出國報告（出國類別：其他）

赴美國核能管制委員會(USNRC)研習核能電廠除役輻射安全審查技術

服務機關：行政院原子能委員會
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派赴國家：美國　華盛頓特區(**Washington DC**)
出國期間：**102** 年 **08** 月 **10** 日至 **102** 年 **08** 月 **19** 日
報告日期：**102** 年 **10** 月 **15** 日

摘 要

本次公差行程爲因應核電廠除役之輻射安全管制審查需要，於102年8月10日至8月19日赴美國核能管制委員會研習核電廠除役輻射安全之審查內容及技術，主題爲「多部會輻射偵檢與廠址調查指引(Multi-Agency Radiation Survey and Site Investigation Manual, MARSSIM)」。

MARSSIM係由美國環保署、核管會、能源部和國防部共同爲核設施除役輻射偵檢研訂的一套技術指引，可適用於各式除污條件之場所。MARSSIM針對潛在污染建築物和表土之解除管制提供一套科學驗證與確認方法，支持除役後廠址土地再利用(簡稱外釋)之安全標準，係依偵檢規劃、量測、評估和決策之程序完成廠址之最終狀態輻射偵檢，以統計檢定方法證實廠址可釋出供作公眾使用(如：綠地)或限制性用途使用。另外，MARSSIM亦提供資料品質管理程序指引，有助於促進數據資源之有效利用。

關鍵字：除役、MARSSIM、輻射安全、土地再利用

目 次

一、 目 的

核能電廠除役爲國家既定政策，依據經濟合作暨開發組織(Organization for Economic Co-operation and Development, OECD)所屬核能署(Nuclear Energy Agency, NEA)的報告指出，核能電廠除役主要的管制重點爲「輻射安全」及「核廢料處理」。

依據我國「核能電廠除役管理方針」，爲管理核電廠之除役，保障國民安全，維護環境生態品質，增進廠址土地資源之安全利用，主管機關(行政院原子能委員會)於核電廠除役前，應積極研訂核電廠除役有關之安全管制法規與標準，規劃除役管制之作業流程，並積極參與核電廠除役之國際合作與國際會議，吸收並引進技術與經驗，加強核電廠除役有關之研究發展工作，以奠定未來引進及發展技術之基礎。

有鑒於台灣電力公司依據我國「核子反應器設施管制法」和「核子反應器設施管制法施行細則」之規定，預計將於 104 年底前提交核能一廠之除役計畫書，以及於 107 年底前完成核能一廠之除役作業細部計畫書，爲因應除役輻射防護與安全管制審查之需要，本次公差行程爲於 102 年 8 月 10 日至 102 年 8 月 19 日派赴美國核能管制委員會(Nuclear Regulatory Commission, NRC)，研習「多部會輻射偵檢與廠址調查指引(Multi-Agency Radiation Survey and Site Investigation Manual, MARSSIM)」課程，藉以吸收並引進美國在除役輻射安全驗證確認釋出技術上之經驗，以作爲我國擬訂除役計畫輻射安全審查導則之技術參考。

MARSSIM 指引係由美國環保署(EPA)、核管會(NRC)、能源部(DOE)和國防部(DOD)四個放射性物質管制權責部會共同研訂而成，目的專為潛在污染場所輻射偵檢與調查作業提供一套全美一致認同的執行作法，亦為國際間採用。MARSSIM 之方法既科學又富彈性，可廣泛適用於各式除污條件之場所。

MARSSIM 既為國際認同之除役輻射安全驗證與確認方法，值得我國相關人員深入了解。MARSSIM 關於廠址「最終狀態輻射偵測規劃」之偵檢目標、設計(標準的應用與推導及偵測點數目的決定等)、量測/取樣位置的決定、調查基準的決定、偵測方法、品質保證方案、偵測結果的評估，以及外釋標準等，都有詳盡的指引說明，而對於其他相關資訊或技術、成本節省方案等亦提供可參考之資訊，可有助於我國有關「核子反應器設施除役計畫導則」所規定第十七章第三項之文件準備時之參考。

二、 過 程

(一) 本次公差行程：

本次公差行程自 102 年 8 月 10 日至 8 月 19 日，共計 10 日。行程如下：

日期	天數	地點	工作內容
102.08.10(六) ~102.08.11(日)	2	台北→洛杉磯(轉機) →華盛頓特區	去程 (台北→華盛頓特區)
102.08.12(一) ~102.08.16(五)	5	華盛頓特區	美國核管會研習 MARSSIM 課程
102.08.17(六)	1	華盛頓特區	資料整理與個人行程
102.08.18(日) ~102.08.19(一)	2	華盛頓特區→洛杉磯 (轉機)→台北	回程 (華盛頓特區→台北)
合計	10		

本次研習地點假美國 NRC 總部之 Three White Flint Building 舉行。Three White Flint Building 的戒備相當森嚴，大廳區分員工與外賓訪客之入內分道，NRC 員工憑證刷卡進入，而外賓訪客則每天須先向保安警察登記換領當日訪客證，進行 X 光機隨身行李與人身安檢，再集體經由保安警察帶領至二樓訓練中心上課，即使午休時間亦必須經由保安警察帶領進出，過程均無法自由進出。

NRC 總部之 Three White Flint Building

研習過程

(二) 課程辦理資訊：

MARSSIM 課程係由美國 NRC 主辦贊助，但委由橡樹嶺聯合大學(Oak Ridge Associated Universities)專業訓練中心(Professional Training Programs)辦理。

Coordinated By:

Tonya Bernhardt, M.S., CHP, Health Physicist

Sponsored By:

U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF THE CHIEF HUMAN CAPITAL OFFICER
HUMAN RESOURCES TRAINING AND DEVELOPMENT DIVISION
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(三) MARSSIM 課程表：

研習期間，講師們均嚴格控管表訂上課時間，據以執行，午休時間亦嚴守 1 小時之規定。對於課程表訂內容，講師們均按表操課，但由於 MARSSIM 課程涉及除役法規與標準規定、其他相關程式應用、其他相關技術文件參照、輻射防護(保健物理)決策邏輯，以及統計演算應用等，內容甚爲龐雜艱澀，講師們爲顧及學員之問與答和理解，偶有落後進度之情形，但均會因應延遲下課以補齊進度；整體而言，講師們已提供學員 MARSSIM 必備之相關資訊，並充份指導課堂演算練習，協助學員完成該課程之結業測驗與學習。

DATE	TIME	TOPIC	INSTRUCTOR(s)
Monday, August 12	8:00 AM	Welcome and Registration	Frame
	9:00 AM	MARSSIM OVERVIEW	FRAME
	12:00 PM	Lunch	
	1:00 PM	MARSSIM OVERVIEW cont'd	FRAME
	3:00 PM	RADIOLOGICAL SURVEY TYPES IN SUPPORT OF DECOMMISSIONING	BERNHARDT
Tuesday, August 13	8:00 AM	DCGLs: SELECTION AND APPLICATION	FRAME
	9:30 AM	RESRAD/DandD, RESRAD Build, VSP	FRAME
	11:30 AM	Lunch	
	12:30 PM	Problem Session: DCGLs	FRAME
	2:30 PM	CLASSIFICATION AND SURVEY UNITS	FRAME
	4:00 PM	ELECTRONIC RESOURCES	FRAME
Wednesday, August 14	8:00 AM	REFERENCE AREAS	FRAME
	10:00 AM	INTEGRATED FINAL STATUS SURVEY	FRAME
	11:30 AM	Lunch	
	12:30 PM	SURVEY ACTIVITY ASSESSMENT & DETECTION SENSITIVITY OF SURVEY INSTRUMENTATION SURVEY	BERNHARDT
	2:30 PM	MARSSIM: STATISTICAL DESIGN OF FINAL STATUS	BERNHARDT
Thursday, August 15	8:00 AM	CLASS EXERCISE: EXAMPLES FOR MARSSIM FSS DESIGN	BERNHARDT
	10:30 AM	NUREG 5849 AND TRIAD AS ALTERNATIVE APPROACHES	FRAME
	11:30 AM	Lunch	
	12:30 PM	MARSAME (SUPPLEMENT TO NUREG-1575)	FRAME
	1:30 PM	DATA QUALITY ASSESSMENT: EVALUATING CUSHING DATA SET	BERNHARDT
	3:00 PM	DATA QUALITY ASSESSMENT: PERFORMING STATISTICAL TESTS RETROSPECTIVE POWER CURVES	BERNHARDT
Friday, August 16	8:00 AM	INDISTINGUISHABLE FROM BACKGROUND	FRAME
	10:30 AM	FINAL STATUS SURVEY REPORTS	FRAME
	11:00 AM	SUMMARY: TAKING ADVANTAGE OF FLEXIBILITY OFFERED BY MARSSIM	FRAME
	11:30 PM	Exam	Staff
	12:00 PM	Course critique and Adjourn	

(四) MARSSIM 課程師資簡介：

全部課程分由二位講師講授，二位講師均爲美國資深保健物理師，除了具有多年核能與輻射防護相關領域之授課經驗外，亦在核能電廠除役保健物理方面具有多年實務經驗，對 MARSSIM 指引之內容與操作應用相當熟稔。

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PROFESSIONAL TRAINING PROGRAMS
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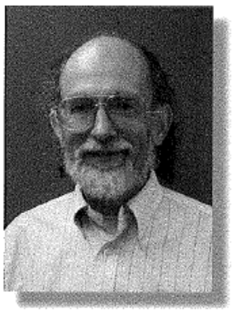

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三、 心 得

A.美國除役法規

MARSSIM 課程一開始先介紹美國核設施停役、除役之輻射安全管制規定：「執照中止輻射安全標準(Radiological Criteria for License Termination)」，相關聯邦法規包括 10 CFR Parts 20, 30, 40, 50, 51, 70 和 72，訂定目的爲美國國內所有準備除役之土地和建築結構，載明其外釋安全標準之規定。這些法規之最終準則(Final Rule)於修訂發布前，曾蒐集大量公眾意見與建議，包括來自於聯邦機關、州政府機關、電力公司、物質與燃料循環設施經營者、美國公民、環保團體、工會、社團組織或個人等的意見，過程歷經各式議題之討論、溝通、回應與修正，最後達成共識後訂定。以下列出上述相關法規之主題：

(1) Part 20—輻射防護安全標準(Standards for Protection Against Radiation)
(2) Part 30—核發(美國)放射性物質執照之通用準則(Rules of General Applicability to Domestic Licensing of Byproduct Material)
(3) Part 40—核發(美國)核子原料執照(Domestic Licensing of Source Material)
(4) Part 50—核發(美國)生產和使用設施執照(Domestic Licensing of Production and Utilization Facilities)
(5) Part 51—核發(美國)執照之環境保護規定及其相關管制職能(Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions)
(6) Part 70—核發(美國)特殊核物質執照(Domestic Licensing of Special

Nuclear Material)

(7) Part 72—用過核燃料和高放射性廢棄物獨立貯存設施之發照規定 (Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste)

其中，Part 20 之法規條文明文規定，廠址之輻射污染殘留活度若對關鍵群體平均每人造成的年有效劑量不超過 0.25 毫西弗(包括供作飲用水之地下水資源)者，則該廠址應考量設定其除役目標爲釋出供作公眾非限制使用(unrestricted use)。

另外，NRC 在執行「執照中止輻射安全標準」最終準則之相關技術文件當中有說明，爲了評估各別污染核種之除污程度是否達法規外釋標準，在執行過程中須先將法規外釋標準(如：0.25 毫西弗/年)轉換成各核種之推定濃度水平(如：建築物表面之貝克/公斤)，建議可使用 DandD 電腦程式作爲保守篩選評估之工具，例如：NRC 採用 DandD 程式模擬廠址作非限制使用之外釋情節，建立建築物表面常見污染核種之可接受推定濃度指引水平(表 1)，以利這些爲節省廠址特性調查評估相關成本之設施經營者直接參用。

建築物表面常見污染核種之可接受推定濃度指引水平

放射性核種	可接受推定濃度指引水平 (貝克/100 平方公分) (非限制使用外釋情節)	放射性核種	可接受推定濃度指引水平 (貝克/100 平方公分) (非限制使用外釋情節)
H-3	1.2E+08	Co-60	7.1E+03
C-14	3.7E+06	Ni-63	1.8E+06
Na-22	9.5E+03	Sr-90	8.7E+03
S-35	1.3E+07	Tc-99	1.3E+06
Cl-36	5.0E+05	I-129	3.5E+04
Mn-54	3.2E+04	Cs-137	2.8E+04
Fe-55	4.5E+06	Ir-192	7.4E+04

B.MARSSIM 概觀

(一)　　總論

MARSSIM 指引係為 NUREG-1575 技術手冊之主題，用以取代 NUREG-5849 技術手冊，主要重點是為「最終狀態輻射偵檢計畫(Final Status Survey, FSS)」提供執行程序之指引。課程研習過程中，講師曾提及一套名為 Visual Sampling Plan 之軟體，該軟體其中一項模組即為 MARSSIM，可用以規劃廠址之最終狀態輻射偵檢。

