報告為基礎，並綜合其後所累積的更新資料、技術與國內外相關資訊進行編寫。

SNFD2021報告中明確參照瑞典KBS-3V的處置概念構建處置場系統的安全理念。主要安全功能分為圍阻與遲滯兩大項，並分別設定處置系統各重要組件的安全功能指標，以實現這些安全功能。此外，基於這些考慮，亦設定一些針對台灣本土的安全功能指標，進行封閉後的安全評估，以釐清安全功能指標是否符合管制要求。此作法完全符合國際標準，亦顯示台灣電力公司具有進行封閉後安全評估的能力。

SNFD2021 報告中所使用的評估流程與程序係參照國際公認的 OECD/NEA 方法。這也與國際標準非常一致，但最重要的是，該方法仍宜循序漸進的發展，以便發展出符合管制體系與在地條件，尤其是適合台灣用過核子燃料特性的方法。

因此，SNFD2021 報告是正確與合理的，台灣電力公司顯然能夠藉由使用國際公認方法的策略，構建可靠的封閉後安全評估，並已考慮台灣本土現況，此為合宜的作法。

雖然封閉後安全評估只是國際原子能總署定義的安全論證與用過核子燃料處置場未來應用的一部分，但 SNFD2021 報告已成功表明台灣電力公司有能力在未來完成台灣所需的安全論證。

在 SNFD2021 報告的同儕審查期間的討論與回應中，台灣處置計畫團隊表現出的技術能力與用心努力值得肯定。在初步展望 SNFD2025 報告的情況下，隨著工作流程、程序與品質保證的持續發展，以及參考本國際同儕審查報告中所提出建議，相信將可進一步強化台灣電力公司的用過核子燃料最終處置計畫。

3. 高層次審查發現

SNFD2021 報告應用了封閉後安全評估方法，但與國際原子能總署對安全論證的定義(例如國際原子能總署 SSG-23 導則)以及術語的使用相比，報告的整體篇章仍缺少相對應的闡釋。因此，建議釐清報告的編撰目的，並建議僅關注封閉後的安全，並更詳細地闡述與最重要背景報告的關聯性。

SNFD2021 報告中對處置系統及其發展過程的描述並不均衡。因此，建議將有關場址研究(例如地質調查)的地圈與生物圈評估基礎，於安全評估與模擬中更完整的整合，整合步驟可以包括資料與建模概念的驗證與確認步驟。由於目前尚在選址前階段，除非可以在潛在場址確認與瑞典 KBS-3V 概念的兼容性，否則宜加強討論工程障壁系統(EBS)的設計替代方案。

在引用文獻時宜注意科學與學術性的完全正確。引用照片、表格、圖片與草圖等應確認取得授權許可。宜考慮報告中的所有參考文獻與資訊，確保所有可能的讀者都可方便取得所有參考文獻。

封閉後的安全評估應考慮安全管制所設定的風險。設計應在最佳可用技術(BAT)中相應的考慮經濟與技術層面的優化(且應考慮合理抑低的合理情況)。此外，極為重要的是，封閉後安全評估報告僅是安全評估，亦即 SNFD2021 報告並非設計基準報告。因此，安全評估應能在國家計畫的早期階段為設計提供回饋，且為如何創建參考設計，並進一步優化與變更提供基準。對於此階段的 SNDF2021 報告與國家計畫而言，參考處置設計似乎過於詳細。

審查小組建議，宜以獨立的報告說明設計規範及其相關程序，否則未來因為安全評估中已植入錯誤的內容，可能陷入無法對技術設計進行工業優化的窘境。如果安全評估僅是用來測試一種設計，則安全評估將僅能回答問題而不能掌控發展方法。同樣的，安全評估應能同時回答問題並導引場址調查與場址建模，而不僅是在 SNFD2021 報告中闡述場址描述模型(SDM)相關工作。

今後有必要繼續推動選址程序，對此應將確保安全列為第一優先，以及向利害關係者(例如公眾、管制機關及工業合作夥伴等)提供資訊、對談及解釋。向利害關係者提供技術資訊，促進良好理解，對選址至關重要。封閉後安全評估即為對選定場址安全性的評估，能夠解釋並積極參與與公眾的對談，是封閉後安全計畫最重要的任務之一。

研發與驗證計畫也應在另一份報告中說明。如上所述，SNFD2021報告應回答問題並引導研究重點與活動。安全評估報告不會具體說明使用的工具或概念；相反的，重點在於從特徵、事件及作用的角度描述所缺乏的知識。例如：(1)孔隙度的概念至關重要，給定的值將影響所有的性能測量，減少不確定性將可顯著改善評估結果；(2)台灣的地震發生、頻率與震幅則是導致廢棄物罐失效的主要風險因素。減少這些參數的不確定性將可顯著改善評估結果。

高放射性廢棄物處置是國際上普遍存在的重要問題，國際技術資訊交流非常重要。建議台灣電力公司宜積極推動與參加瑞典、芬蘭、法國等先進國家處置計畫，並與日本、韓國、捷克、美國等處置計畫發展中國家進行國際技術交流，向先進國家學習，共享研究成果，並與非先進的國家共同進步。特別值得投注興趣的是，與具有相似地質環境的國家交流知識與實務經驗，以便有效的獲得必要的資料、技術及資訊等。利用地下研究實驗室參與國際研發合作計畫尤為重要(例如：DECOVALEX計畫)。總之，台灣電力公司宜在目前的初期階段以及隨著計畫的發展，在其安全論證工作中思考更廣泛的處置計畫策略，促使台灣處置計畫更為穩健、彈性與獨立，適合國情且有別於其他國家的計畫。

就一般而言，國際審查小組並不瞭解台灣管制機關(原子能委員會)在整體工作與階段性實施計畫層面上扮演的角色。國際審查小組亦不清楚管制機關迄今為止對先前工作與發展的管制立場，例如用過核子燃料特性方面、熱設計方面等。放射性廢棄物管理組織跟管制機關之間的對談、監督及互動，以及將此種交流做成記錄與法定文件至關重要。

4. 詳細發現

4.1 方法論

SNFD2021 報告中應用的方法嚴謹的遵循瑞典 SKB 公司在其封閉後安全評估工作中的方法，例如 SKB TR-11-01 報告 (SKB,2011)，該方法係基於 OECD/NEA 的建議，並且與國際原子能總署 SSG-23 導則一致。值得注意的是，OECD/NEA 以及芬蘭 Posiva 公司使用安全論證一詞，主要用於描述與封閉後安全評估相關的部分。國際原子能總署則在其 SSG-23 導則中將安全論證一詞做更廣泛的使用。國際原子能總署將申請放射性廢棄物最終處置場選址、設計、建造及運轉所需全部資訊的彙編與評估，統稱為安全論證。

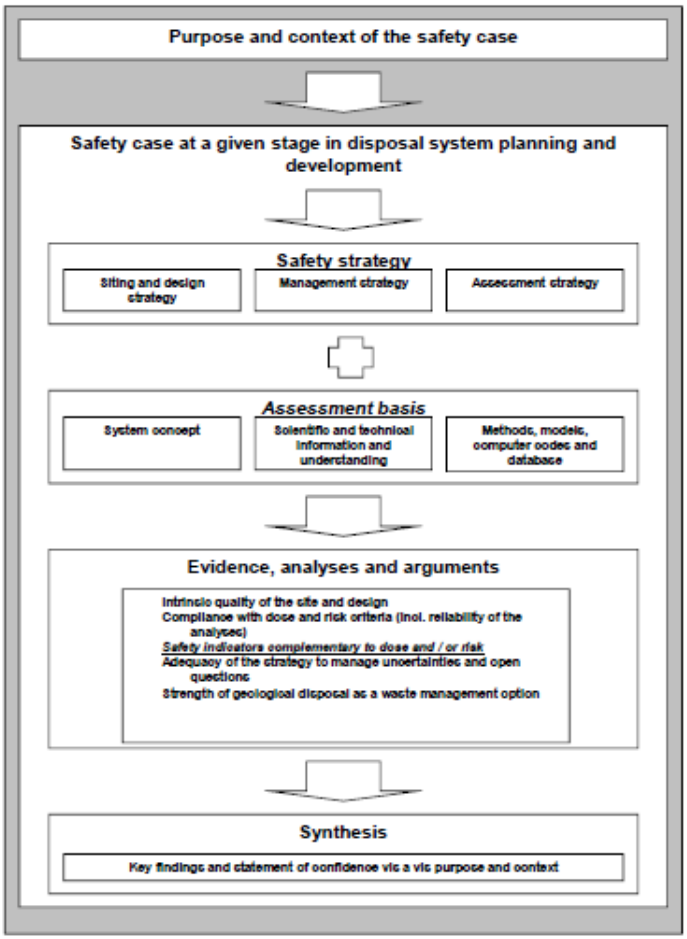

圖 4-1：安全論證要項的概述

資料來源： NEA(2004)

應注意，瑞典 SKB 公司的處置計畫處於先進狀態，且 SKB 公司在瑞典的階段過程中已經完成評估與相關方法的發展。因此，該方法在某些方面非常適合高度詳細的設計或先進的場址描述模型。建議台灣宜發展自己的方法論，同時發展自己的工程障壁計畫，以及增加詳細的場址描述。

關於方法論的其他詳細評論將在之後相關的內容中說明。

(1) SNFD2021 報告的階層架構

SNFD2021 報告的架構與預期內容在實際方面與 SKB TR-11-01 (SKB,2011)的主報告相同，如下面的圖 4-2 所示。主報告係由三個階層架構的報告支持，實務上須建立此三個階層的報告以建構合理的封閉後安全辯證(safety arguments)。

值得注意的是，本次國際同儕審查只針對 SNFD2021 的主報告，並且在某些相關部分無法確定是否存在重要參考文獻。這一事實削弱封閉後安全辯證，有時會產生對情節與案例選擇正確性的不確定性。

因此，強烈建議 SNFD2025 主報告與階層架構的相關技術支援報告應一併發展，並且詳細程度宜越來越高，且這些技術支援報告應遵循同儕審查的國際與科學慣例，可編寫為英文版以提供國際同儕審查。

(2) 品質保證

SNFD2021 報告中使用的品質保證係基於國際品質保證標準，例如美國 10 CFR 50.,60，並符合其要求與安全導則(例如國際原子能總署 SSR-5 與 SSG-23 導則)。這種建立品質保證計畫的方法已被適當發展並遵循國際公認的程序。

此外，重要的是在程序中的各個相關階段，能合理說明地質環境、設計與安全評估之間的關係，並從這個角度說明各設計值與模型參數的相關依據，從而確保透明度與可追溯性。

建議宜建立品質保證體系，在整個性能評估過程中系統性的顯示與地質處置場及其技術發展相關的所有綜合性能評估報告的品質，證明在過程中的各階段均可達到預期目的。

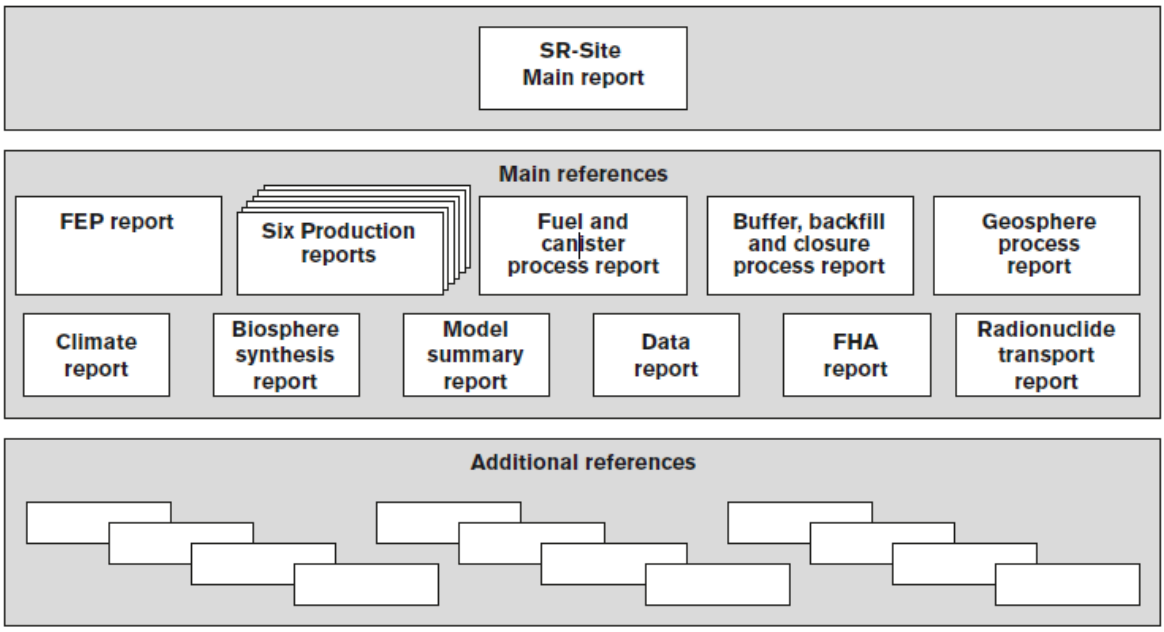

圖 4-2：SR-Site 處置計畫的主報告與附屬參考文件的階層架構

參考來源：SKB(2011)

4.2 特徵/事件/作用

SNFD2021 報告中特徵、事件及作用的呈現方式，以及如何評估與處理這些內容，經審查認為已遵循國際實務與方法。

然而，相關章節仍缺少部分主要參考文獻。因此，未能清楚的證明該過程已納入所有的基本步驟與考慮因素。因此，建議未來 SNFD2025 報告的工作流程與程序中，宜針對特徵、事件及作用進行重建評估並詳細記錄。

對特徵、事件及作用的評估必須遵循國際標準，台灣的國家資料庫必須包含相關聯的國際資料庫，且內容一致。台灣處置計畫現階段，SNFD2021 報告中對於特徵、事件及作用已做了良好的處理。

然而，特徵、事件及作用以及相關的工作流程亦應能引導封閉後安全評估的進行，特別是對於情節的擬定。因此，強烈建議應配合處置計畫發展工作流程與方法論。

特徵、事件及作用的一項特殊考量是有關岩石開挖與岩石障壁的相關定義，以及不被視為障壁的地下處置設施。類似於特徵、事件及作用

中對於工程障壁設計過程所考慮的缺陷，亦可對於地下處置設施設計與建造過程中的缺陷進行考慮。

4.3 處置場的初始狀態

SNFD2021 報告已設定一套固定的參考案例初始狀態，該初始狀態一部分依據實驗室中與處置計畫相關的調查與場址條件測試，但主要係依據台灣與其他國家特定場址評估的文獻資料。該初始狀態涵蓋工程障壁的描述、地質、熱力學與力學特性、水文地質、水文地球化學條件、傳輸特性及生物圈等。該初始狀態的描述在結構上涵蓋各領域所觀察到的國際資訊。

在 SNFD2021 報告中，選址前階段參考案例的設定應說明是假設的，係基於執行安全評估的需要而選定。

SNFD2021 報告中工程障壁系統的初始狀態係根據瑞典 SKB 公司的文件進行描述。安全評估的重要範疇是探討工程障壁系統製造與安裝的不確定性，SNFD2021 報告中尚未對選址前階段的此類不確定性進行評估或討論。就當前的設計或替代方案而言，初始狀態下品質不合格的製造或安裝錯誤，可能會導致長期潛在障壁性能的下降。未來必須解決這些不確定性，以提高安全評估的穩健性。

SNFD2021 報告中研究了包括評估處置場熱演化的數值模型，此係基於許多假設，並大致遵循例如 SKB 公司所採用的方法。

這些假設是合理的，但由於欠缺特定場址的資料，故熱評估得視為是對數值模型概念化與建構，以及評估與運跑並產出成果的能力證明。

未來隨著台灣處置計畫的發展，迄今發展的模擬技術應持續更新。隨著處置計畫發展可能出現的一些問題討論如後。

如同其他國際評估的情況，熱限制可以應用於封閉後的安全評估。但是，最好能瞭解台灣在最高允許溫度方面的本土立場。為什麼以及如何得出此溫度?以及處置場設計、廢棄物封裝與用過核子燃料封裝前貯存的決策，這些應如何整體考慮，以解決對於最高溫度的要求。

SNFD2021 報告對前述問題已指出一些不確定性，這是一個正向的措施。瞭解調整模型中的相關參數對於最高溫度變化的影響，將有助於

判定影響不確定性的關鍵敏感度。此將利於對未來的研究、設計、場址調查及模擬等進行優先排序，確保處置計畫以需求為導向，不會過度關注優先度較低的議題。

值得注意的是，對於迄今完成的模擬，應就產出成果的保守度提供評論。例如，如果就膨潤土的性能與膨潤土-廢棄物罐界面的飽和狀態做出不同的決定，那麼模擬的熱演化是否會與迄今為止的工作成果有顯著差異？建議未來台灣處置計畫應與其他研究計畫與其他國家計畫結合，以便有機會根據處置計畫的決定來改進設計與地下設施配置。例如，歐盟委員會(EC)資助的溫度對黏土質材料之影響計畫(HITEC)，正在考慮膨潤土在超過攝氏 100 度溫度下的性能。

SNFD2021 報告中所提到的地質調查資料主要是在 SNFD2017 報告之前完成的，SNFD2021 報告充分參考前期資料。根據前期的評估與法規框架，SNFD2021 報告的參考案例已建立大致的邊界條件，這些重要性質包括低抬升速率與處置場位於遠離火山活動假想場址的情況。

然而，由於台灣的區域環境與選址前階段的考量，長期演化的不確定性傳遞，以及抬升速率與火山活動對處置場安全的影響等，仍應進一步研究。

SNFD2021 報告中提及台灣本島與離島參考地區有明顯的抬升速率差異。不過，為清晰起見，建議對 SNFD2021 報告內文進行改寫，先說明台灣的抬升速率有很大的變異性，然後定量說明各地區的抬升速率是如何變化的，以及說明用於估計長期抬升速率的方法及其正當性。對於抬升速率與剝蝕(侵蝕)速率相同的假設，國際審查小組同意這是一個可以接受的保守假設。然而，在地體構造活動頻繁區域，需要更確實的估計侵蝕速率以避免過度保守的評估。

SNFD2021 報告中提及台灣有三處火山活動地區：(1)西部地區；(2)東部地區；及(3)北部地區。但未對參考地區進行說明，建議提供有關目標地區的一些描述。國際審查小組同意參考地區現在沒有火山活動，但是，從長遠來看，仍可能需要評估火山活動的可能性，因為菲律賓海板塊隱沒延伸至參考區域下方。

就活動斷層而言，在 SNFD2017 報告中顯示，活動斷層與地震在台灣十分的重要。

在 SNFD2021 報告中提及，根據國家法規要求不得位於活動斷層足以影響處置設施安全之地區，但未說明如何避免活動斷層。建議增加一些說明或參考國內或國際現有知識加以補述。例如，參考具有相似地質條件的日本經驗可能會有所助益。此外，如果有任何文件可說明管制要求的背景，則強烈建議應納入參考。