此外，MARSSIM 亦描述廠址輻射特性之調查方法，然而，其僅針對建築物表面和表層土壤(表面 15 公分)部分之外釋評估，並不包括物質、設備和次表土(subsurface soil)等部分。關於物質和設備之特性調查與外釋評估驗證，是寫在 MARSSIM 的補充手冊—「多部會輻射偵檢與物質設備評估指引(Multi-agency Radiation Survey and Assessment of Materials and Equipment, MARSAME)」當中，至於次表土之輻射特性調查與外釋評估，NRC 等相關權責部會預計將出版另一套補充手冊—「多部會輻射偵檢與次表土評估指引(Multi-agency Radiation Survey and Assessment of the Subsurface, MARSAS)」，目前應該還在研訂當中。

與 MARSSIM 相關的重要技術文件尚包括：NUREG-1505、NUREG-1507，以及 NUREG-1757(共三卷)。分別在下面幾段中介紹。

NUREG-1505 又名為「A Nonparametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys」，其內容除了涵蓋 MARSSIM 之大部分重點外，另外在統計部分又做了更詳盡的著墨；此外，NUREG-1505 尚提供 MARSSIM 所沒提到的替代方法(Alternative ways)，而這些替代方法仍保有與 MARSSIM 相同之精神。說到

NUREG-1505，另外還有一項重點必須特別強調，亦即，關於「情節 B (Scenario B)：污染核種存在於背景中(indistinguishable from background)」之評估，NUREG-1505 才是主要的參考指引。

NUREG-1507 則名爲「Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions」，亦爲 MARSSIM 的補充手冊，係針對 MARSSIM 之掃描式偵檢(scan)和量測(measurement)所關心之偵檢儀器最小可偵測濃度(Minimum Detectable Concentrations, MDCs)議題，額外補充說明 MDCs 的計算方式；除此之外，NUREG-1507 也提供儀器計數統計(counting statistics)之資訊，並採用 ISO-7503 來量化表面污染。

NUREG-1757：「Consolidated Decommissioning Guidance」，共分爲三卷冊，係 NRC 對於除役之一些面向提供綜合技術指引，其中第二卷：「Characterization, Survey and Determination of Radiological Criteria」涵蓋最終狀態輻射偵檢計畫和 MARSSIM 之履行，以及其他主題如：劑量評估模式、合理抑低(ALARA)等，該卷二之附錄部分的資訊特別有用，值得參考。

MARSSIM 指引有其優點，亦有其缺點限制，分別列舉如下：

優點 1：可彈性靈活使用。

優點 2：統計方法應用非參數統計法(non-parametric statistics)。

優點 3：可大量減少量測和(或)取樣數目。

優點 4：在評估受污染之土壤時，MARSSIM 方法有助於大大降低輻射偵檢的成本，尤其是當土壤取樣樣品必須使用到放射化學分析方法時。

缺點 1：僅適用於建築物表面和表面土壤(表面下 15 公分)之污染，對

於廠址其他部分之污染，尚且需要參考其他補充指引如：MARSAME 等。

缺點 2：MARSSIM 如要獲得有效執行，則需要審查者端和經營者端之間有充分的溝通。

缺點 3：MARSSIM 之內容龐雜繁複，容易誤解。

就整體而言，MARSSIM 指引雖不完美，但卻是一套堪稱誠實的作法，這對評估輻射污染來說是相當重要的特質。MARSSIM 或許會遇到某些特殊情況使其指引可能顯得不適切或不足，而此時正得仰賴其在運作上所提出的資料品質保證程序以及執行者的輻射防護專業判斷。

(二) 資料品質目標(Data Quality Objectives, DQOs)程序

MARSSIM 爲確保數據資料之品質並促進這些資源的有效利用，而採用科學系統的資料品質目標(Data Quality Objectives, DQOs)程序，來剔除不必要的、重複的或過度精確的數據收集，以減少除役輻射偵檢的開支，並且可確保這些資料用於決策時，其環境數據的形式、質與量均能符合預定用途，使最後的決定在技術上合理可行。

在正式介紹 DQO 程序之前，首先介紹一個名詞：「資料利用週期(Data Life Cycle, DLC)」，包含四個階段：規劃(Planning)、執行(Implementation)、評估(Assessment)與決策(Decision)。MARSSIM 在資料規劃階段即採用 DQO 程序來進行輻射偵檢計畫之規劃，如此將可促進偵檢計畫的有效性(effectiveness)與效率性(efficiency)。DQO 程序分由七個步驟，藉以規劃最佳的輻射偵檢設計：

步驟 1：陳述問題

選出規劃團隊和決策者，劃定期限，資源定義，並簡單清楚

地描述出問題爲何。

步驟 2：確認決定

以最終狀態輻射偵檢計畫來說，其可以是爲支持「某偵檢單元區域裡的污染殘存量是低於外釋標準」的論證而下決定。

步驟 3：確認決定的輸入資料

擬出欲解答的問題，例如：廠址要調查哪些特性、污染物有哪些化學特性必須確定等等，並列出準備使用哪些方法來找出這些問題的答案。這些資訊將用來建立推定污染物濃度水平(DCGLs)。

步驟 4：定好研究界限

定出欲評估的廠址區域範圍以及輻射偵檢時程。

步驟 5：建立決定法則

定出使用的統計方法以描述殘存活度，例如：平均值(mean)、中數(median)等，訂出調查基準(investigation level)。

步驟 6：明定決定誤差的限制

評估偵檢單元量測時的可能誤差，確認虛無假設(null hypothesis)，定義第一類(Type I)誤判和第二類(Type II)誤判就健康、政策、資源等議題上的後果，定出 Type I 誤差之 α 值和 Type II 誤差之 β 值。

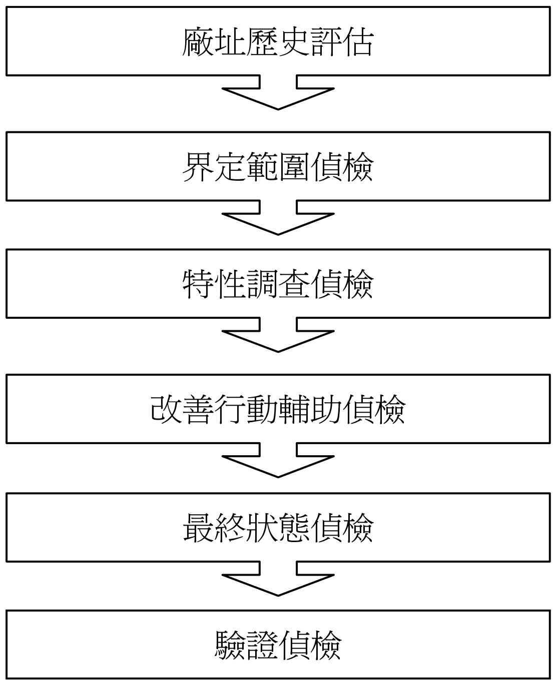
步驟 7：偵檢設計最適化以收集數據

評估幾個收集數據的替代方案，選出其中最佳的方案。

(三) 輻射偵檢與廠址調查程序

同一除役廠址可實施不同型式的輻射偵檢，MARSSIM 將此部分的執行方法寫成輻射偵檢與廠址調查(Radiation Survey and Site Investigation, RSSI)程序，分別在 MARSSIM 之第二章和第五章當中說明。MARSSIM

對每一種型式之輻射偵檢均有詳細著墨，且提供檢核表範本。執行輻射偵檢的程序可依下述流程進行：



RSSI 程序之第一步「廠址歷史評估」與後面其他步驟不太一樣的是它並沒有真正實施輻射偵檢，但即使如此，此步驟也是同等重要。廠址歷史評估之工作涉及整理並重新檢視一個廠址的運轉歷史相關資料，包括：審視過去的輻射偵檢紀錄文件、早期的地理空拍圖件，與現職工作人員和從前在此廠址工作過的人員對談等等。關於廠址歷史評估之內容，可於 MARSSIM 之第三章獲得詳細說明。

就大部分情況而言，RSSI 程序在同一廠址之不同區域裡是可以獨立進行的，換言之，某廠址的某一區域可能僅需執行最終狀態輻射偵檢即可，但其相鄰或其他區域則可能會需要從界定範圍偵檢到驗證偵檢都執行。

另外的重點是，對於廠址有受到污染影響的區域(impacted areas)，RSSI

程序當中的最終狀態偵檢是唯一總是需要執行的偵檢步驟。相反地，對於被評估指定為非影響區域(non-impacted areas)者，則甚至最終狀態輻射偵檢之步驟也可以省略不執行。此外，在 RSSI 步驟當中除了驗證偵檢外，其他所有偵檢步驟都必須由經營者或承包商執行完成，而驗證偵檢則可由審查單位委由第三公正獨立組織來執行。

(四) 規劃最終狀態輻射偵檢

規劃最終狀態輻射偵檢之流程可歸納成為 10 個步驟(相當於附錄二「MARSSIM 作弊卡」之 17 個步驟)：

步驟 1：決定個別單一核種和多核種之推定濃度指引水平(DCGLs)

推定濃度指引水平(Derived Concentration Guideline Levels, DCGLs)係指某一定義區域內之污染活度的最大許可平均值(dpm/100cm^2 或 pCi/g)，該活度濃度值相當於會符合法規外釋標準的劑量。誠如前面 1.1 節所述，美國 NRC 規定除役外釋標準為每年 0.25 毫西弗，所有 DCGLs 值對 NRC 來說都應相當於此外釋標準，然而對於美國個別州政府而言，則可以訂定比 NRC 更嚴格的外釋標準，但不能更寬鬆，例如：New Jersey 訂定除役外釋標準為 0.15 毫西弗/年。

DCGL 基本上可分為兩類型，一為 $DCGL_W$，另一為 $DCGL_{EMC}$，分別說明如下：

$DCGL_W$ —指在一個完整的偵檢單元內之 DCGL 平均值。

$DCGL_{EMC}$—指在一偵檢單元當中所另外定義出的某一塊更小區域內之 DCGL 平均值，或許也可以把它想成是熱區(hot spot)內的 DCGL 平均值。

我們可以計算個別單一核種之 DCGL，也可以計算某特定混合核種的 DCGL。個別單一核種之 $DCGL_w$ 可定爲篩選水平，相對來說是比較保守的,但設施經營者也可因其廠址之特殊條件而選擇建立數值較高的廠址特定(site-specific)之 DCGL。NUREG-1757 之第二卷中有針對一些常見核種建立 DCGL 篩選水平，如要計算其他核種之 DCGL 篩選水平，則可依該卷指引之建議使用最新版本的 DandD 程式，採預設參數值來計算。至於廠址特定之 $DCGL_w$，則可依建議使用的 RESRAD (to estimate radiation doses and risks from RESidual RADioactive materials) 和 RESRAD-Build 程式(註：由美國奧勒岡實驗室(Argonne National Laboratory)研發並已經過驗證與確認)來計算得到。

而 $DCGL_{EMC}$ 則是利用下列公式來計算：

$$DCGL_{EMC} = DCGL_W \times AF$$

其中，AF 爲區域因子(area factor)，其值大於或等於 1，必須經由電腦程式如：RESRAD 或 RESRAD-Build 計算而得，應用於特定核種和特定區域上，對於面積小一點的區域，其 AF 值會比較大。MARSSIM 和 NUREG-1505 雖均有提供 AF 參考表，但這些都用不到。

接下來要說明的是多核種(總貝他/阿伐(gross beta/alpha))的 DCGL 計算。當有量測到總貝他(或阿伐)活度之情形時，我們通常不會去區分出是來自於哪些個別核種。當要計算多核種之 DCGL 時，有兩種情形存在，一是已知這些核種之間對貝他(或阿伐)活度的貢獻比率是多少，另一則是貢獻比率未知。

如爲上述第一種情形(已知比率)者，則較高(亦較不保守)之DCGL 值是可被允許的，其計算公式爲：

$$DCGL_{gross} = \frac{1}{\frac{f_1}{DCGL_1} + \frac{f_2}{DCGL_2} + ... + \frac{f_n}{DCGL_n}}$$

其中，

$DCGL_{gross}$　為代表所有核種之 DCGL 值

$DCGL_1$　爲第 1 種核種(例如：Cs-137)的 DCGL 值

f_1　爲第 1 種核種的活度貢獻分率

$DCGL_2$　爲第 2 種核種(例如：Co-60)的 DCGL 值

f_2　爲第 2 種核種的活度貢獻分率

以此類推。

而如爲上述第二種情形(未知比率)者，則建議使用所有核種當中最爲嚴格(即數值最小)的 DCGL 值作爲代表，亦即保守假設總貝他(或阿伐)活度均來自於此最小 DCGL 值之核種之貢獻。

針對評估土壤放射性核種之情形，MARSSIM 另建議需要找一個代表核種(surrogate nuclide)來計算 DCGL 值的方法，其原因乃基於成本考量，因土壤核種之量測與分析技術多比在建築結構表面量測總貝他(或阿伐)之技術較爲昂貴，假如土壤核種是屬於不會釋放加馬射線者(如：Sr-90)，此時因無法使用加馬能譜分析技術來分析，將需要使用到放射化學分析方法來進行分析，其多爲昂貴技術，會增加分析成本。爲了有效降低分析成本，MARSSIM 提出此計算代表核種之 DCGL 的方法。假如能事先藉由一些放射化學分析技術評估出非加馬核種(推論核種，例如：Sr-90)與加馬

核種(代表核種，例如：Cs-137)之間的比率，然後藉由以下公式調整計算此代表核種(Cs-137)在土壤亦含有推論核種之情況下之DCGL 值，此時經過調整的 DCGL 值會比原來小，如此正可說明土壤裡確實含有推論核種存在的事實。此種方法的好處是，雖然事先也需使用到放射化學分析技術來評估推論核種(Sr-90)所佔比率，然而一但此步驟一完成，則接下來的工作僅需要去量化土壤樣品裡所含代表核種(Cr-137)之活度即可，將可大大降低後續放射化學分析技術的需求與成本。

$$DCGL_{adj\ sur} = \frac{1}{\frac{1}{DCGL_{sur}} + \frac{R_1}{DCGL_1} + \ldots + \frac{R_n}{DCGL_n}}$$

其中，

$DCGL_{adj\ sur}$	爲代表核種(如：Cs-137)經調整後(adjusted)的 DCGL 值(其數值會比未調整前的 DCGL 值還低)
$DCGL_{sur}$	爲代表核種尚未調整(unadjusted)前的 DCGL 值
$DCGL_1$	爲第 1 種推論核種(如：Sr-90)的 DCGL 值
R_1	爲第 1 種推論核種(Sr-90)之活度比上代表核種(Cs-137)活度之比值
$DCGL_n$	爲第 n 種推論核種的 DCGL 值
R_n	爲第 n 種推論核種之活度比上代表核種(Cs-137)活度之比值

步驟 2：廠址區域分類，劃定偵檢單元和參考區域

廠址之每個區域均需依其受污染的潛在影響情形來進行分類，可二分法分爲兩類：影響區(impacted area)和非影響區

(non-impacted area)。

倘若某一區域是屬於潛在污染地區，則分類爲影響區，此影響區又依影響程度由高至低分爲三級：

第一級(class 1)影響區—表示現在或過去有量測活度高於 $DCGL_w$ 的潛力，

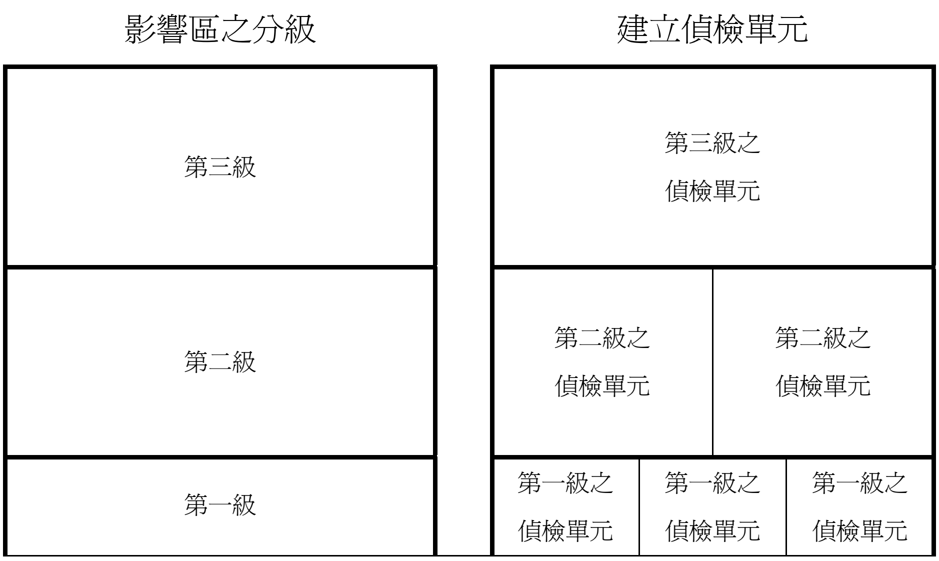
第二級(class 2)影響區—表示現在或過去雖受過潛在污染影響，但是量測時應該僅有少數會高於 $DCGL_w$，

第三級(class 3)影響區—則表示沒有潛在影響或影響潛力非常淺。

至於非影響區，則表示從來就沒有受輻射污染影響的考量。

各區域之空間又因偵檢規劃與執行之需要，需分割成許多塊小單元，稱爲偵檢單元(survey units)。除役之法規外釋驗證是以一個個偵檢單元爲基礎來決定的，一個廠址要能外釋，必須其內所有偵檢單元均符合外釋標準才行。各個偵檢單元的大小與其區域分類等級息息相關，越具污染潛力之區域，其偵檢單元就要分割地越小。以下爲影響區分級與偵檢單元之關係示意圖：

影響區分級與偵檢單元之關係示意圖



		第一級之偵檢單元	第一級之偵檢單元	第一級之偵檢單元

步驟3：決定採用情節A或情節B及統計檢定法(Sign Test或WRS Test)

大部分的案例都是使用情節 A (Scenario A)，可視爲預設情節，其虛無假設(Null hypothesis)可假設爲「該(待評估)偵檢單元不符合外釋標準」，統計檢定時是比較該偵檢單元之污染物活度濃度與其 DCGL。

會使用到情節 B (Scenario B)之情形則有：$DCGL_w$ 很低，污染物存在於背景中，背景輻射變動範圍大，或儀器之偵檢能力很差等。情節 B 之虛無假設可假設爲「該(待評估)偵檢單元符合外釋標準」。MARSSIM 指引並未提及太多關於情節 B 之說明，主要是要參考 NUREG-1505 手冊。

關於統計檢定方法，MARSSIM 乃建議採用二個非參數(non-parametric)統計檢定法：Sign Test 和 Wilcoxon Rank Sum (WRS) Test，容易操作應用。非參數統計檢定法之最大優點爲不用對資料的分布狀況作太多假設，不似參數統計檢定法(如：student *t* test)須先假設數據資料是呈常態分布。

Sign Test 的使用時機爲污染核種不存在背景中(或即使核種存在於背景中，其活度相對於 DCGL 來說非常低)和使用核種特性分析時，例如：土壤之 Co-60 加馬能譜分析。而 WRS Test 之使用時機則是當污染核種明顯存在於背景中(污染核種之活度相對於 DCGL 來說算高)和使用核種特性分析時，例如：土壤之 Cs-137 加馬能譜分析。而當在建築物表面量測總阿伐或貝他時，以下檢

定方法可擇一使用：

(1) 使用 WRS Test。

(2) 當 DCGL 相對於背景來說相當高時，可使用 Sign Test 並忽略背景。

(3) 總活度減掉背景活度，然後使用 Sign Test。

步驟 4：決定是否運用「歸一法則」

當每一取樣地點或每個取樣樣品可獲取超過 1 個數據資料時，就要使用到「歸一法則(unity rule)」，以下舉二個例子來說明：

例 1：在每個土壤樣品中都分析到 Co-60 和 Cs-137。

例 2：在同一個取樣位置同時測量到總阿伐和總貝他活度。

使用歸一法則會影響後續我們如何決定適當取樣(或量測)數目的方式，以及影響資料統計檢定的方式。

步驟 5：量測設備選擇和量測程序

輻射偵檢行動有兩種基本形式，一爲掃描式偵檢(scan)形式，另一爲量測(Measurements)或取樣(Sample)收集形式。掃描式偵檢形式是爲了找出活度可能超過外釋標準的熱區(small areas of elevated activity, or hot spots)，掃描式偵檢儀器在潛在污染表面上移動偵測。

而量測和取樣收集形式則再分爲兩種類型，一爲非偏差式(unbiased)，另一爲偏差式(biased)：

(1) 非偏差式取樣或量測

此型式取得的數據是用以估計偵檢單元內之平均污染水

平，或要用於統計檢定中。另外，在第一級影響區內採用非偏差式量測可助於定位出個別熱區之位置。量測位置採隨機選擇或系統選擇。

(2) 偏差式取樣或量測

取樣或量測位置包括：經由掃描式偵檢已確認是高活度區，和基於專業判斷有必須特別挑選出來的位置，這些位置在室內者如：地面排水管、近工作區、斷裂/接合位置、地板錨釘、水平表面，在室外者如：裝卸碼頭、凹陷或隆起區、動物的地洞、圍籬、任何表面有蓄積可能性的區域。

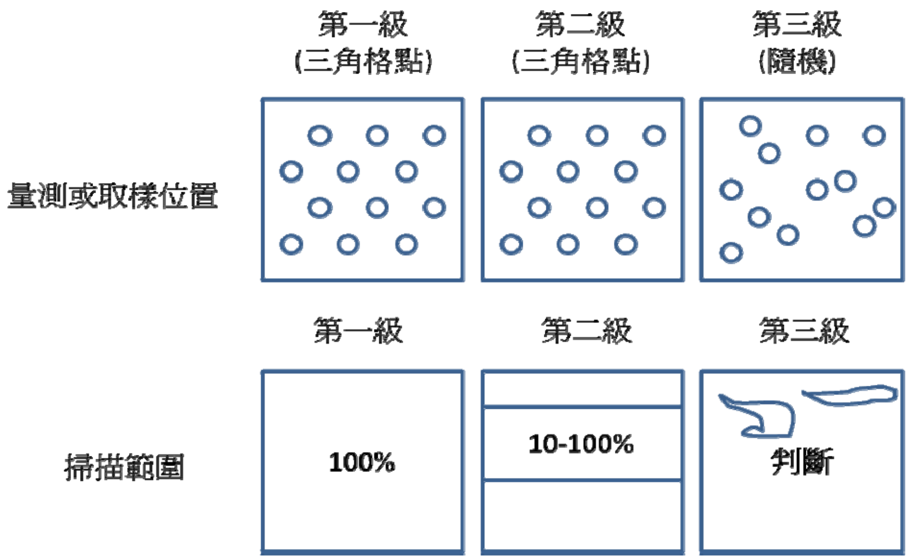
對於建築物結構表面之量測儀器，基本要求爲可量測總阿伐(或貝他)活度，以及可在牆面、地板等進行移動掃描，一般建議使用氣流式比例計數器(gas-flow proportional counter)。至於土壤量測之儀器，於掃描土壤之加馬核種時建議使用碘化鈉偵檢器(NaI detector)，而土壤測量時，通常是先收集土壤樣品，再送實驗室進行加馬能譜分析或放射化學分析。

掃描範圍依影響區分級而定。第一級偵檢單元之掃描範圍必須 100%涵蓋，而量測/取樣範圍建議採用三角格點模式(triangular pattern)。第二級偵檢單元之掃描範圍則爲 10 - 100%涵蓋範圍，其量測/取樣方式亦建議採用三角格點模式。第三級偵檢單元之掃描範圍則需要專業判斷，量測/取樣方法採隨機量測/取樣。對於非影響區，都不需要掃描和量測。

量測設備選擇和量測程序摘要表

	掃描目的是爲找出熱區，掃描範圍則依偵檢單元之影響分級而定	量測以求平均濃度，適當取樣數目需先計算相對偏移(relative shift)
建築物結構表面(室內)	掃描總貝他(或阿伐)(氣流式比例計數器)	量測貝他(或阿伐)活度(計數 1 分鐘)
土壤(室外)	掃描加馬射線(碘化鈉閃爍偵檢器)	土壤取樣後實驗室分析

量測/取樣模式和掃描範圍示意圖



另外，MARSSIM 亦聲明：「擦拭(smear)取樣之結果不應用於驗證法規承諾(compliance)。但如有必要進一步調查時，這些擦拭取樣結果應可用作診斷工具。」

步驟 6：決定掃描式偵檢和量測之最小可偵測濃度(MDCs)

步驟 6 之目標爲使量測之 MDC 低於或等於 $DCGL_w$ 之

10-50%，倘若無法達到此目標，則至少一定要低於 $DCGL_w$。而掃描偵檢之 MDC 在第一級偵檢單元內一定要低於或等於 $DCGL_{EMC}$。計算 MDCs 之說明列在 MARSSIM 的第六章和 NUREG-1507 手冊裡，相關表格亦可在這些地方查詢得到。

步驟 7：決定輻射偵檢之調查基準

調查基準設定在儀器上，由儀器響應警示是否需要展開進一步調查。第一級偵檢單元之調查基準可以設定為 $DCGL_{EMC}$ 相對應的計數率(count rate)，第二級偵檢單元之調查基準可設為 DCGLw 相對應的計數率(count rate)，而第三級偵檢單元之調查基準則可設定在 DCGLw 之某百分比程度相對應的計數率(count rate)。如為需要進一步調查的熱區，可用粉筆或插旗之方式來劃定調查範圍。