假想場址經判定包含三種不同的地質單元，這些單元被兩個離散裂隙網絡(DFN)域所涵蓋，且其中一個地質單元存在兩個破碎帶。地下深度 70 公尺以上的上部地質單元(岩屑風化層)與 70 公尺以下的其餘岩層，被兩個離散裂隙網絡域所涵蓋，岩性均為花崗岩且含有主要的導水裂隙。

裂隙性質的資料引用自其他結晶岩場址(例如瑞典的 Forsmark)，並已提供相關參考文獻。

使用 DFN 模型對兩個裂隙域中的裂隙進行建模。DFN 模型參數是根據 DFN 清單導出的。選擇的模型與參數應是合理的，但似乎缺乏模擬前的校準步驟。例如，應該針對已執行的封塞試驗與隧道壁測繪所取得的裂隙資料進行校準。若能清楚說明校準的步驟，則可增加評估裂隙模型與後續模擬的可靠性。

參考案例的設定係取決於地質調查地區的性質，並為建模帶來不確定性，從而影響安全評估的結論。建議應根據可用的地質調查或其他資料來源對安全評估的建模設定進行驗證與確認。例如，合理選擇與流動相關的傳輸阻力(F)做為安全功能指標。然而，F 值可能被高估的裂隙密度(必須考慮哪些裂隙有助於流動)及欠缺對管流效應的相關評估而被誇大。提高對於模型的信心非常重要，強烈建議參與國際處置計畫以驗證 DFN 模型。

根據實驗室調查與現地封塞試驗，花崗岩母岩(下層裂隙域)的水力傳導係數在 4.1×10^{-12} m/s 與 1×10^{-9} m/s 之間，破碎帶的水力傳導係數則估計為 3.0×10^{-8} m/s 與 1×10^{-4} m/s 之間。然而，從 SNFD2017 報告中提及的六個調查鑽孔(KMBH01-06)獲得的至少部分水力傳導係數可能與裂隙域描述中的評估相關，因此宜再評估所描述的有效水力傳導係數。

水文地球化學已被納入為地質調查的一部分，其組成範圍亦被定義。SNDF2021 報告中提及的一些水文地球化學濃度似乎低於 SNFD2017 報告中提供的值，且未解釋這些較低值從何而來，故需說明資料使用的正當理由。對於長期演化中的安全評估建模，水文地球化學應考慮包括平均河流與海水成分，也盡可能包括地表水的類型。

SNFD2017 報告中提供的水文地球化學資料顯示很大的變異性。此變異性需要加以檢視與解釋。此種差異可能代表水流系統是分區的，應將此反映於水流模型中。

水文地球化學的不確定性應傳遞納入安全評估中，特別是在母岩的傳輸性質。在 SNFD2021 報告中，在評估時間尺度內引用 Olkiluoto(芬蘭)與 Forsmark 場址(瑞典)的傳輸性質做為參考資料，但很少討論所涉及的不確定性。建議宜基於地質學、水文地質學及水文地球化學的評估，對安全評估的傳輸性質進行更廣泛的背景合理性說明。建議將來宜進行更深的調查鑽孔，藉由這種深層鑽孔可用於定義與參數化地下深處的邊界條件。

生物圈的參考案例的設定已包括對土地利用的地景與生態系之描述。選址前階段已對自然狀況、發生中的作用與人類習性等進行適當程度的描述，並著重於判定人類的重要曝露情況與潛在曝露群體(PEG)。在未來的評估中，生物圈參考案例設定的改進應側重於作用的理解(地質、水文與生物循環)與非人類生物群(例如代表性物種)，以符合國際建議(ICRP 2013，IRCP 2008)。對於作用理解的改進應側重於對地圈-生物圈界面與相關交互作用的處理，例如在場址描述或安全評估時為地下水流建模設置邊界條件。

4.4 外部因子

值得注意的是，典型的外部因子分為四類考慮，即氣候相關、大規模地質作用(例如剝蝕、抬升、地體構造、火山活動)、未來人類活動(FHA)與其他(例如隕石撞擊)。

SNFD2021 報告已考慮氣候相關、大規模地質作用及未來人類活動等外部因子，此符合國際相關實務做法。

然而，須注意的是，SNFD2021 報告中對於火山活動、剝蝕與抬升的處理相對簡略，這對於所選擇的假想場址來說似乎是足夠的，但對於整個台灣來說並不足夠。由於台灣地區有顯著的抬升速率以及活躍的火山活動，因此，建議在未來擴大與發展此階段處置計畫的封閉後安全評估。

4.5 內部作用

SNFD2021 報告對於內部作用的處理，符合國際相關的實務與標準。

然而，須注意的是關於特徵、事件及作用的描述顯然存在類似的不足，亦即缺乏主要的參考文獻，且未能明確闡述該過程已包含所有的必要步驟與考量。因此，建議未來宜針對內部作用重建 SNFD2025 報告的工作流程與程序，並建立良好的文件記錄。

4.6 安全功能與安全功能指標

SNFD2021 報告所包含相關的安全功能，符合國際相關的實務與標準。

然而，宜注意安全功能指標與安全功能指標標準的設定，會跟當地場址條件、參考設計如何在當地場址條件中發揮作用及場址條件隨著時間發展等因素密切相關。

台灣在此階段的處置計畫中，評估國際設計與指標是一種可接受的方法。然而，隨著處置計畫進展，設定安全功能指標與相關標準的工作流程，宜配合初始狀態、參考設計及參考演化做完全一致的整體考量。

4.7 輸入資料與資料不確定性

在此階段，可用的場址資料以及本土參考設計資料至少可以說是有限的。因此，彙集國際資料是一種可以接受且典型的評估作法。遵循國際標準實施有品質的工作流程與評估，在科學的角度是正確的。

然而，需要注意的是，SNFD2021 報告在結果呈現中包含對有效數字(significant number)的各種評估。在應用科學方法時，科學性、學術性與完全正確性是很重要的。

此外，值得注意的是，假想場址的資料彙集並不平衡。重要的是，場址特性調查資料應該是可理解的、合乎邏輯的以及物理真實的。任何模型都需要基於有根據的資料與可重複的調查。

(1) 不確定性

SNFD2021 報告中評估的不確定性，其定義與分類係基於 OECD/NEA 與芬蘭 Posiva 公司的做法，劃分為系統/情節不確定性、概念/模型不確定性與資料不確定性。

關於 SNFD2021 報告中描述的不確定性處理方式，國際審查小組審查認為是科學正確與適當的，且與其他國際的評估一致。

然而，對於選址前階段，尚可考慮其他國家處置計畫對於不確定性的處理方法，例如參考日本綜合技術報告「NUMO 選址前基於 SDM 之安全論證」，因其配合選址與地質環境調查評估階段，逐步處理不確定性(NUMO，2021)。

4.8 參考演化

值得注意的是，在典型的封閉後安全評估報告中，參考演化本身就是最具高度要求的部分。參考演化是選擇相關特徵、事件及作用以及建立安全功能指標的基礎。國際審查小組注意到，SNFD2021 報告並沒有很好地平衡處理。參考地區(如假想場址)的參考演化發展尚待加強，在評估時間尺度內對場址演化情節的描述不易完全理解與符合邏輯。台灣現為選址前階段，尚待進一步發展完整的演化情節，此可理解。相反的，若選擇嚴謹與高度完整的工程障壁參考設計，將使得報告有些混亂，亦使安全評估中包含額外的發展不確定性。

在未來的評估中應妥善發展涵蓋完整演化時間尺度的參考演化邏輯與細節，特別是針對場址的參考演化。此外，這部分亦需要有科學合理與明確的參考資料支持。將演化推演至未來 10 萬年之預測的爭論是不言而喻的，因此需要強大而廣泛的科學依據。

SNFD2021 報告中對於工程障壁的參考演化具備較完整的說明，未來可以考量由於腐蝕導致廢棄物罐失效，此為 KBS-3V 處置系統中圍阻安全功能失效的重要機制。SNFD2021 報告通過考量處置設施開挖與運轉期間以及封閉後的演化中，好氧與厭氧環境條件，評估長期演化過程的銅腐蝕。評估應涵蓋有限與長期的腐蝕物來源，以及緩衝材料達到平流條件與未達平流條件的評估結果。對所有處置孔評估與地下水中硫化物相關的腐蝕速率，並選擇腐蝕深度最深的五個處置孔進行進一步安全評估。

SNFD2021 報告中對銅罐腐蝕負載已進行適當處置，但僅針對假想場址的水文地質模型相耦合。因此，可能存在忽視冰河循環，反覆發生的水文地球化學擾動的危險。為提高未來安全評估的穩健性，建議對腐蝕負載進行進一步評估，包括如源自火山活動引起的水文地球化學擾動的腐蝕負載(雖然受限於初始狀態)、氯化物濃度升高時的銅腐蝕以及噴發殘留物中的氮化合物對銅應力腐蝕的影響。此外，宜以更系統化的評估方式，發展腐蝕負載對安全功能性能的相關不確定性，以便回饋於安全評估。

做為緩衝與回填的膨潤土應具有安全功能，例如保護處置容器免受腐蝕性化學物質的腐蝕、並能抑制微生物活動、保護處置容器免受岩石移動的影響、限制地下水促進放射性與非放射性污染物從任何失效容器(包括膠體傳輸)遷移、並為母岩提供力學支撐。膨潤土因其礦物組成具有良好的特性(例如回脹能力、低水力傳導度與離子交換/吸附能力)，故能實現這些安全功能。