步驟 8：決定第一類誤差(Type I error)和第二類誤差(Type II error)之可接受錯誤判斷機率值(α 和 β)，並定出灰色區域之下限(LBGR)

當實施統計檢定時，其結果只有兩種情形：不是駁回(reject)虛無假設，就是無法駁回(fail to reject)虛無假設。而無論結果是前者還是後者，在統計判斷過程中都存在著錯誤判斷的可能性。假如虛無假設是與真實情況相符的情形時，則可能存在著第一類判斷誤差(Type I error)—「誤駁回虛無假設」；同樣地，當虛無假設實際上是不符真實情況時，則可能存在著第二類判斷誤差(Type II error)—「誤判斷成未能駁回虛無假設」。

上述兩種發生錯誤判斷的可能性機率應事先決定好，其中發生第一類判斷誤差之可能機率稱為 α，而發生第二類判斷誤差之

可能機率則稱爲 β。要想讓發生錯誤判斷的可能性降爲零的唯一方法就是要有無限大的量的量測數據；換言之，α 和 β 的值若訂得越小，就需要有越多的量測或取樣數據。

α 值應定義在 DCGL(外釋標準)上，比較污染濃度和 DCGL 是否通過統計測試。以情節 A 爲例，其虛無假設爲「偵檢單元不符合外釋標準」，倘若真實情況爲偵檢單元的污染濃度高於 DCGL，但統計檢定卻因存在著第一類判斷誤差而發生「誤駁回虛無假設」之結果，使得該偵檢單元被誤判爲符合外釋標準，而影響到除役輻射安全，此結果應是審查者最不願樂見的結果，審查者爲了輻射安全，當然會期望能合理降低此種誤判機率，亦即希望 α 值越小越好。綜上，因 α 值攸關除役之輻射安全，因此實務上應由審查者來訂定其可接受值。

反過來說，β 值之大小就是經營者端所關心的值。同樣以情節 A 爲例，倘若真實情況爲偵檢單元的污染濃度低於 DCGL，因此情節 A 之虛無假設「偵檢單元不符合外釋標準」本身就是個錯誤的假設，然而由於統計檢定因存在著第二類判斷誤差而發生「誤判斷成未能駁回虛無假設」之結果，使得該偵檢單元被誤判爲不符合外釋標準，此結果應是經營者最不願樂見的結果，因爲這結果將造成後續大幅的改善、偵檢等成本。因此實務上，此 β 值之大小是由經營者來設定。經營者在設定 β 時還需同時設定灰色區域之下限值(Lower Bound of the Gray Region, LBGR)，LBGR 通常是設在污染物濃度的期望水平(expected level)上，由 LBGR 與 DCGL 相比。

誠如前面所述，β 和 α 的值若訂得越小，就需要有越多的量測

或取樣數據以增加統計檢定力(power, 1-β)和信心(confidence, 1-α)。而對於 LBGR 來說，當 LBGR 越大(即越接近 DCGL 值)，也需要越多的量測或取樣數據來縮小資料的分布擴散。

步驟 9：決定適當的取樣(量測)數目

如上面所述，當 LBGR 越大，就需要越多的量測或取樣數據來縮小資料的擴散分布，亦即降低 σ (sigma)。在決定適當的取樣或量測之數目前，我們須先計算相對偏移(Relative shift)，計算公式如下：

$$\text{Relative Shift} = \frac{\Delta}{\sigma} = \frac{DCGL_w - LBGR}{\sigma}$$

其中，

$\Delta = DCGL_w - LBGR$ 即灰色區域。

σ 爲數據資料之變異性的期望值

當有使用到「歸一法則」時，則混合核種的 LBGR 和 σ 之計算必須由下面公式來調整：

$$DCGL = 1$$

$$LBGR = \left(\frac{\text{期望濃度}}{\text{DCGL}}\right)_{\text{核種1}} + \left(\frac{\text{期望濃度}}{\text{DCGL}}\right)_{\text{核種2}} + \ldots$$

$$\sigma = \sqrt{\left(\frac{\sigma}{\text{DCGL}}\right)^2_{\text{核種1}} + \left(\frac{\sigma}{\text{DCGL}}\right)^2_{\text{核種2}} + \ldots}$$

相對偏移大於 1 時會產生合理的取樣或量測數目，當相對偏移小於 1，則取樣或量測數目會飆高。關於 WRS Test 之取樣或量

測數目可查 MARSSIM 的表-5.3，而 Sign Test 之取樣或量測數目則可查 MARSSIM 的表-5.5，要注意這些表的取樣或量測數目都已多增加了 20%以作爲緩衝目的。

MARSSIM 用這方法來決定適當的取樣/量測數目，目的是爲了提供經營者一個指引，但這方法並非一定要一五一十地照作。經營者當然可以依其想要量測/取樣多少數據就作多少數據，只是要注意的是，量測數據太少的話就是會增加資料無法通過統計檢定的機會。

藉由上述方法選非偏差式量測所需要的數目，用以決定偵檢單元的濃度平均值和中數，而這種非偏差式量測有助於訂出熱點的位置，可能其中一個數據就剛好落在一個熱點上。

對於第一級偵檢單元，掃描 MDC 必須低於或等於 $DCGL_{EMC}$，亦即低於或等於 $DCGL_w$ X AF。若說掃描 MDC 小於 $DCGL_w$ 時，則一定永遠能符合安全標準；然而，當掃描 MDC 大於 $DCGL_{EMC}$ 時，則就還需要額外的量測/取樣數目。$DCGL_{EMC}$ 是來自於由 4 個取樣/量測點所圍成的區域。如何評估還需要多少額外的取樣/量測數目，可依循下列步驟來計算：

(1) 以真正的掃描 MDC 除以 $DCGL_w$ 來計算新的面積因子(AF_{req})。

$$AF_{req} = \frac{actual\ scan\ MDC}{DCGL_w}$$

(2) 決定 AF_{req} 相應之面積(a’)。

(3) 計算得新的取樣/量測數目(n’)。

$$n' = \frac{A_{survey\ unit}\left(m^2\right)}{a'}$$

步驟 10：製作參考網格(reference grid)並決定取樣(量測)點位置

經營者自己可決定是否製作參考網格建立座標地圖。製作參考網格的好處是讓使用的人易懂，能夠清楚快速地依座標方位尋找到取樣/量測位置。

網格距離資訊需要參考三角格點模式之距離計算公式：

$$L = \sqrt{\frac{A}{0.866n}}$$

其中，

A 爲偵檢單元的面積(單位：平方公尺)

n 爲步驟 9 最後計算得出的新取樣/量測數目(即 n’)

研習 MARSSIM 課程之過程中，講師曾以美國 Cushing 電廠設施之除役爲案例，以其廠址地圖(Cushing 電廠廠址圖如附錄(一))說明該電廠之影響區和非影響區的劃分，並以此練習前述之各項步驟，如：分級、計算影響區(該圖上的 RMA)範圍等。

(五) 資料評估

廠址輻射量測所收集到的資料，其品質之可信度必須經由一些驗證與確認(Verification and Validation, V&V)程序來加以評估。該小節即爲介紹評估資料時所應包涵的內容。評估資料之過程涉及三部分：驗證、確認和品質評估。

資料驗證之部分在 MARSSIM 之第 9.3.1 節和 NUREG-1576 之第八章中有詳細說明，主要係針對執行量測和取樣之實驗室的能力驗證，確認內容應包括：該實驗室是否有使用選定的分析方法、該實驗室是否每日檢核儀器性能、該實驗室是否有分析品管試樣(QC samples)、該實驗室是否參加過實驗室能力試驗比對等。

資料確認之部分則在 MARSSIM 之第 9.3.2 節和 NUREG-1576 之第八章中有說明，建議對於每個資料數據都應重新檢視過，並加以符號標籤做用途分類，例如：有疑問的數據標示爲 Q、低於 MDC 的數據標示爲 U、不能用的數據標示爲 R 等。確認資料時，確認人員應依據廠址運轉史、核種化學特性、核種之觀察到的值與其期望值之比率等多方面來加以判斷該數據是否合理。

關於資料品質評估(Data Quality Assessment, DQA)之程序，MARSSIM 在第 8.2 節中有詳細描述，建議 DQA 應依循：重新檢視 DQOs 和偵檢設計→資料初檢→選擇統計檢定方法→驗證統計檢定之虛無假設→下結論之五步驟來執行。然而，因偵檢設計期間早已選定好要使用的統計檢定法了，因此，MARSSIM 所建議的 DQA 五步驟在實務操作上建議調整爲：DQOs 和資料初檢→繪數據圖→必要時進行統計檢定→熱區(elevated measurement comparison, EMC)調查評估→必要時評估所有污染源造成的總劑量是否符合外釋標準。以下就每個步驟稍加說明：

步驟 1：DQOs 和資料初檢

首先確認有效資料的數目、最小量測値、最大量測値、平均値、中數、標準誤差等，再依序確認區域分類是否正確、量測取樣數目是否已達要求，以及平均値是高於或低於 LBGR。接下來

判斷偵檢單元是否通過外釋標準，若統計檢定(Sign Test 或 WRS Test)之結果爲污染平均值超過 $DCGL_w$，則直接宣告該偵檢單元無法通過外釋標準，而倘若統計檢定之結果爲污染平均值低於 $DCGL_w$，則仍應依下列情況考慮是否再做進一步的再檢定：

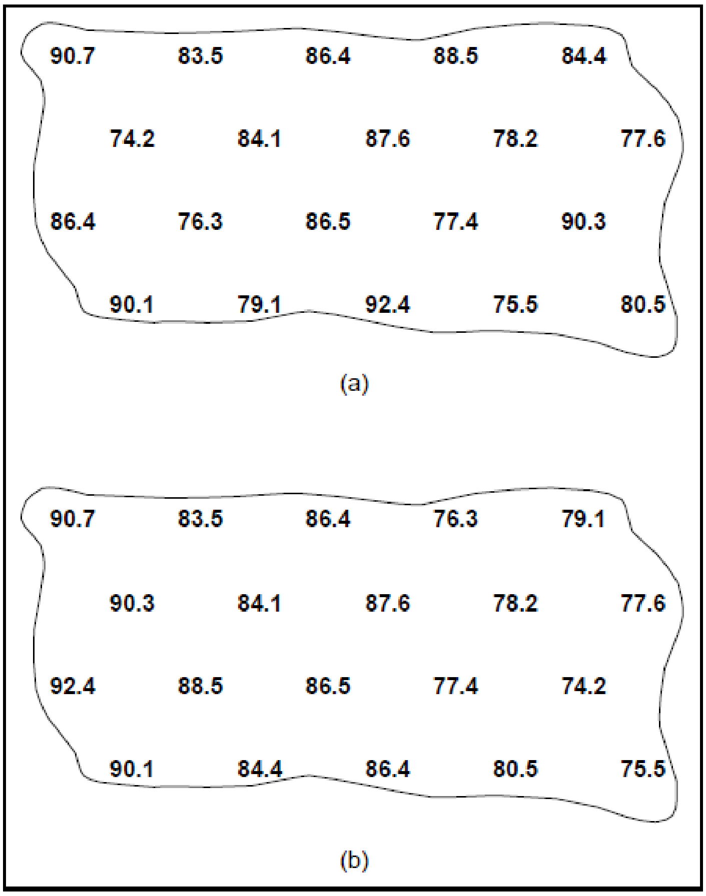
第 1 種情況：當所有量測值均低於 $DCGL_w$ 時，就無須做進一步的再檢定。

第 2 種情況：當有部分量測值高於 $DCGL_w$ 時，則需要進一步再檢定。

步驟 2：繪製輻射數據圖

此步驟係建議將量測數據標示於各個量測/取樣座標點上，如下圖：

輻射數據圖



步驟 3：必要時進行統計再檢定

步驟 1 所謂的再檢定，亦即再以統計方法測試虛無假設，其操作方法將依第一次使用何種檢定法(Sign Test 或 WRS Test)而有所不同，操作技術之細節請詳參 MARSSIM 第 8.3 節和 NUREG-1505 之第五章。以 Sign Test 爲例，此統計測試所要比較的是「低於 $DCGL_w$ 之數據的數量」和「臨界值(critical value, CV)」，當低於 $DCGL_w$ 之數據數量大於臨界值時，則確定「駁回虛無假設」，判斷「該偵檢單元符合外釋標準」。前述臨界值可於 MARSSIM 附錄 I 之表 I.3 (for Sign Test)和 I.4 (for WRS Test)中查表得知。

步驟 4：熱區(elevated measurement comparison, EMC)調查評估

所有高於調查基準的量測值均須進一步進行調查，調查內容包括：確認初始量測數據、污染區域範圍、熱區的平均濃度、熱區的 $DCGL_{EMC}$ 等。然後以下列公式之左式進行計算：

$$\left[\frac{平均濃度}{DCGL_{EMC}}\right]_{核種1}+\left[\frac{平均濃度}{DCGL_{EMC}}\right]_{核種2}+\left[\frac{平均濃度}{DCGL_{EMC}}\right]_{核種3}+\ldots<1$$