然而，膨潤土也有一些限制/不確定性。如高溫條件下，可能導致原具有回脹能力的蒙脫石，轉化為不具有回脹能力的伊利石。部分飽和膨潤土中產生的蒸汽可能會降低膨潤土的回脹能力。由於飽和時間長，或可能在大氣條件下預製工程障壁系統(EBS)，含有熱特性廢棄物的地下水擴散狀態尤其值得關注。此外，高離子強度的地下水可能會降低膨潤土的回脹能力，並影響膨潤土孔隙水的緩衝能力。膨潤土材料中可能存在腐蝕處置容器的雜質，以及膨潤土由廢棄物及處置容器產生氣體的相關行為亦需仔細考慮

高流率或是低離子強度進入處置孔的地下水，所造成力學的或化學的管流與侵蝕，都會對安全評估產生重大影響。

國際審查小組已聽取有關評估緩衝材料與回填材料(均假定為膨潤土)飽和度的建模研究工作報告。台灣電力公司迄今為止報告的工作部分已考慮前述與膨潤土有關的要求以及相關的限制/不確定性議題。

台灣電力公司的工作成果，已展現在假設地質條件與 KBS-3V 處置概念的背景下模擬膨潤土再飽和的能力，但提供處置設施工程障壁系統關鍵功能的膨潤土演化，尚未涉及更廣泛地安全論證內容。迄今完成的建模工作可以在未來持續發展，且應形成一個合理的基礎，表明台灣電力公司除了可以使用適當的軟體來進行這項相當複雜的建模作業外，也同時擁有經驗豐富的專家—這是一項值得信賴的成就，藉此可確保台灣電力公司能夠發展其與工程障壁系統演化相關的條件。

SNFD2021 報告可參考歐盟委員會「膨潤土力學演化」計畫(BEACON)成果，該計畫近期公開發布膨潤土力學演化的研究成果。未來的工作宜參考 BEACON 計畫的成果，並考慮如何比較國內工作與國際工作，包含模型驗證、模型確認、品質保證、同儕審查等作法。

4.9 情節選擇

國際審查小組對於同儕審查會議上的簡報留下深刻的印象，所提出的情節選擇方法相當徹底，相對國際立場所表現出對地質處置背景下，情節分析有良好的認知，並做出有意義與明智的嘗試，將台灣的放射性廢棄物處置、地質與地質作用等的方法置入於情節分析中。

抬升/沉降與火山活動等反映在情節分析中，對選址工作的產出將是很重要的，某些情節可能會因為更合理/高優先度而脫穎而出，而某些情節則變得不那麼引人關注，這是計畫不斷發展過程中的正常現象。當然，重要的是，所有國家級計畫，例如選址計畫與設計計畫，都必須與從事情節分析工作的研究團隊保持充分聯繫，避免獨自作業。而台灣電力公司的內部工作程序需要確保有足夠的時間進行辦公室內部/計畫內部的知識交流與研究團隊的技能提升。

建議台灣處置計畫宜更全面的考慮人類入侵情節。可參考國際原子能總署「放射性廢棄物處置背景下的人為入侵」計畫(HIDRA)中對於人類入侵情節的例子(例如鑽探案例)，或參考日本 NUMO 的文獻(例如 NUMO-SC20-SR6-32, 2021)。人類入侵情節需要仔細思考一個問題，假設一個社會有足夠的技能鑽到處置場深處，但卻沒有足夠的技能來識別放射性廢棄物、廢棄物罐、工程障壁系統等，這樣合理嗎？不瞭解放射性廢棄物性質的假設會導致不合理的情節發展。例如，居民在放射性廢棄物中種植食物並食用，這當然會受到高輻射劑量而不足為奇！

稍具確切的評論是，對於台灣電力公司來說，在新的場址資料可用之前，目前的處置計畫應該思考練習選址計畫闡明情節將如何演化/重新確定情節優先級別，例如：未來選定的場址比目前假想的失效更多，或者地下水化學成分明顯不同等。這種思考練習可能闡明，例如，廢棄物罐壽命成為需非常具有信心的關鍵議題，或者可能需要重新設計相同的廢棄物罐(外部容器材料的不同選擇？)。此外，確定是否存在某些場址特性是不能通過重新設計地質處置設施、工程障壁系統、處置容器等來容忍的。確定這些重要的場址特性有助於指出哪些因素可能會導致台灣電力公司撤離(不選擇)該場址嗎。這種基於更廣泛的情節分析可以闡明該方法對台灣電力公司不斷發展的處置計畫的潛在影響，也可以讓台灣電力公司就場址性質與場址現象等問題與處置概念的兼容性提供警訊。

4.10 分析

(1) 安全評估

安全評估構成 SNFD2021 報告的關鍵內容。評估的基準係以具有部分地質調查資料的結晶岩 K 區為假想場址，以及參考瑞典 SR-Site 安全評估中 Forsmark 場址的 KBS-3 設計為處置概念。安全評估充分遵循合理的方法：分析安全功能、擬定情節、分析核種釋出後果及證明符合管制風險限值。用於分析核種釋出後果的文獻資料還包括來自芬蘭 Olkiluoto 場址安全評估的資料。

在選址前階段，安全評估在有限的評估範圍內，已考慮來自評估基準中的重要不確定性，因此，SNFD2021 報告的結論包含不確

定性的討論。可以藉由考慮額外的情節或對所使用的資料進行變化來提高穩健性。在選址前階段最重要的是，水文地質模型的可靠性較低，應改進這種不確定性對安全評估的傳遞。根據安全評估的需要，產生功能測度的建模步驟可以考慮判定與計算敏感度案例，以提高對安全評估中資料不確定性與推論的理解。以水文地質模型為例，結合連續多孔介質模型(CPM)與離散裂隙網絡模型(DFN)的作法，可評估包括例如封塞的失效、開挖損傷帶(EDZ)的替代假設或增強地下水流管流效應等。

SNFD2021 報告中對放射性核種釋出、傳輸與釋出分析的劑量計算已進行充分描述，但對於處置系統各部分關鍵資料的呈現與簡化未平衡地展現。該計算在評估時間尺度內同時使用 Forsmark 與 Olkiluoto 安全評估的資料，做為合理的替代方案，但可能對提升台灣本土條件的可信度則有侷限。因此，建議增加與場址描述與場址演化評估的整合，以改進安全評估中資料選擇的論證。

SNFD2021 報告的放射性核種遷移與劑量計算中，不確定性與敏感度分析側重於 SKB 公司導出的參數不確定性與假想場址的水文地質模型。通過使用具有多種實現(realisations)的獨立取樣方式(蒙地卡羅)來計算結果，對腐蝕破壞與岩石剪力破壞導致的重要放射性核種釋出情節進行計算。選擇的計算終點是參考群體個人的年劑量，提供輻射影響的結論依據。由於，未包括生物圈評估資料的不確定性(即生物圈模型是固定的)，雖然是以年平均劑量進行計算的結果，此分析與結論仍應視為是延伸至生物圈的放射性核種釋出與遷移模擬結果。建議，今後進一步檢查生物圈建模中的重要資料不確定性(例如放射性核種遷移)，以改進對資料不確定性的總體安全評估與處理。

資料不確定性的獨立取樣適合評估所考慮模型的敏感度。然而，存在資料不確定性的相關性(例如由於水文地質模型性質與化學相似性)，建議進一步改進以避免不合理的參數組合(例如非常高的傳輸阻力與地圈釋出途徑非常低的平流傳輸時間)傳遞到計算終點的不確定性，尤其是在將結果與法規限值進行比較時。通過

執行具備相關性與無相關性的性能評估，可以檢查建模端點不確定性與對輸入不確定性的敏感度。

SNFD2021 報告安全評估中的敏感度分析是藉由使用局部分析與篩選方法進行的，以呈現安全評估中包含的最重要的資料不確定性。該方法適用於選址前階段，但可以藉由更系統性的檢查模型採樣輸入的參數與相應的模型計算端點來實現改進。藉由蒙地卡羅方法進行 10,000 次實現的計算，可判定參數之間的交互作用與非線性效應，有助於理解安全評估機率式計算中的模型行為。然而，適當的方法與足夠深入的敏感度分析在某種程度上取決於所討論的案例研究，並且存在不同的方法來獲取模型輸入與輸出分布之間關係的不同資訊(參見例如 Swiler et al., 2021)。

SNFD2021 報告評估全球暖化對參考地區的影響，不會導致額外的替代演化路線，或影響地景演化。然而，擴大對氣候演化替代方案的審視與考慮，將有助於未來的處置系統評估，以提高穩健性(例如高硫化物含量海水的入滲)。

(2) 生物圈評估

SNFD2021 報告中的生物圈評估，包含多個安全評估方法的相關步驟。評估方法相較 SNFD2017 報告已有所改進，並考慮地景演化與對輻射曝露途徑的影響。生物圈參考案例的設定係基於一個虛擬的熱帶島嶼，由於長期演化中海平面下降，該島嶼經歷轉變內陸。對於選址前階段而言，應用當地活動的推理來涵蓋人類生活習性，並且判定潛在曝露群體(PEG)，此應已足夠。