當計算結果小於 1 時，評估爲該熱區內的污染未超過外釋標準，反之，當結果大於或等於 1 時，該熱區內的污染並不符合外釋標準。換言之，上述公式僅用以評估一熱區內的劑量是否符合外釋標準，但其結果並不能直接代表整個偵檢單元內的劑量一定也符合或不符合外釋標準，亦即仍須另外評估整個偵檢單元內所有污染源造成的總劑量。當評估一熱區內的劑量不符合外釋標準

時，就要對此熱區實施改善補救行動(remedial action)。關於此步驟，MARSSIM 第 8.5.1 節和 NUREG-1505 第六章均有相關詳細說明。

步驟 5：必要時評估所有污染源造成的總劑量是否符合外釋標準

MARSSIM 第 8.5.2 節和 NUREG-1505 第 8.1 節中有提供如何完成此評估步驟的方法建議，公式如下：

$$\frac{\delta}{\mathrm{DCGL}_w}+\frac{\text{熱區1的平均值}-\delta}{\text{熱區1的}\mathrm{DCGL}_{\mathrm{EMC}}}+\frac{\text{熱區2的平均值}-\delta}{\text{熱區2的}\mathrm{DCGL}_{\mathrm{EMC}}}+\ldots<1$$

其中，δ 表示一偵檢單元內的平均濃度。

(六) 資料利用週期之決策階段

當發生下列情形之一者，設施經營者必須決定下一步該怎麼做：

情形 1：偵檢單元分類錯誤。

原分類爲第二級影響區的偵檢單元，當其真實量測值高於 DCGL 時，表示在輻射偵檢規劃時對此單元做了錯誤分類。同理，原分類爲第三級影響區的偵檢單元，當發生量測值稍高於 DCGL 時，表示此偵檢單元亦分類錯誤。若發生錯誤分類的情況，這些區域應重新進行分類，再分割成更小的偵檢單元，並重新偵檢。

當審查者審查到此種情形時，建議應考慮保持彈性作法，對於「錯誤分類的跡象不太明顯且評估其劑量很小」的情況，或許也可允許讓設施經營者以「清除現有疑慮之地方」的作法來取代「重新分類與偵檢」，如此將可大大減低相關成本支出。

情形 2：偵檢單元之平均濃度超過 DCGL。

遇到此種情形時可有幾個想法或對策：

(1) 可對整個偵檢單元進行改善補救行動並重新偵檢，

(2) $DCGL_w$ 可能設太低，可重新檢討 RESRAD 運跑時之特性參數，修正輸入值，重訂高一點的 DCGL；和

(3) 外釋目標改為限制使用用途。

情形 3：偵檢單元無法通過統計檢定。

遇到此種情形時也有相應對策或可檢討的原因：

(1) 可對整個偵檢單元進行改善補救行動並重新偵檢，

(2) 檢查統計檢定過程有沒有做錯，

(3) 檢討是否因量測/取樣數目不夠而導致無法通過統計檢定，倘若真的是因為這種原因所造成，那麼審查者應可考慮允許讓設施經營者進行一次「二次取樣(double sampling)」來增加數據數量；和

(4) 檢討是否因參考區域的量測數目少於偵檢單元的量測數目，可考慮評估參考區域是否適當。

對於上述(三)，有兩種原因可採擬相信是因量測/取樣數目不夠而導致無法通過統計檢定：一為真實量測值的標準誤差高於在計算相對偏移時所用到的標準誤差，另一為真實量測值的平均值大於在計算相對偏移時所用到的 LBGR。當進行「二次取樣」時，這些額外量測的取樣位置採隨機選擇，取得的新數據加進原數據群中，再重新做一次統計檢定。當然我們並不鼓勵時常以採取「二次取樣」的方式來補救，會需要用到「二次取樣」就表示一開始

在執行輻射偵檢規劃時即已出現問題，而我們只建議給予一次機會可採「二次取樣」來解決此問題，倘若給超過一次的機會的話，那將表示整個廠址的輻射偵檢規劃可能潛藏多項錯誤在裡面，這種偵檢規劃勢必遭受質疑。

情形 4：偵檢單元內的熱區評估不通過。

遇到此種情形時可有幾個想法或對策：

(1) 可對這些熱區進行改善補救行動並重新偵檢，

(2) DCGL 可能設太低，可重新檢討 RESRAD 運跑時之特性參數，修正輸入值，重訂高一點的 DCGL；和

(3) 面積因子(AF)可能太低，可修正 RESRAD 的特性運跑參數，重新計算出 AF 值。

情形 5：偵檢單元內的總劑量超過外釋標準。

(七) 節省成本之可行方法

MARSSIM 歸納一些可節省除役成本之可行方法，條列如下：

(1) 若 DCGLs 訂很低使得難以符合除役外釋輻射安全標準，可考慮採用 RESRAD 程式建立廠址特性之 DCGLs(數值較高)。

(2) 若背景活度相對於 DCGLs 來說很低，可考慮忽略掉背景活度，並採用 Sign Test 方法檢定總活度，如此可免去處理參考區域資料的需求。

(3) 當遇到需要評估混合核種之總阿伐和(或)貝他活度之情形時，可考慮採用最嚴格的 DCGL 值，如此可免去處理分析不同核種(有時會處理到難測核種)間之比率的實驗室程序。

(4) 有一種情形爲同時存在很多核種且(或)這些核種的分析技術又所皆不斐，對此情形，MARSSIM 認爲並非一定要對這些核種全部都做詳細分析，審查者可允許經營者選擇忽略、放棄分析那些對外釋劑量貢獻不大的核種(註：即這些核種造成的劑量總和小於外釋劑量標準之 10%，且其曝露途徑較不重要[參見 NUREG-1757 第 3.3 節])；然而，所有核種造成的總劑量仍舊要評估，以驗證是否符合法規外釋標準。當遇到這種情形，MARSSIM 建議執行方法可爲先將法規外釋劑量標準減去其 10%，用這減完剩下的值取代原外釋劑量標準(如：0.25 毫西弗/年-0.025 毫西弗/年=0.225 毫西弗/年，用 0.225 毫西弗/年當作外釋劑量標準)，用以計算其他貢獻較大且曝露途徑較爲重要的核種的 DCGLs 值。當然，當經營者聲稱其廠址內某一偵檢單元因部分核種的劑量和小於外釋標準的 10%而決定省略不分析時，那麼不用說，是一定要向審查者提出數據以支持該聲明的。

(5) 可考慮將偵檢單元數目最小化，亦即讓個別偵檢單元盡可能大一點。

(6) 若將相鄰的幾個偵檢單元(第一級或第二級)結合起來變成一個超大的偵檢單元並不會導致掃描範圍縮小和取樣數目變少時，審查者是可以考慮允許此種結合偵檢單元之作法。

(7) 盡可能自動化資料管理，如：使用空白表格程式。

(八) 建築物表面和表層土壤以外的他項

MARSSIM 係主要針對廠址之建築物表面和表層土壤(表面 15 公分)提供最終狀態輻射偵檢的評估驗證程序，然而除此之外的其他部分，MARSSIM 並未提供方法，但有提供相關文件以供連結查詢。這些他項和其參考文件爲：

(1) 次表土的污染(subsurface contamination)：相關參考文件爲 NUREG-1757 第二卷之 G.2.1 節。

(2) 地表水和沉積物(surface water and sediments)：相關參考文件爲 NUREG-1757 第二卷之 F.6 節。

(3) 碎石、破瓦殘礫和岩石(rubble, debris and rocks)：相關參考文件爲 NUREG-1757 第二卷之 G.2.2 節。

(4) 埋的管線(embedded piping)：相關參考文件爲 NUREG-1757 第二卷之 G.1.5 節。

(5) 通風管道(ventilation ducts)：相關參考文件爲 NUREG-1757 第二卷之 G.1.4 節。

(6) 污水下水道系統、污水管系統和地面排水管(sewer systems, waste plumbing systems, and floor drains)：相關參考文件爲 NUREG-1757 第二卷之 G.1.3 節。

四、 建 議

MARSSIM 是一套已發展成熟且具有豐富實際使用經驗(如：Cushing 電廠除役)的指引，係以科學爲基礎所建立的方法，可因應各式各樣準備除役之廠址，從廠址最終狀態輻射偵檢之規劃到證明符合法規外釋標準，提供一連續不斷的科學步驟程序，並提出除役輻射偵檢過程中可能產生的問題及建議解決方案，解決方案同時兼顧輻射安全目標與偵檢成本控制之考量，可供除役審查者端與廠址設施經營者端都能據以實施的一套指引，故如據以施行所提交的符合法規外釋標準之聲明文件將具有高度可信度；此外，其程序執行過程中所建議搭配使用的電腦程式或軟體如：DandD、RESRAD、RESRAD-Build、Visual Sampling Plan 等，都是經過驗證與確認(V&V)的，因此建議我國可引進採用。

然而，由於 MARSSIM 只針對廠址建築物結構表面(室內)和表層土壤(室外)提供如何支持廠址外釋聲明之執行方法，對於廠址其他部分如：物質、設備、次表土、地表水、碎石瓦礫、污水管線處理系統等，MARSSIM 並未提供具體實施方法，但有提供各別相關參考指引，因此，如國內欲採用 MARSSIM 技術，則這些相關補充文件應同時採用，於驗證符合法規外釋標準之程序中，應同時考量全部項目，以爲完整之除役輻射防護與安全目標。

MARSSIM 對於廠址除役之文件、紀錄和輻射偵檢數據資料等，建議採用具科學效率之品質保證目標流程來進行文件資料之管理、處理和利用，促使文件系統化、相關資源能有效再利用；此外，MARSSIM 對於數據資料之品質，亦建議須經由統計檢定方法一再地驗證，以確保所提數據的可靠性。因此，當採行 MARSSIM 方法來準備廠址除役之品質保證計畫時，一方面將有助於設施經營者管理除役龐雜的文件資料，一方面也有助於管制審查者有足夠信心去相信設施經營者所提數據之品質。當然，MARSSIM 文件管理流程與其他 ISO 品保系統並不

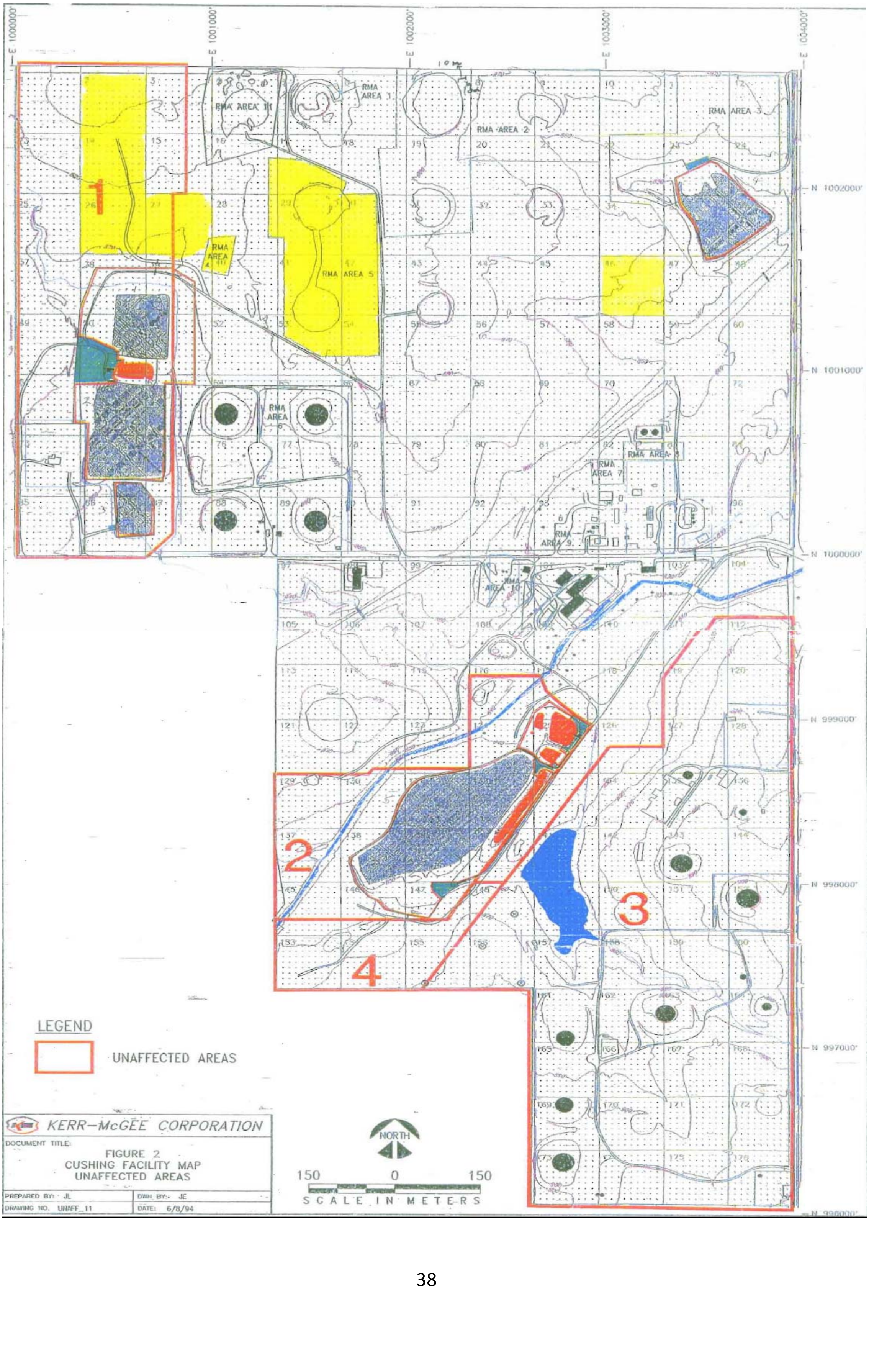
相違背，應可同時並行以加強廠址文件資料之管理。

MARSSIM 對於偵檢數據資料建議採用統計方法來檢定與再評估，以證明廠址是否符合外釋標準。然而，統計檢定之過程本來就存在著誤判的可能性，不用說，每個人都希望這誤判的可能性是越低越好。就除役輻射安全之統計假設來說，當發生第一類型之錯誤判斷時，將會因而犧牲掉某種程度的輻射安全，若此誤判機率越高(σ 值)，則除役輻射安全的疑慮就越高，這正是輻射安全審查人員最關心的問題，因此建議由審查者來訂定第一類誤判之發生機率，一般常用的 σ 值為 0.05，亦即具有 95%的正確判斷信心水平；而當發生第二類型之錯誤判斷時，其結果將導致廠址後續整治改善之相關成本的提高，這是設施經營者最關心的問題，其發生機率(β 值)是由設施經營者來提出。為了在輻射安全與除役成本二者之間求取平衡，以同時達到確保除役輻射安全又能良好控管除役成本之目標，MARSSIM 於最終狀態輻射偵檢計畫之規劃到決策期間，建議審查者端與設施經營者端之間應持續保持良好的技術溝通與協商，依廠址特性與除役外釋設定目標做經常性的溝通與協調，以找出雙方均可接受之最佳 σ 值和 β 值。

誠如前面所述，一個廠址的除役，其輻射安全涉及之範圍除了 MARSSIM 外，尚包括其他相關專業所需具備的技術與知能，如：MARSAME、MARLAP、MARSAS、NUREG-1757、RESRAD 程式、Visual Sampling Plan 程式等，因此建議積極參與這些相關技術之國際會議或訓練，廣泛且持續性地吸收國際最新技術與經驗，培訓國內除役輻射安全審查工作之專業團隊，以為國內核設施除役工作做好把關，促進土地再利用且國民輻射安全之長程總目標。

五、 附 錄

(一) 美國 Cushing 核電廠之廠址地圖



(二) MARSSIM 作弊卡(Cheat Sheet)，實爲 MARSSIM 之精華濃縮版，其中所列 17 個步驟相當於本文內所述之 10 個步驟。

PTP's MARSSIM CHEAT SHEET

Professional Training Programs at Oak Ridge Associated Universities has been providing the best hands-on training in the radiological sciences since 1948. For information about upcoming courses, visit our website at www.orau.org/ptp . You can also contact our Registrar by phone (865) 576 3576 or by email registrar@orau.org.

MARSSIM OVERVIEW

• MARSSIM (NUREG-1575) is a document that provides guidance for conducting final status surveys at radiologically contaminated facilities undergoing decommissioning.

• The final status survey is conducted by the licensee (or a subcontractor) after they have concluded that further remedial action is not necessary. In other words, the site should be relatively clean and is expected to meet the release criterion established by the regulator.

• A single final status survey is not conducted over the entire site. Instead, final status surveys are conducted in discrete areas of the site known as survey units. The planning, implementation and data assessment for the final status surveys proceed independently for each survey unit. Ultimately, every survey unit at a site must be demonstrated to meet the regulator's release criterion.

• The Nuclear Regulatory Commission's criterion for unrestricted release of a property can be summarized as follows: residual contamination that is distinguishable from background should not result in more than 25 mrem in a single year to an average member of the critical population. Many individual states employ lower criteria (e.g., 10 mrem), but we will assume for the purpose of this discussion that the criterion is 25 mrem.

• The concentrations (typically in soil or on building surfaces) that result in 25 mrem are referred to as derived concentration guideline levels (DCGLs).

IMPORTANT GUIDANCE DOCUMENTS

Abelquist, E. Decommissioning Health Physics. A Handbook for MARSSIM Users. Institute of Physics. 2001.

NUREG-1505. Nuclear Regulatory Commission. A Nonparametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys. Revision 1. 1998.

NUREG-1507. Nuclear Regulatory Commission. Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions (pre-published draft) . June 1998.

NUREG-1575. Multi-Agency Radiation Site Survey and Investigation Manual (MARSSIM). Revision 1. August 2000.

NUREG-1576. Multi-Agency Radiological Laboratory Analytical Protocols Manual. July 2004.

NUREG-1757 (three volumes). Nuclear Regulatory Commission. Consolidated Decommissioning Guidance.

DATA QUALITY OBJECTIVES (DQO) PROCESS (MARSSIM Appendix D)

The seven step DQO process is an integral component of the planning phase of the data life cycle. Its primary purpose is to ensure that all the important issues are addressed. These seven steps can be boiled down to the following:

1. State the problem: Identify the planning team, decision makers, deadlines, resources and a concise description of the problem.
2. Identify the decision: for a final status survey this would be "Is the level of residual contamination in a given survey unit below the release criteria." Then, the alternative actions are identified e.g. further remediation, reevaluation of the DCGL's, restrictions on release etc.
3. Identify inputs to the decision. Identify the specific questions to be answered, e.g., "What physical characteristics of the site need to be evaluated," "What chemical characteristics of the contamination need to be determined," etc. The chosen means to answer these questions are identified. The information needed to establish the DGCLs is identified. What methods will be used to provide the necessary data is determined.
4. Define the study boundaries. Areas of the site to be evaluated are defined and the time frame in which the survey will be performed is defined
5. Develop a decision rule: the statistical method for describing the residual activity is identified e.g. the mean, median for the survey unit, etc. The action levels are identified.
6. Specify limits on decision errors: Estimate the likely variation in the measurements for the survey unit, identify the null hypothesis and define the consequences of Type I and Type II errors in terms of health, political, and resource issues. Specify acceptable values for Type I and II error rates (alpha and beta). The formal DQO process does not reference the LBGR, but the latter should be specified when beta is specified.
7. Optimize the design of the survey for obtaining the data. Evaluate data collection design alternatives, develop the mathematical expressions that will be necessary to implement the alternatives and select the optimal options.

MARSSIM DATA LIFE CYCLE (MARSSIM 2.3)

In all four phases of the data life cycle, communication between the licensee and the regulator is essential.

1. Planning Phase (design the survey)	**2. Implementation Phase** (perform the survey)
3. Assessment Phase (evaluate the measurements)	**4. Decision Making Phase** (what to do if the survey unit fails to meet the release criterion)

(待續)

1. PLANNING PHASE OF THE DATA LIFE CYCLE

1. Determine the $DCGL_W$ for Individual Nuclides (outside scope of MARSSIM)

- It might be possible to use screening levels published by the NRC (NUREG 1757 Vol 2.) with minimal justification.
- If a screening level is not available for a particular radionuclide, one might be calculated using default input parameters and the DandD code.
- A less conservative (i.e.,higher) DCGL might be calculated using site specific input parameters and the computer code RESRAD or RESRAD-Build.

2. Determine the Gross $DCGL_W$ for Multiple Nuclides when Performing Gross Alpha or Beta Measurements (MARSSIM 4.3.4)

- Use the most restrictive (lowest) of the $DCGL_s$ for individual nuclides, or
- Determine the fraction of the total activity (alpha or beta) contributed by the various nuclides and use the following equation:

$$DCGL_{GROSS} = \frac{1}{\frac{f_1}{DCGL_1} + \frac{f_2}{DCGL_2} + \dots \frac{f_n}{DCGL_n}}$$

$DCGL_{GROSS}$ is the gross alpha or beta activity DCGL for the specified mix of nuclides.
f_1, f_2, etc are the fractions of the total alpha or beta activity contributed by nuclide 1, nuclide 2, etc.
$DCGL_1$, $DCGL_2$, etc are the individual DCGLs for nuclide 1, nuclide 2, etc.

3. Adjust (lower) the $DCGL_W$ for Surrogate Nuclides (MARSSIM 4.3.2)

- It is possible to use measurements of a nuclide that is inexpensive to analyze (e.g., Cs-137 by gamma spec) as a surrogate for the measurements of one or more expensive to analyze nuclides (e.g., Sr-90 by radiochemistry) if a ratio can be established between the nuclides. When this is done, the DCGL for the nuclide that is measured (the surrogate) must be adjusted downwards.

$$DCGL_{ADJ\ SURR} = \frac{1}{\frac{1}{DCGL_{SURR}} + \frac{R_2}{DCGL_2} + \dots \frac{R_n}{DCGL_n}}$$

$DCGL_{ADJ\ SURR}$ is the adjusted (lowered) DCGL for the surrogate nuclide.
R_2, etc are the expected ratios of the activities of the non-detected nuclides to the activity of the surrogate nuclide.
$DCGL_2$, etc are the individual DCGLs for nuclide 2, etc.

4. Determine the DCGLEMC (NUREG-1505 Chapter 8)

The $DCGL_{EMC}$ is the maximum permitted average concentration in a hot spot. It is the concentration of a specified nuclide in a specified area (smaller than the survey unit) that is assumed to result in 25 mrem in a year (i.e., the release criterion). It is calculated as follows:

$DCGL_{EMC} = DCGL_W \times AF$ **AF** is an area factor that is specific to the nuclide and area.

Although tables of example area factors have been published, there are no default area factors (or $DCGL_{EMC}$s for that matter). To calculate the area factor, divide the dose predicted with RESRAD (or RESRAD-Build) for the survey unit (or default area) by the dose predicted for the area of the hot spot. In the planning phase of the data life cycle (e.g., step 15) a worst case hot spot size must be assumed. This assumed area is that bounded by four measurement/sampling points. During data assessment, actual hot spot areas are used to determine the $DCGL_{EMC}$.

5. Classify the Site According to Contamination Potential (MARSSIM 4.4, NUREG-1505 2.2.3, 2.2.4)

Each area of the site is assigned one of the following classifications according to its potential for contamination

- Class 1 impacted areas have or had a potential for individual measurements above the DCGL. Remediated areas generally considered Class 1.
- Class 2 impacted areas have or had a potential for contamination at a significant fraction of the DCGL. Individual measurements should not exceed the DCGL.
- Class 3 impacted areas have little or no potential for contamination. Individual measurements should not exceed a significant fraction (e.g., 10-20%) of the DCGL.
- Non-impacted areas have no potential for contamination. If possible, reference area(s) are established in non-impacted area.

Note that the definitions of impacted areas in NUREG 1757 are more flexible than the above which are given in MARSSIM.

6. Establish Survey Units (MARSSIM 4.6)

The site is divided up into areas of similar contamination potential known as survey units. The survey unit is the fundamental unit of compliance. Planning, implementation and data assessment are conducted independently for each survey unit. Maximum recommended survey unit areas:

	Structure (e.g., building)	Land Area
Class 1	100 m^2 floor area	2000 m^2
Class 2	1000 m^2 floor area	10,000 m^2
Class 3	no limit	no limit

7. Determine Whether Scenario A or B will be Used

- Scenario A is the most commonly employed approach in final status surveys, and the only approach described in MARSSIM (NUREG 1575). The object is to demonstrate that the average/median level of residual radioactivity in a survey unit is less than the DCGL.
- In Scenario B, the object is to demonstrate that measurements in the survey unit are indistinguishable from those in background. Scenario B is used when the DCGL is low, the radionuclide is in background (or the measurements are not nuclide specific) and background is variable. The primary source of guidance for Scenario B is NUREG 1505.