生物圈評估中的劑量評估係基於生物圈劑量轉換因子(BDCF)的應用，該因子考慮每個放射性核種的(穩定)單位釋出率(1 Bq/年)。BDCF 用於將計算的生物圈釋出率轉換為每個 PEG 中曝露個人的年劑量(不同階段使用不同最大值)。該方法係參考瑞典 Forsmark 場址(SKB, 2010)安全評估類似的作法，且選用保守資料，以確保放射性影響具有一定程度的保守性。

為改進安全評估中的生物圈評估，可以進一步應用國際建議與導則(例如 ICRP,2013)來制定需要解決的基本問題。生物圈評估的

問題應基於處置場封閉後地表環境的潛在演化，瞭解特徵、事件及作用(相關地質、水文及生物循環下的遷移與聚集特性)，人類對地表環境的利用，放射性核種釋出的曝露條件，以及非人類生物群體(植物與動物)的曝露條件。

SNFD2021 報告中包含許多重要面向，但仍存在侷限性。例如，尚未解決非人類生物群體的曝露問題，雖然在選址前階段可以接受。儘管與其他類似評估相比，評估結果仍屬保守(例如 SKB, 2010; Broed, 2007)。依據類似評估的國際方法，理解生物圈曝露模型的處理過程，但重要作用的背景資料並未以平衡的方式呈現。因此，建議參考關鍵背景報告，並將所使用的近場與遠場放射性核種釋出與傳輸建模資料，適當地呈現在 SNFD2021 報告中。

SNFD2021 報告中 PEG 所涵蓋的人類習性著重於水產養殖(例如養魚)與農業(例如種植農作物)，但森林產品的使用未包括在當地活動中(儘管台灣確實存在森林生態系統)。未來，宜結合某些 PEG 對森林進行進一步檢視，以確認潛在的曝露途徑(例如潛在食用自然產物)。

SNFD2021 報告中的生物圈評估，包含所有適用於 SNF 廢棄物罐的源項中之放射性核種(總共 34 個)，但其中僅有一小部分貢獻安全評估結果計算的年劑量。由於生物圈評估著重輻射影響，因此，可以採用非常悲觀的推理，確認處置計畫下階段資料需求的優先順序(例如藉由篩選貢獻最顯著的源項放射性核種存量或向生物圈的核種釋出)。此外，根據 SNFD2021 報告評估結果顯示，年劑量主要是受到地景中放射性核種釋出的地點所影響。對安全評估中不確定性與敏感度分析的改進，可以將重要資料不確定性的影響納入考量，以便更全面的瞭解整個模擬處置系統中的資料不確定性。

SNFD2021 報告在選址前階段對地圈-生物圈界面進行適當的簡化處理，並且在生物圈評估中僅採用釋出至生物圈的釋出率，據以計算安全評估的年劑量結果。為改進水文地質模型的參考案例設定，建議將地圈的水文地質模型與生物圈地表水文的聯繫概念

化。隨著地表水文的後續建模，藉由設定更有效的水文地質模型邊界條件，可以改善地圈-生物圈界面的處理。另一方面，對於地表水文的瞭解，提供放射性核種遷移與聚積重要資訊，以加強輻射影響評估的基礎。

4.11 對設計、場址及研發與驗證計畫的反饋

SNFD2021 報告所述的回饋是合理的，國際審查小組認同大多數回饋。但是，以下幾點建議可能會進一步改進未來的計畫，例如：

國際審查小組認同在細部特性調查中對開挖損傷帶(EDZ)進行調查，然而，EDZ 的機制仍然知之甚少，尤其是對淺層負面機制(減少徑向 K 值)的理解仍需要進一步發展。

國際審查小組認同減少離散裂隙網絡 (DFN)的不確定性很重要，也同意 SNFD2021 報告所描述的措施有助於減少不確定性。然而，由於天然裂隙的空間異質性與場址特性調查的實際限制，無法避免不確定性。另一方面，可能有某些 DFN 幾何參數對結果不那麼敏感。因此，建議宜瞭解 DFN 模型參數的敏感度並優化場址特性調查技術。

國際審查小組認同「連通導水裂隙的判定」極為重要。此外，認同使用現地抽水試驗來判定連通的導水裂隙，此通常為主要的導水裂隙。此將有助於理解主要裂隙(或斷層)的水力連通性。然而，亦建議重視滲透性較小的裂隙，因為與處置孔相交滲透性較小的裂隙，其連通性對於評估母岩的遲滯能力很重要。

國際審查小組認同發展考慮水文地質模型的水文地球化學模型。此外，認同所述的調查項目。建議亦需要建立採樣程序，以獲取最少擾動的地下水，例如遇到不同壓力時停止鑽井並進行取樣，或是在鑽井循環水中增加示蹤劑，並在採樣時監測示蹤劑濃度，以判斷現場的地下水是否受到鑽井循環水的影響。

SNFD2021 報告「對參考設計與設計前提的回饋」與「對詳細場址調查與 SDM 的回饋」部分中，指出可以藉由迭代設計與選址調查與回饋的方式，降低處置設施安全設計與安全評估中的不確定性，此種策略方

法可成為確保處置場安全可靠性的合理方法。國際審查小組建議宜更詳細的摘述策略方法論，包括各階段進行整合的必要性。

國際審查小組預期處置計畫將反覆推動選址調查的每個階段任務。對於安全論證的發展而言，更重要的是整合每一步驟的結果，並反映到下一步驟。藉由更新與更增加準確的資料可減少不確定性。因此，建議這些進展情況的結果宜提報管制機關進行評估與確認，在各階段向地方政府報告，並持續以透明與可追溯的方式向利害相關者揭露進度資訊。

SNFD2021 報告中應明確說明，在確保安全方面，這種逐步推動處置作業方法具備的各種好處。(NUMO, 2021; NUMO 選址前基於 SDM 之安全論證, NUMO-TR-21-01; 逐步特性調查之作法, NUMO-SC20-SR3-07,08)。

SNFD2021 報告中指出，地質處置計畫從場址調查階段到確認封閉期間，需要從確保安全與環境保護的角度進行各類監測。監測是確認處置計畫是否正常實施的重要手段，向公眾與居民公開資訊對於提高處置計畫的公信力是不可或缺的。建議在台灣應考慮並建立更詳細的監測概念。

為逐步發展安全論證，更重要的是建立一個用以獲取數據、資訊、文件等綜合資料庫，該資料庫包含水文地質調查方法/技術、設計、建造、障壁性能、安全情節、安全功能指標、安全評估資訊等。該資料庫可用於確保台灣未來安全論證發展所需的透明度與可追溯性。

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附件一：國際審查小組審查委員簡歷

Curriculum Vitae

Name: Vidstrand, Patrik Christopher

Born: July 10 1968, Limhamn (Malmö)

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Phone: +46 73 7741687
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Education:
1999: Engineering geology (Technical licentiate), Chalmers Tekniska Högskola
1995: Civil Engineering (M.Sc.), Chalmers Tekniska Högskola
1988: Chemical Engineering, Pauli tekniska gymnasium

Language:
Swedish (native)
English
German (five years of school German)

Profile

Manager with experience of both small and medium-sized organizations with high technical and scientific competence. Good at enforcing organizational change and implementing new ways of working. Prefers to work at a high pace with many on-going activities, but also thrives in a managerial role where the focus is on nurturing and developing staff within a well-defined business.

Technical focus

Engineering geology with focus on hydrogeology: Conceptual and numerical modeling and site description in all stages of projects, eg. feasibility studies, system design, engineering geological forecasts and outcome evaluations.
Extensive scientific- and consultant-based experience in descriptive geological and hydrogeological modeling, including coupled processes such as thermal, mechanical and chemical.
Many years of consultancy in traditional engineering geological work such as planning and design work related to constructability and grouting issues in hard rock.

Memberships

IAH – International Association of Hydrogeologists
SGF – Svenska Geotekniska Föreningen (Swedish association of geotechnical engineers)

Curriculum Vitae

Professional expirience

2021-	**Managing Director, Foundation of Rock Engineering Research (BeFo)** The Foundation has for 50 years, been the centre of Swedish rock engineering research, development and innovation along with founding research projects. As Director I start-up, follow, and manage research and development project. I also distribute scientific reports, present results and broadly represents the rock engineering companies of Sweden.
2019-2021	**Head of unit, SKB** The unit, Research and post-closure safety, consists of four groups and approximately 50 employees. The main working tasks consisted of establish, operate and further develop the unit's strategic and organizational work as well as its main responsibilities related to analyzing post-closure safety. Also, I participated at an overall level within SKB's work to implement major construction projects, perform forecasting and follow-up work of the geoscientific conditions in planned and operational facilities, and to ensure that safety-related requirements are met throughout SKB's operations. In addition to leading the unit's management team, I was responsible for SKB's research council, participating in several of SKB's safety committees and am part of both international, national and internal steering- and reference groups for various projects and research and development programs.
2018-2021	**Member of the board Foundation of Rock Engineering Research (BeFo)** The main tasks consisted of strategic work as well as financial and organizational follow-up of the foundation's research portfolio. Hold the position as vice chairman in 2019. BeFo's work is partly integrated with work within the Swedish Rock Technology Association and there is some collaboration.
2018-2018	**Assistant head of Research and safety assessment unit, SKB** The main tasks consisted of, together with the unit head, managing and developing the unit via a shared leadership as well as personnel responsibility for about half of the unit's approximately 35 employees. Furthermore, activities related to operations were included within steering and reference groups for various assignments and projects within SKB.
2013-2018	**Expert Hydrogeology, SKB** The main tasks consisted of the responsibility for groundwater modeling, user support and all development of the SKB-owned multi-purpose tool (software) DarcyTools. Participated in analyzes of post-closure safety as a technical manager/assignment manager and contractor. Furthermore, I worked as a technical expert in geological and hydrogeological issues, including support for internal contractors Rock and BBC (Buffer material, backfill material and sealing techniques), Environmental Impact Assessment work, design issues but also directly against technology development projects and as a consultant for SKB International which is a wholly owned subsidiary of SKB that offers consulting services, primarily internationally, in final repository technology including siting processes.

Curriculum Vitae

2012-2013	**Chairman of the board for Aspen Montessori** (Private school)
2008-2013	**Consultant, TerraSolve AB** The main work consisted of modeling work for SKB's various analysis work, but various infrastructure assignments were also performed for different customers in Sweden. For example, work as a technical expert in construction law disputes, handling of hydrogeological investigations and review of major projects such as the Stockholm By-pass. The work was performed as a task leader, specialist and administrator.
2008-2016	**Member of the board and owner of TerraSolve AB**
2007-2012	**Member of the board for Aspen Montessori** During the period I was, among other things, property manager and planned and procured on-going maintenance and new construction.
2006-2008	**Head of group Hydrogeology, Bergab** As head of the Hydrogeology group at Bergab in Gothenburg.
2005-2006	**Member of the board, Bergab**
2001-2008	**Consultant, Engineering geology, Bergab** Work was performed as a task leader and specialist.
2001	**Associate professor, Geologiska institutionen, Chalmers Tekniska Högskola** As associate professor, I was responsible for the undergraduate education in technical geology. Planned courses, excursions, responsible for examinations.
2000-2001	**Consultant, Engineering geology, Scandiaconsult Sverige AB** Work was performed as a task leader and specialist.
2000	**Associate professor, Edinburgh University**
1999	**Guest researcher, Edinburgh University**
1995-2000	**PhD position, Geologiska institutionen, Chalmers Tekniska Högskola**
1994-1998	**Member of the board for Chalmers Studentkårs Restaurang AB**
1994-1996	**Chairman of the board for Chalmers Studentkårs Restaurang AB** In addition to leading the board and running the restaurant company's long-term work and development, I had personnel responsibility for the company's CEO.
1989-1990	**Assistant Construction manager, Skanska**

Curriculum Vitae

Examples of publications

Peer reviewed	Boulton, G. S., Lunn, R, **Vidstrand, P**., Zatsepin, S., 2007: Subglacial drainage by groundwater-channel coupling, and the origin of esker systems: Part 1-glaciological observations *Quaternary Science Review, Volume 26, Issue 7-8,* April 2007, pp 1067-1090.
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Peer reviewed	Selroos, J-O., Cheng, H., Painter, S., **Vidstrand, P.,** 2012: Radionuclide transport during glacial cycles: Comparison of two different approaches for representing flow transients. Physics and Chemistry of the Earth.
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EDUCATIONAL DETAILS

2009: Ph.D in Engineering. Graduate School of Natural Science and Technology, Okayama University
1977-1979: M.Sc. in Science. Graduate School of Science, University of Tokyo
1972-1977: B.Sc. in Science. Faculty of Science, University of Tokyo

PROFESSIONAL DETAILS

2020-present: President, Fracture Flow Solutions
2017-2020: Technical Counsellor, Division of Research for Nuclear Fuel Cycle and Radioactive Waste, Secretariat of NRA (Nuclear Regulation Authority, Japan)
2014-2017: Director, Division of Research for Nuclear Fuel Cycle and Radioactive Waste, Secretariat of NRA (Nuclear Regulation Authority, Japan)
2013-2014: Deputy Director, Nuclear Fuel Cycle and Radioactive Waste Management Safety Department, JNES (Japan Nuclear Energy Safety Organization)
2010-2013: Group Leader, Radioactive Waste Disposal Safety Evaluation Group, Nuclear Fuel Cycle and Radioactive Waste Management Safety Department, JNES (Japan Nuclear Energy Safety Organization)
2008-2010: Deputy Director General, Tono Geoscience Center, JAEA
Group Leader, Crystalline Environment Research Group and Neotectonics Research Group, JAEA
2005-2008: Group Leader, Crystalline Environment Research Group,
Geological Isolation Research and Development Directorate, JAEA
2000-2005: Group Leader, System Analysis Group, Geological Isolation Research Division, Tokai-Works, JNC
1998-2005: Waste Isolation Research Section, Environment Technology Development Research Division, Tokai-Works, PNC
1985-1998: Geological Isolation Research Section, Head Office, PNC
1983-1985: Nuclear Safety Section, Science and Technology Agency
1979-1983: Uranium Exploration Division, PNC

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Dershowitz, W., Shuttle, D. and Uchida, M. (2004). Task 6A and 6B/6B2. GoldSim and FracMan/LTG modelling. Performance assessment modeling using site charaterisation data (PASC). Swedish Nuclear Fuel and Waste Management Company (SKB), International Progress Report, IPR 04-32, 97p.

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International Cooperation Report, ICR 94-09

CV

Motoi KAWANISHI, Dr.　（河西 基）

1) Central Research Institute of Electric Power Industry (CRIEPI)
Honorary Research Advisor
2) Asano Taiseikiso Engineering Co., Ltd. (ATK)
Director, Chief Engineer

<Personal history>

1979 Completed Graduate of Tokyo University (Doctoral course)
1979 Engaged in CRIEPI
Environmental Hydraulics Department
1995 Doctoral degree of Tokyo University
2004 Associate Vice President
Director of Nuclear Fuel Cycle Backend Research Center, CRIEPI
2011 Senior Associate Vice President
Director of Nuclear Fuel Cycle Backend Research Center, CRIEPI
Jun. 2013～
- Research Advisor (～2015 Mar.), Honorary Research Advisor (2015 Apr.～), CRIEPI
- Director, Chief Engineer, Asano Taiseikiso Engineering Co., Ltd.

Nov. 2013～Mar.2016 (additionally)
- Advisor
- Tokyo Electric Power Company Ltd. (TEPCO)
Fukushima Dajichi Decommissioning and Decontamination Engineering Company

<Main Research Work>

・Hydraulics of dam and river
・Investigation and modeling of groundwater flow
・Safety assessment on radioactive waste disposal
・R&D for radioactive waste management

<Main related contribution for radioactive waste management projects in Taiwan>

・Oct. 2015　A member of the Japanese team for the “2015 Technical Workshop for The High

Level Radioactive Waste Final Disposal Program" held by Taiwan Power Company.

- May 2016　A member of the international peer review team for the "Evaluation of Technical Feasibility for Low Level Radioactive Waste Disposal International Peer Review Report" prepared for Taiwan Power Company.
- Jan. 2020　A member of the international peer review team for the "Technical Advancement Assessment Report for Low Level Radioactive Waste Final Disposal, Republic of China" prepared for SINOTECH.

<Related Title>

- Former Director of EAFORM sub-committee in AESJ(Atomic Energy Society of Japan)
- Fellow Member of JSCE(Japan Society of Civil Engineering) and AESJ(Atomic Energy Society of Japan)

CURRICULUM VITAE

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Personal Statement

Dr Simon Norris is a well-qualified and authoritative scientist, with over 28 years' national and international expertise in the radioactive waste management industry. He is a highly experienced project manager and line manager, familiar with the technical, financial and human resources aspects of complex projects, including the co-ordination of inputs from a significant contractor and stakeholder base. He has well-developed interpersonal skills, presents frequently, has published extensively, and is a recognised national and international expert in his field. He was recently appointed as an honorary professor.

Career Summary

Principal Research Manager

Radioactive Waste Management Limited, UK
1994 – Present Day

- Responsible for interpreting the needs of the Safety Case, site-specific assessments and RWM Ltd's engineering design for scientific knowledge and translating these into a well-defined research strategy and programme.
- Responsible for contributing to development of RWM Ltd's technical strategy and plan.
- Responsible for obtaining solutions (e.g. scientific knowledge and modelling) by acting as intelligent client for the engineered barrier, host rock and gas research areas of RWM Ltd's programme.
- Responsible for acting as technical authority and providing authoritative advice and input to RWM Ltd in the relation to engineered barrier, host rock and gas research.
- Responsible for acting as RWM, NDA and UK representative at national and international scientific fora and events, as relevant to research expertise.
- Responsible for scientific liaison with University Departments, industry wide scientific fora and scientific institutes.
- Responsible for understanding the content and relevance of overseas research programmes to RWM's safety case and engineering interests.

Achievements (see also Appendix A for publication list)

- Leads company research on engineered barrier, host rock and gas issues, including contributing to status reports, Science and Technology Plan and generic-to-site specific research strategy development.
- Produced the Environmental Safety Case for a Geological Disposal Facility for UK higher-activity radioactive wastes and led the post-closure performance assessment programme to assess the long-term suitability of a site for radioactive waste disposal, resulting in the '*Nirex 97*' assessment.
- Set-up multi-contractor Framework Agreements pursuant to EC purchasing regulations, specifying a strategic multi-year programme of work, setting selection criteria, assessing proposals, and choosing preferred organisations.
- Led company input to the European Commission FORGE, GASNET, CARBOWASTE, CAST, BEACON, Modern2020, MODATS, GAS, HITEC and RED-IMPACT projects – these interactions have allowed the development of an extensive network and personal knowledge base of the national and international status of radioactive waste management.
- Represents UK at International Atomic Energy Agency fora; co-author of TECDOCs.
- Represented RWM at USA Nuclear Waste Technical Review Board workshop on URLs.
- Published in IAEA, Nuclear Energy Agency and European Commission reports, and in industry and international journals.
- Invited by ANDRA and ONDRAF / NIRAS to serve on Scientific Committees for major international radioactive waste conferences.
- Qualified as a scrutineer of Chartered Geologist applications for the Geological Society, assisting with the Continued Professional Development of young professionals. Additionally qualified as a coach within NDA as part of a Capability Framework initiative, assisting colleagues to progress their value to the company.