8. Determine Whether Sign Test or Wilcoxon Rank Sum (WRS) Test Will Be Used To Assess The Data.

- Analysis is nuclide-specific and the nuclide is not in background (e.g., Co-60 in soil) - use the Sign Test
- Analysis is nuclide-specific and the nuclide is in background (e.g., Pu-239 in soil) at a small fraction of the DCGL - use the Sign Test,
- Analysis is nuclide-specific, and the nuclide is in background (e.g., Ra-226 in soil) at a significant fraction of the DCGL - use WRS test
- Analysis is not nuclide-specific (e.g., gross beta on surfaces) and background is a small fraction of the DCGL - use the Sign Test
- Analysis is not nuclide-specific (e.g., gross alpha on surfaces) and background is a significant fraction of the DCGL. This situation can be problematic if surface types and background vary from one survey unit to another. In this case, there are several options to account for background (Chapter 12 NUREG 1505):
  - use WRS test, or
  - subtract average background for surface types from survey unit gross measurements and use Sign test on net values, or
  - subtract paired background measurements for surface types from gross measurements and use Sign test on net values

9. Determine if the Unity Rule will be used in the Statistical Tests (NUREG-1505 Chapter 11)

The unity rule is used when two or more nuclides are analyzed in each soil sample (or alpha and beta measurements are performed at each location). The unity rule can be thought of as a sum of the fractions approach wherein the "concentrations" of multiple radionuclides are expressed as fractions of the DCGLs. When a DCGL for multiple nuclides is used in these tests, it is assigned a value of 1.

$$\text{Combined concentration of multiple nuclides} = \frac{\text{Conc. nuclide1}}{DCGL_1} + \frac{\text{Conc. nuclide2}}{DCGL_2} + etc.$$

(待續)

1. PLANNING PHASE OF THE DATA LIFE CYCLE continued

10. Select Type of Detection Equipment (MARSSIM Chapter 6)

- Performing scans and static measurements on structural surfaces - gas flow proportional counters usually preferred
- Performing scans for gamma emitters in soil - sodium iodide detectors usually preferred
- Measuring contaminants in soil - collect soil samples and analyze by gamma spectroscopy and/or radiochemistry. Contaminants in soil might also be measured by in-situ gamma spectroscopy

11. Determine Measurement Protocols (MARSSIM 5.5.3)

- Class 1 Survey Units - Scan coverage: 100%. Measurements/samples collected in systematic (e.g., triangular) pattern
- Class 2 Survey Units - Scan coverage: 10 to 100%. Measurements/samples collected in systematic (e.g., triangular) pattern
- Class 3 Survey Units - Scan coverage: judgmental. Measurements/samples distributed randomly
- Non-impacted area - No scan or measurements required.

12. Determine the Measurement and Scan MDCs (MARSSIM 6.7, NUREG-1507 3.1 and Chapter 6). One of the few absolute requirements in MARSSIM is that the measurement MDC be below the DCGLW . Nevertheless, MARSSIM recommends a MDC that is 10-50% of the $DCGL_W$. Typical measurement MDCs for gas flow proportional counters found in NUREG-1507 Table 5.2. Example lab sensitivities found in MARSSIM Table 7.3.

$$Measurement\ MDC\,(dpm/100cm^2) = \frac{3 + 4.65\sqrt{C_B}}{t\,E_i\,E_s\,\frac{A}{100}}$$

C_B is the background count (counts)
t is the count time (min). This equation assumes background and sample count times are identical
E_i is the instrument (2 pi) efficiency (counts per particle leaving the surface)
E_s is the surface efficiency (fraction of the decays that a detectable particle leaves the surface). Default is 0.5 for betas with maximum energies above 400 keV and 0.25 for alphas and betas with maximum energies between 150 and 400 keV.
A is the probe area (cm^2)

Typical NaI scan MDCs can be found in Table 6.7 of MARSSIM and Table 6.4 of NUREG-1507.

$$Scan\ MDC\,(dpm/100cm^2) = \frac{60\,d'\sqrt{C_{Bi}}}{i\sqrt{p}\,E_i\,E_s\,\frac{A}{100}}$$

d' is 2.32 if the acceptable probability of false positives is 0.25 and the acceptable probability of a correct detection is 0.95 (see MARSSIM Table 6.5)
C_{Bi} is the background count during the time interval i
i is the time interval (sec) that the probe is over the hot spot (of an assumed size)
p is the surveyor efficiency (MARSSIM recommends 0.5 be used)

13. Determine the Scan and Measurement Investigation Levels (MARSSIM 5.5.2.6)

The investigation level is the instrument response (e.g., cpm) that triggers an investigation when exceeded. MARSSIM suggests the following:

- Class 1 survey unit. The instrument response corresponding to the $DCGLE_{MC}$ for the area bounded by four measurement points.
- Class 2 survey unit. The instrument response corresponding to the $DCGL_W$. If this is exceeded, the survey unit might have been misclassified.
- Class 3 survey unit. The instrument response corresponding to some fraction of the $DCGL_W$. If the scan MDC exceeds the $DCGL_W$, the instrument response at the scan MDC might be used.

14. Determine Acceptability of Type I and type II Errors and Set the LBGR (MARSSIM Appendix D, NUREG 1505 Chapter 2)

For the purpose of the statistical tests, the Null (working) Hypothesis is that the median level of contamination in the survey unit exceeds the $DCGL_W$.

- Regulator establishes maximum acceptable probability (alpha) of the statistical test falsely concluding that the median level of contamination (above background) in the survey unit is below the $DCGL_W$ when it is actually at or above it. The most likely value for alpha is 0.05 (i.e., 5%).
- Licensee establishes acceptable probability (beta) of the statistical test falsely concluding that the median level of contamination (above background) exceeds the DCGLw when it is at a concentration known as the lower boundary of the gray region (LBGR).
- The licensee sets the LBGR at some concentration below the $DCGL_W$. In general, the LBGR should be set at the expected average/median concentration in the survey unit.

15. Determine Appropriate Number of Measurements or Samples (MARSSIM 5.5.2, NUREG-1505 Chapter 9)

Calculate the relative shift. Given the relative shift and values for alpha and beta, the required number of measurements or samples can then be found in Table 5.3 of MARSSIM if the WRS test is to be used. If the Sign test is to be used, the number of measurements is found in Table 5.5.

$$Relative\ Shift = \frac{DCGL_W - LBGR}{\sigma}$$

The relative shift is a unitless number (often between 1 and 4) related to the chance that individual measurements will exceed the $DCGL_W$. The smaller the relative shift, the greater the likelihood some measurements exceed the $DCGL_W$ and the greater the number of measurements that should be made.
σ is the expected variability of the measurements. It, like the LBGR, is based on earlier characterizations.

If the unity rule is employed:
- use 1 as the value for the DCGL in the relative shift calculation, and
- use the following equations to determine the appropriate values for the LBGR and σ

$$LBGR = \frac{Expected\ conc.\ nuclide1}{DCGL_1} + \frac{Expected\ conc.\ nuclide2}{DCGL_2} + etc.$$

$$\sigma = \sqrt{\left(\frac{\sigma}{DCGL}\right)^2_{NUCLIDE1} + \left(\frac{\sigma}{DCGL}\right)^2_{NUCLIDE2} + etc.}$$

16. For Class 1 Survey Units, the Number of Measurements might need to be Increased (MARSSIM 5.5.2.4)

This is because the scan must be sufficiently sensitive to detect a hot spot exceeding its $DCGL_{EMC}$. The largest (worst case) potential hot spot area is assumed to be that bounded by four measurement points (the survey unit area divided by the number of measurements/samples). If the scan MDC is below the $DCGL_W$, the scan MDC is also below the $DCGL_{EMC}$ and there is no problem. If the scan MDC is above the $DCGL_W$, it must be compared with the $DCGL_{EMC}$ for a hot spot of that area. Then, if the scan MDC is above the $DCGL_{EMC}$, the number of fixed measurements/samples must be increased so that the increased $DCGL_{EMC}$ equals the scan MDC. To do this, we first divide the actual scan MDC by the $DCGL_W$. This gives the area factor for the new smaller hot spot where the scan MDC equals the $DCGL_{EMC}$. Then the hot spot area corresponding to this area factor is determined. Dividing this new area into the total survey unit area gives the new required number of measurements/samples.

17. Establish Reference Grid and Determine Measurement/Sample Locations (MARSSIM 5.5.2.5, NUREG-1505 Chapter 3.5)

MARSSIM does not recommend a particular type of reference grid. When measurements/samples are to be distributed in a systematic pattern (Class 1 and 2 survey units), MARSSIM recommends a triangular (equilateral) pattern. The reference grid coordinates of the starting point for a systematic pattern are determined using random numbers. If the measurements/samples are to be distributed randomly (class 3 survey units), the coordinates for all the locations are selected using random numbers.

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2. IMPLEMETATION PHASE OF THE DATA LIFE CYCLE

1. Scan Surfaces for Contamination (MARSSIM 6.4.2)

The detector probe is slowly moved back and forth over potentially contaminated surfaces while the surveyor listens to the detector's audio output for indications that the investigation levels have been exceeded. The primary purpose of the scan is to locate small areas of elevated activity, i.e., hot spots. If located, the latter are characterized by additional measurements/samples to determine that the contamination is below the $DCGL_{EMC}$.

- For alpha and beta scans, the probe is usually 0.5 to 1.0 cm above the surface. A typical scan rate might be one half to one probe width per second.
- For gamma scans, a NaI probe is swung over the ground in a 1 m arc approximately 10 to 15 cm above the surface. A typical scan rate is 0.5 m/s.

2. Perform Static Measurements on Surfaces and/or Collect Soil Samples (MARSSIM 6.4.1, 7.5)

This is done to obtain accurate determinations of the contamination levels at a number of unbiased locations. This data will be assessed statistically to determine if the contamination levels in the survey unit are below the $DCGL_W$ and used to determine that the survey unit was properly classified.

- Static measurements of alpha or beta concentrations are performed with the probe directly on, or just above, the surface (in the final status survey, the surfaces should be clean with little to no removable activity). Measurements are typically performed using scalars set to one minute count times.

$$C = \frac{R_N}{E_i \, E_s \, \frac{A}{100}}$$

C is the surface concentration (dpm/100 cm²)
R_N is the net count rate (cpm)
E_i is the instrument efficiency (2 pi efficiency)
E_s is the surface efficiency
A is the probe area (cm²)

Default values for surface efficiency (E_s):

- 0.5 for betas with maximum energies above 400 keV
- 0.25 for alphas and betas with maximum energies between 150 and 400 keV.

- Soil samples are generally collected to a depth of 15 cm. One kilogram samples are usually collected for gamma spec analysis while smaller samples might be obtained if a radiochemical analysis is performed.

3. ASSESSMENT PHASE OF THE DATA LIFE CYCLE

1. Data Verification (MARSSIM 9.3.1, NUREG-1576 Chapter 8)

It is determined whether or not the laboratory and field personnel did what they were supposed to do, e.g.,

- were the correct instruments used and were daily QC checks on the instruments performed
- were the count times and sample masses what they were supposed to be (i.e., were the requisite MDCs obtained)
- were the requisite number of split, duplicate, blank samples performed
- is there missing documentation

2. Data Validation (MARSSIM 9.3.2, App. N, NUREG-1576 Chapter 8)

Data points are assessed and flagged as necessary. In essence, this is a reality check on individual measurements. Typical qualifiers (flags) are

- U measurement less than critical level • J measurement very uncertain or questionable • R data point rejected

3. Preliminary Data Review (MARSSIM 8.2.2)

- Determine the following: number of valid measurements, lowest measurement, highest measurement, mean, median, standard deviation
- Based on the measurements and scan data, determine if the area classification appears correct
- Determine that the requisite number of measurements made
- Determine if the mean is above or below the LBGR
- Survey unit fails if the average measurement (Sign test) or the difference between the average survey unit and reference area measurements (WRS test) exceeds the $DCGL_W$. Note, this does not include biased measurements, only those collected for the purpose of the statistical tests.
- A statistical test is not necessary if all the measurements (Sign test), or the difference between the highest survey unit measurement minus the lowest background measurement (WRS test), is below the $DCGL_W$. As before, this does not include judgmental and biased measurements.
- A statistical test is necessary if the average measurement (Sign test) or the difference between the average survey unit and reference area measurements (WRS test) is below the $DCGL_W$ but some measurements are above the $DCGL_W$. This doesn't include biased measurements.

4. Data are Plotted/Graphed (MARSSIM 8.4, NUREG-1505 4.2.2)

- A posting plot is produced in which the measurements (e.g., pCi/g or dpm/100 cm²) are indicated on a drawing of the survey unit at the locations where the measurements were taken.
- A histogram might also be generated

5. If necessary, the Sign Test is Performed (MARSSIM 8.3, NUREG-1505 Chapter 5)

This test only employs the unbiased randomly distributed or systematic measurements. Judgmental or otherwise biased data are not used.

- The total number of measurements being evaluated in the survey unit is N. The number below the $DCGL_W$ is the statistic S. If a measurement is the same as the $DCGL_W$, it is not counted and the total number of measurements (N) is reduced by one.
- If S is above the appropriate critical value in Table I.3 of Appendix I in MARSSIM, the Null Hypothesis (that the survey unit exceeds the release criterion) is rejected.
- If S is tied with or below the critical value, we fail to reject the Null Hypothesis and a decision must be made as to how to proceed.

6. If necessary, the Wilcoxon Rank Sum (WRS) Test is Performed (MARSSIM 8.4, NUREG-1505 Chapter 6)

This test only employs the unbiased randomly distributed or systematic measurements. Judgmental or otherwise biased data are not used.