Research Associate

Department of Earth Sciences, University of Liverpool, UK
1989 - 1994
Employed on BP and Shell UK-funded projects that investigated the structural and thermal evolution of offshore UK sedimentary basins.

Achievements

- Developed state-of-the-art software to investigate offshore UK sedimentary basin evolution in 3D, which had commercial application in a niche market. The application of this software led to highly innovative work, giving the clients a technical advantage for use in commercial activities.
- Presented and reported project deliverables to technical and managerial stakeholders and at international conferences. This benefited the clients by promoting their association with leading edge scientific work, and ensured the related achievements were well-publicised. As a result, the clients subsequently built on their association with the university.
- Submitted a report based on work undertaken for BP as a Ph.D. thesis. Following the examination process, this was judged of a suitable standard for award of a Doctorate.

Education and Training

Qualifications

Honorary Professor, University of Manchester, 2022
Chartered Scientist (The Science Council, 2005)
European Geologist (European Federation of Geologists, 1997)
Chartered Geologist (Geological Society, 1996)
Chartered Physicist (Institute of Physics, 1996)
Ph.D. in *Geophysical Sedimentary Basin Modelling* (University of Liverpool, 1993)
B.Sc. (Honours), First Class, in *Geophysics with Geology* (University of Liverpool, 1989)

Membership of Learned Organisations

Member of the Institute of Physics (1996)
Fellow of the Geological Society (1993)
Member of Petroleum Exploration Society of Great Britain (1992)

Training

Executive coaching (Lance Edynbry Partnership, 2009)
Line management development programme (Blue Beetle, 2009)
PRINCE2 Practitioner (QA IQ, 2008)
Capability Framework coach (Scala Group, 2007)
Influencing Strategies and Skills (Ashridge Business School, 2006)
In-house Mentoring (2006-2008)
Meeting Facilitation and Chairing Courses (Essentia Ltd, 2005)
Employment Law (Prospect Trade Union, 2006)
Handling Personal Cases (Prospect Trade Union, 2005)
Health and Safety (1990s onwards)

Personal

Married with four adult children, he enjoys long walks with the dogs, keeping fit, and a bit of cycling whenever possible. He is keen on football (watching rather than playing now, unfortunately), and international travel (including the associated culinary delights often to be sampled).

Appendix A: External Publications (named attribution)

[1] J.D.A. Piper, D. Atkinson, S. Norris & S. Thomas, 1992*. Palaeomagnetic Study of the Derbyshire Lavas and Intrusions, Central England: Definition of Carboniferous Apparent Polar Wander.* Physics of the Earth and Planetary Interiors *69, 37–55.*

[2] *Nirex 97: An Assessment of the Post-closure Performance Assessment of a Deep Waste Repository at Sellafield, Overview*, S. Norris, L.E.F. Bailey, M.M. Askarieh & G.E. Hickford, Nirex Science Report S/97/012, December 1997.

[3] *Overview Description of the Base Scenario Derived from FEP Analysis*, J. Locke, L.E.F. Bailey, D.E. Billington, A.V. Chambers, G.E. Hickford, M. Kelly, S. Norris, J.D. Porter, J.H. Rees, M.C. Thorne & C.J. Tweed, Nirex Science Report S/98/011, November 1998.

[4] *Modelling Requirements for Future Assessments Based on FEP Analysis*, J. Locke and L.E.F. Bailey, M.M. Askarieh, A.J. Baker, D.E. Billington, A.V. Chambers, K.A. Cliffe, P.J. Degnan, G.E. Hickford, J.L. Knight, D.A. Lever, A.K. Littleboy, U.M. Michie, S. Norris, N.J. Pilkington, J.D. Porter, J.H. Rees, M.C. Thorne & C.J. Tweed, Nirex Science Report S/98/012, November 1998.

[5] *Nirex 97: An Assessment of the Post-closure Performance Assessment of a Deep Waste Repository at Sellafield - Report on Peer Review by QuantiSci Ltd,* S. Norris, N.A. Chapman & P.R. Maul, Nirex Science Report S/98/014, December 1998*.*

[6] *Nirex 97: An Assessment of the Post-closure Performance Assessment of a Deep Waste Repository at Sellafield – Summary Report*, S. Norris (Editor), Nirex Science Report S/98/015, December 1998.

[7] *The Nirex Disposal Concept: Evaluating Performance*, L.E.F. Bailey, A.K. Littleboy, M.M. Askarieh, A.J. Baker, G.E. Hickford, C.P. Jackson, D.A. Lever, S. Norris, M.J. Poole, W.R. Rodwell & P.J. Sumner, Nirex Report N/011, 2000.

[8] *Post-closure Performance Assessment: Generic Performance Assessment*. L.E.F. Bailey, S. Norris, M.M. Askarieh & E.C. Atherton, Nirex Report N/031, 2001.

[9] *The Use of the Generic Post-Closure Performance Assessment in the Nirex Packaging Advice Process*, M.M. Askarieh & S. Norris, Nirex Report N/065, 2004.

[10] *Accounting for Natural Hazards in Safety Assessments*, A.W. Herbert and S. Norris. IBC Technical Services Conference: Radioactive Waste Disposal (London, United Kingdom, November 1996). Also at the "British Association Annual Festival of Science", The University of Birmingham, 8-13 September 1996.

[11] *Use of Uncertainty Analysis for Chloride in the Calibration of Groundwater Flow Models of the Sellafield Site*, A.H. Bath, W.G. Harding, K. Forde, P.J. Degnan, S. Norris, C.P. Jackson and S.P. Watson. In proceedings of NEA-SEDE Workshop on '*Use of Hydrogeochemical Information in Testing Groundwater Flow Models*' (Borgholm, Sweden, September 1997).

[12] *Site Characterisation Strategy and its Role in Post Closure Performance Assessment*, A.K. Littleboy, P.J. Degnan, R.S. McLeod and S. Norris. In proceedings of '*MRS'97: 21st International Symposium on the Scientific Basis for Nuclear Waste Management',* Volume 506, pp 719-730 (Davos, Switzerland, September 1997).

[13] *The Treatment of Water-conducting Features in Groundwater Flow and Transport Modelling of the Borrowdale Volcanic Group in Nirex 97*, C.P. Jackson, S. Norris, S.J. Todman and S.P. Watson. In proceedings of NEA-GEOTRAP Workshop on '*Water-conducting Features in Radionuclide Migration*' (held in Barcelona, Spain, 10-12 June 1998), OECD-NEA, ISBN 92-64-17124-X, 1999.

[14] *Site Investigation and its Role in Post-closure Performance Assessment*, S. Norris, SET99 - Science, Engineering and Technology for Britain (House of Commons, London, United Kingdom, March 1999).

[15] *The Role of Matrix Diffusion in Transport Modelling in a Site-specific Performance Assessment: Nirex 97*, S. Norris & J.L. Knight. In proceedings of NEA-GEOTRAP Workshop on '*Confidence in Models of Radionuclide Transport for Site-specific Assessment*' (held in Carlsbad, New Mexico, USA, 14-17 June 1999). OECD-NEA, ISBN 92-64-18620-4, 2001.

[16] *Use of a Matrix Diagram in Modelling Coupled Transport Processes in Performance Assessment*, L.E.F. Bailey & S. Norris. In proceedings of NEA-GEOTRAP Workshop on '*Confidence in Models of Radionuclide Transport for Site-specific Assessment*' (held in Carlsbad, New Mexico, USA, 14-17 June 1999). OECD-NEA, ISBN 92-64-18620-4, 2001.

[17] *Managing Radioactive Waste*, S. Norris & A.J. Hooper. Chemistry & Industry, No. 22, pp 876-880, November 1999.

[18] *Natural Safety Indicators and their Application in the UK*, W. Miller & S. Norris. Progress report to IAEA Co-ordinated Research Project on "*The Use of Selected Safety Indicators (concentrations; fluxes) in the Assessment of Radioactive Waste Disposal*", International Atomic Energy Authority, Vienna, October 2000.

[19] *The Nirex Phased Disposal Concept for Radioactive Wastes*, L.E.F. Bailey & S. Norris, Waste Management Seminar, The Physics Congress, Heriot-Watt University, 2003.

[20] *Generic Performance Assessment for a Deep Repository for Low and Intermediate-level Waste in the UK – a Case Study in Assessing Radiological Impacts on the Natural Environment*, S.R. Jones, D. Patton, D. Copplestone, S. Norris & P. O'Sullivan, Journal of Environmental Radioactivity, v66, pp89-119, 2003.

[21] *A Thematic Network on Gas Issues in Safety Assessment of Deep Repositories for Radioactive Waste (GASNET)*, W.R. Rodwell and S. Norris, EUR 20620, ISBN 92-894-6401-1, 2003.

[22] *Multiple Lines of Evidence Involved in Safety Case Arguments, Conclusions of Working Group*, S. Norris & E. Mouche. In proceedings of NEA-AMIGO Workshop on '*Geological Disposal: Building Confidence Using Multiple Lines of Evidence*' (held in Yverdon-les-Bains, Switzerland, 3-5 June 2003). OECD-NEA, ISBN 92-64-01592-2, 2004.

[23] *GASNET: A Thematic Network on Gas Issues in Safety Assessment of Deep Repositories for Radioactive Waste*, S. Norris, UK Power Journal, Issue 4, 2004.

[24] *Assessment Methodology for the Treatment of the Chemical Toxicological Impact in the Groundwater Pathway for the Nirex Phased Geological Repository Concept*, M.M. Askarieh, A.V. Chambers and S. Norris, The 10th International Conference on Environmental Remediation and Radioactive Waste Management September 4-8, 2005, Scottish Exhibition & Conference Centre, Glasgow, Scotland.

[25] *Near Field Sensitivity Studies of a Reference Repository Concept for UK High-level Waste/Spent Fuel,* S. Norris & M.J. Poole, Deliverable 5.1.11, European Commission NF-PRO Project, 2006.

[26] *Use of Geoscientific Arguments in the Nirex Phased Geological Repository Concept: Illustrative Desk Study*, S. Norris, B. Breen and J.L. Knight. In Proceedings of Second NEA AMIGO Workshop on *Linkage of Geoscientific Arguments and Evidence in Supporting the Safety Case*, Toronto, Canada, September 2005.

[27] *Impact of P&T on Geological Repositories: An Overview Of The Euratom Red Impact Project***,** D. Westlén, S. Norris, E.M. Gonzalez-Romero, D. Greneche, L. Boucher, J. Marivoet, C. Zimmerman and W. von Lensa, Global 2007 Advanced Fuel Cycles and Systems Conference, Boise, Idaho, USA, September 2007.

[28] *Comparison of Results from the MAGGAS and SMOGG Gas Generation Models*, Serco Assurance report SERCO/ERRA-0802 Issue 1, A.R. Hoch, S. Norris, B.T. Swift and M.M. Askarieh, 2007.

[29] *Understanding and Physical and Numerical Modelling of the Key Processes in the Near-field and their Coupling for Different Host Rocks and Repository Strategies, Deliverable 5.2.3 to EC NF PRO Project,* L. Johnson, J. Alonso, F. Plas, D. Pellegrini, O. Bildstein, M. Van Geet, D. Becker, P. Sellin, J.L. Cormenzana, H. Nordman, J. Lehikoinen, X. Sillen, E. Weetjens, H. Schnier, A. Vokal, D. Hodgkinson, C. Serres, S. Norris, M. Amme, C. Bauer, G.Mathieu and A. Hautojärvi, 2008

[30] *Uncertainties Associated with Modelling the Consequences of Gas*, EC PAMINA Project Topic 2 Deliverable Task 2.2.B Model Uncertainty, S. Norris, 2008.

[31] *Assessment of Impact to Non-human Biota from a Generic Waste Repository in the UK*, K.L. Smith, C.A. Robinson, S.R. Jones, J.V.I. Batlle and S. Norris, International Conference on Radioecology and Environmental Radioactivity, Bergen, Norway, June 2008.

[32] *CARBOWASTE - An Integrated Approach to Irradiated Graphite*, A.W. Banford, H. Eccles, M.J. Graves, W. von Lensa and S. Norris, Nuclear Future; Volume 04, Issue 05; September/October 2008; ISSN 1745-2058, 2008.

[33] *Approaches to Demonstrating Optimisation in the Safety Case for Geological Disposal of Higher-activity Radioactive Wastes*, M. Egan and S. Norris, VALDOR09, Stockholm, Sweden, June 2009.

[34] *Implementation of a Geological Disposal Facility (GDF) in the UK by the NDA Radioactive Waste Management Directorate (RWMD): Coupled Modelling of Gas Generation and Multiphase Flow between the Co-Located ILW/LLW and HLW/SF Components of a GDF.* A. Bond, G. Towler, A. Paulley, and S. Norris. Proceedings of the 12th International Conference on Environmental Remediation and Radioactive Waste Management. ICEM'09/DECOM'09, October 11-15, Liverpool, UK, 2009.

[35] *Summary of Gas Generation and Migration Current State of the Art,* editor S. Norris, EC FORGE Project Milestone 15, European Commission, 2010.

[36] *Impact on Non-human Biota from a Generic Geological Disposal Facility for Radioactive Waste: Some Key Assessment Issues*, C.A. Robinson, K.L. Smith and S. Norris, Journal of Radiological Protection, Volume 30, Number 2, pp161-173, 2010.

[37] *On the Role of Caprock and Fracture Zones in Dispersing Gas Plumes in the Subsurface*, A.W. Woods and S. Norris, Water Resources Research, Volume 46, W08522, 2010.

[38] *Buoyancy Driven Flow from a Waning Source through a Porous Leaky Aquifer*, A.W. Woods and S. Norris, Journal of Structural Geology, Volume 32, pp1827-1833, 2010.

[39] *Non-human Biota Assessments for Geological Disposal Facilities - a Study of the Key Uncertainties and Importance for Dose Estimates*, A.T.K Ikonen, K.L. Smith, C.A. Robinson, I. De La Cruz, T. Lindborg, Y. Thiry, P. Strand, S. Norris, International Conference on Radioecology & Environmental Radioactivity - Environment & Nuclear Renaissance, 19–24 June 2011 Hamilton, Canada.

[40] *Improving Confidence in Long-term Dose Assessments for U-238 Series Radionuclides*, L.M.C. Limer, A. Albrecht, M.-O. Gallerand, F. Garisto, V. Hormann, C. Medri, S. Norris, D. Pérez-Sánchez, M.C. Thorne and G.M. Smith, International Conference on Radioecology & Environmental Radioactivity - Environment & Nuclear Renaissance, 19–24 June 2011 Hamilton, Canada.

[41] *A Comparison of Models for Assessing the Radiological Impact of 14C Released to Soils in Gaseous Form Following the Geological Disposal of Solid Radioactive Wastes*, S. Norris, A. Albrecht, L.M.C. Limer, R. Cummings, L. Marang, G.M. Smith, K.L. Smith, M.C. Thorne and S. Xu, International Conference on Radioecology & Environmental Radioactivity - Environment & Nuclear Renaissance, 19–24 June 2011 Hamilton, Canada.

[42] *BIOPROTA: An International Forum for the Assessment of the Long-term Behaviour and Consequences of Potential Radionuclide Release to the Environment*, S. Keesmann, R. Cummings, M.-O. Gallerand, P. Gierszewski, J. Jeong, A.T.K. Ikonen, G. Kirchner, A. Liland, T. Lindborg, L. Marang, K. Nakai, S. Norris, T. Ohi, G. Olyslaegers, D. Perez-Sanchez, G.M. Smith, K.L. Smith, A. Sowder, Y. Thiry, S. Xu, International Conference on Radioecology & Environmental Radioactivity - Environment & Nuclear Renaissance, 19–24 June 2011 Hamilton, Canada.

[43] *Studies on the Retention of Se-79 in Soils and Uptake by Plants*, K.L. Smith, S. Sheppard, A. Albrecht, F. Coppin, L. Fevrier, A.-M. Lahdenpera, R. Keskinen, L. Marang, D. Perez-Sanchez, G.M. Smith, Y. Thiry, S. Norris, L.M.C Limer, M.C. Thorne and D. Jackson, International Conference on Radioecology & Environmental Radioactivity - Environment & Nuclear Renaissance, 19–24 June 2011 Hamilton, Canada.

[44] *Illustrative Assessment of Human Health Issues Arising from the Potential Release of Chemotoxic Substances from a Generic Geological Disposal Facility for Radioactive Waste*, J.C Wilson, M.C. Thorne, G. Towler and S. Norris, Journal of Radiological Protection, Volume 31, pp411-430, 2011.

[45] *EU CARBOWASTE project: Development of a Toolbox for Graphite Waste Management*, M.P. Metcalfe, A.W. Banford, H. Eccles, S. Norris, Journal of Nuclear Materials (2012), doi: http://dx.doi.org/10.1016/j.jnucmat.2012.11.016

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Modelling Expert

Incisive and technically knowledgeable professional with demonstrated expertise in developing, implementing and extending sophisticated models to predict long-term safety and risks associated with disposal of spent nuclear fuel. Adept at leading teams in building and analysing models as part of larger research projects, ensuring timely delivery of high-quality results. Extensive experience in collaborating with multidiscipline internal and international colleagues, researchers and other experts.

Areas of Expertise

- Long-term Safety Assessments
- Radionuclide Transport Modelling
- Modelling Task Project Management
- Statistical Analysis Methods
- Data Science Techniques
- Programming/Coding
- Machine Learning/Deep Learning
- Spent Nuclear Fuel Disposal
- International & Team Collaboration

Career Experience

Posiva Oy – Helsinki, Finland

Modelling Expert, 1/2017 to Present

Oversee planning and co-ordination of modelling tasks for long-term safety assessment project related to Posiva's operating license application for spent nuclear fuel disposal facility. Collaborate with biosphere assessment and primary safety assessment project teams. Attend international meetings and seminars focused on sensitivity analyses, long-term safety assessment modelling and other specific topics.

- Leverage expertise to develop and execute complex models, building on previous research to determine long-term safety and risks of disposal of spent nuclear fuel.
- Performed data processing to modelling parameters, including assessment of uncertainties.
- Produced technical reports on topics relevant to long-term safety, such as conceptual models, modelling methodology and quality assurance.

Fortum Power and Heat Oy – Espoo, Finland

Design Engineer, 11/2014 to 1/2017

Implemented model created for thesis in Ecolego software, developed modifications to extend usage (report published by Posiva) and performed additional studies. Managed inventory assessment for Loviisa LILW repository and assisted with international activities in support of Posiva, including IGD-TP and IAEA MODARIA meetings