- Add the $DCGL_W$ to each of the reference area measurements.
- The adjusted Reference area measurements are then pooled with the survey unit measurements
- The pooled measurements are ranked (sorted) from lowest to highest (1, 2, 3, etc.). Tied values are assigned an average rank (e.g., 2.5)
- The sum of the ranks of the adjusted reference area measurements is the statistic W_r.
- If W_r is above the appropriate critical value in Table I.4 of Appendix I in MARSSIM, the Null Hypothesis (that the survey unit exceeds the release criterion) is rejected.
- If W_r is tied with or below the critical value, we fail to reject the Null Hypothesis and a decision must be made as to how to proceed.

7. Perform an Elevated Measurement Comparison (MARSSIM 8.5.1, NUREG-1505 Chapter 8)

This test involves all the survey unit measurements, i.e., biased and unbiased measurements.

- Every measurement (above background) above the Investigation Level triggers an investigation.
- The investigation involves confirming the measurement and then determining the area, average concentration, and $DCGL_{EMC}$ for each hot spot.

8. Determine that the Total Dose from All Sources is Below the Release Criterion (MARSSIM 8.5.2, NUREG-1505 8.1)

$$\frac{\delta}{DCGL_W} + \frac{(ave.conc.\ hot\ spot1 - \delta)}{DCGL_{EMC}\ \ for\ hot\ spot1} + \frac{(ave.conc.\ hot\ spot2 - \delta)}{DCGL_{EMC}\ \ for\ hot\ spot2} + etc. < 1$$

δ is the average concentration in the survey unit determined from unbiased measurements

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❹ DECISION MAKING PHASE OF THE DATA LIFE CYCLE

A decision must be made as to how to proceed if the survey unit was misclassified, failed the elevated measurement comparison, failed the statistical assessment, or the total dose from all radiation sources exceeded the release criterion.

- Measurements in Class 2 or 3 survey units exceeding the $DCGL_W$ indicate that the area might have been misclassified. If so, the area (including nearby survey units) may have to be recharacterized, reclassified, subdivided into smaller survey units, and resurveyed.
- If the average concentration (above background) in a hot spot is determined during the elevated measurement comparison to exceed the $DCGL_{EMC}$ for that hot spot, the hot spot is remediated and resurveyed.
- If the average concentration (above background) in the survey unit exceeds the $DCGL_W$, or the statistical test fails to reject the Null Hypothesis, the entire survey may have to be remediated and resurveyed.
- The statistical test might fail to reject the Null Hypothesis because the test was performed incorrectly. Check to see if this was the case.
- The statistical test might fail to reject the Null Hypothesis because not enough measurements/samples were obtained. If there is reason to believe that this is the case, the regulator might permit one round of "double sampling." Some indications that not enough measurements/samples were taken include an observation that the actual standard deviation of the measurements was greater than that estimated when the relative shift was calculated, and/or the average of the measurements was higher than the LBGR. In double sampling, additional measurements/samples are obtained at randomly selected locations. These measurements are added to the pool of measurements already obtained and the statistical test is redone.
- The statistical test might fail to reject the Null Hypothesis because the reference area measurements were lower than appropriate for the survey unit. Assess the suitability of the reference area.
- The $DCGL_W$ or $DCGL_{EMC}$ might have been too conservative (low). Consider reevaluating the assumptions/parameters in the dose modeling. Note that this is a last resort. Evaluations of the dose modeling should have been done much earlier.
- Consider releasing the site under restricted conditions.

STATISTICAL CALCULATIONS IN SCENARIO B - INDISTINGUISHABLE FROM BACKGROUND (NUREG-1505 Chapter 13)

In Scenario B, two statistical tests are performed for each survey unit: the WRS test and the Quantile test. The Null Hypothesis in these tests is that the survey unit measurements are indistinguishable from background. As such, the goal is to fail to reject the Null Hypothesis in both tests.

1. Perform the Kruskal-Wallis Test

The purpose of this test is to show that significant variability exists in background. This can be considered a justification for employing scenario B. The Null Hypothesis is that no significant variability exists.

- Obtain measurements/samples in at least four reference areas. NUREG-1505 recommends at least 10 measurements in each, whereas NUREG-1757 recommends at least 15.
- Rank the pooled measurements from all the reference areas. Sum the ranks in the individual reference areas.
- Calculate the Kruskal-Wallis statistic (K) using the following equation:

$$K = \frac{12}{N(N+1)}\left(\sum \frac{R_i^2}{n_i}\right) - 3(N+1)$$

N is the total number of measurements in all the reference areas
n_i is the number of measurements in a given reference area
R_i is the sum of the ranks in a given reference area

- Compare K with critical value in Table 13.1 of NUREG-1505. In this table, k is the number of reference areas (usually 4). NUREG-1505 recommends an alpha of 0.1 whereas NUREG-1757 recommends a value of 0.2.
- If K exceeds the critical value, the null hypothesis is rejected and the conclusion is that there is significant variability in the background data.

2. Determine a Concentration that is Indistinguishable from Background (e.g., 3 ω)

- The concentration that is indistinguishable from background is some multiple of ω. NUREG-1505 and NUREG-1757 both use three as the multiple.

$$\omega = \sqrt{\frac{(s_B^2 - s_W^2)}{n_0}}$$

s_B is the mean square between the reference areas
s_W is the mean square within the reference areas
n_0 is related to the number of measurements in the reference areas

$$s_B^2 = \frac{\sum_{i=1}^{k} n_i(\bar{x}_i)^2 - \left(\sum_{i=1}^{k}\sum_{j=1}^{n_i} x_{ij}\right)^2 / \sum_{i=1}^{k} n_i}{k-1} \qquad s_w^2 = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n_i} x_{ij}^2 - \sum_{i=1}^{k} n_i(\bar{x}_i)^2}{\sum_{i=1}^{k}(n_i - 1)}$$

$$n_0 = \frac{N - \frac{1}{N}\sum_{i=1}^{k} n_i^2}{k-1}$$

N is the total number of measurements in all the reference areas
n_i is the number of measurements in a given reference area
k is the number of reference areas
x_i is an individual measurement in reference area i

3. Perform Wilcoxon Rank Sum Test on the Survey Unit Data (NUREG-1505 6.3)

- Adjust survey unit data by subtracting the concentration that is indistinguishable from background (3ω) from each survey unit measurement
- Rank the adjusted survey unit data and the unadjusted reference area data
- Sum the ranks of the adjusted survey unit data. This statistic (W_s) is compared with the critical value in Table A.7 of NUREG-1505 (m and n are the numbers of survey unit and reference area measurements respectively)
- If W_s is less than or equal to the critical value, the null hypothesis is not rejected and the survey unit is assumed indistinguishable from background.

4. Perform Quantile Test on the Survey Unit Data (NUREG-1505 Chapter 7)

- Each rank is identified as being from the survey unit (S) or a reference area (R). These identifications are then sorted in order from the lowest to highest rank.
- The number of the r highest ranks that are from the survey unit is compared with the value k. Values for r and k are indicated in NUREG-1505's Table A.7. Note that the meanings of m and n are the reverse of those in the WRS test.
- If this number is less than k, the Null Hypothesis is not rejected and the survey unit is assumed indistinguishable from background.

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Table 5.3 from MARSSIM.

Values of N/2 for Use with the Wilcoxon Rank Sum Test

To achieve the desired DQOs (acceptable rates of Type I and Type II errors), the total number of measurements is N.

N/2 measurements are taken in the survey unit, and N/2 are taken in the reference area.

Δ/σ is the relative shift

Table 5.3 Values of N/2 for Use with the Wilcoxon Rank Sum Test

	α=0.01					α=0.025					α=0.05					α=0.10					α=0.25				
	β					β					β					β					β				
Δ/σ	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25
0.1	5452	4627	3972	3278	2268	4627	3870	3273	2646	1748	3972	3273	2726	2157	1355	3278	2646	2157	1655	964	2268	1748	1355	964	459
0.2	1370	1163	998	824	570	1163	973	823	665	440	998	823	685	542	341	824	665	542	416	243	570	440	341	243	116
0.3	614	521	448	370	256	521	436	369	298	197	448	369	307	243	153	370	298	243	187	109	256	197	153	109	52
0.4	350	297	255	211	146	297	248	210	170	112	255	210	175	139	87	211	170	139	106	62	146	112	87	62	30
0.5	227	193	166	137	95	193	162	137	111	73	166	137	114	90	57	137	111	90	69	41	95	73	57	41	20
0.6	161	137	117	97	67	137	114	97	78	52	117	97	81	64	40	97	78	64	49	29	67	52	40	29	14
0.7	121	103	88	73	51	103	86	73	59	39	88	73	61	48	30	73	59	48	37	22	51	39	30	22	11
0.8	95	81	69	57	40	81	68	57	46	31	69	57	48	38	24	57	46	38	29	17	40	31	24	17	8
0.9	77	66	56	47	32	66	55	46	38	25	56	46	39	31	20	47	38	31	24	14	32	25	20	14	7
1.0	64	55	47	39	27	55	46	39	32	21	47	39	33	26	16	39	32	26	20	12	27	21	16	12	6
1.1	55	47	40	33	23	47	39	33	27	18	40	33	28	22	14	33	27	22	17	10	23	18	14	10	5
1.2	48	41	35	29	20	41	34	29	24	16	35	29	24	19	12	29	24	19	15	9	20	16	12	9	4
1.3	43	36	31	26	18	36	30	26	21	14	31	26	22	17	11	26	21	17	13	8	18	14	11	8	4
1.4	38	32	28	23	16	32	27	23	19	13	28	23	19	15	10	23	19	15	12	7	16	13	10	7	4
1.5	35	30	25	21	15	30	25	21	17	11	25	21	18	14	9	21	17	14	11	7	15	11	9	7	3
1.6	32	27	23	19	14	27	23	19	16	11	23	19	16	13	8	19	16	13	10	6	14	11	9	6	3
1.7	30	25	22	18	13	25	21	18	15	10	22	18	15	12	8	18	15	12	9	6	13	10	8	6	3
1.8	28	24	20	17	12	24	20	17	14	9	20	17	14	11	7	17	14	11	9	5	12	9	7	5	3
1.9	26	22	19	16	11	22	19	16	13	9	19	16	13	11	7	16	13	11	8	5	11	9	7	5	3
2.0	25	21	18	15	11	21	18	15	12	8	18	15	13	10	7	15	12	10	8	5	11	8	7	5	3
2.25	22	19	16	14	10	19	16	14	11	8	16	14	11	9	6	14	11	9	7	4	10	8	6	4	2
2.5	21	18	15	13	9	18	15	13	10	7	15	13	11	9	6	13	10	9	7	4	9	7	6	4	2
2.75	20	17	15	12	9	17	14	12	10	7	15	12	10	8	5	12	10	8	6	4	9	7	5	4	2
3.0	19	16	14	12	8	16	14	12	10	6	14	12	10	8	5	12	10	8	6	4	8	6	5	4	2
3.5	18	16	13	11	8	16	13	11	9	6	13	11	9	8	5	11	9	8	6	4	8	6	5	4	2
4.0	18	15	13	11	8	15	13	11	9	6	13	11	9	7	5	11	9	7	6	4	8	6	5	4	2

Table 5.5 from MARSSIM.

Values of N for Use with the Sign Test

To achieve the chosen DQOs (acceptable rates of Type I and Type II errors), N measurements are taken in the survey unit. There are no reference area measurements.

Δ/σ is the relative shift

Table 5.5 Values of N for Use with the Sign Test

	α=0.01					α=0.025					α=0.05					α=0.10					α=0.25				
	β					β					β					β					β				
Δ/σ	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25
0.1	4095	3476	2984	2463	1704	3476	2907	2459	1989	1313	2984	2459	2048	1620	1018	2463	1989	1620	1244	725	1704	1313	1018	725	345
0.2	1035	879	754	623	431	879	735	622	503	333	754	622	518	410	258	623	503	410	315	184	431	333	258	184	88
0.3	468	398	341	282	195	398	333	281	227	150	341	281	234	185	117	282	227	185	143	83	195	150	117	83	40
0.4	270	230	197	162	113	230	1921	162	131	87	197	162	136	107	68	162	131	107	82	48	113	87	68	48	23
0.5	178	152	130	107	75	152	126	107	87	58	130	107	89	71	45	107	87	71	54	33	75	58	45	33	16
0.6	129	110	94	77	54	110	92	77	63	42	94	77	65	52	33	77	63	52	40	23	54	42	33	23	11
0.7	99	83	72	59	41	83	70	59	48	33	72	59	50	40	26	59	48	40	30	18	41	33	26	18	9
0.8	80	68	58	48	34	68	57	48	39	26	58	48	40	32	21	48	39	32	24	15	34	26	21	15	8
0.9	66	57	48	40	28	57	47	40	33	22	48	40	34	27	17	40	33	27	21	12	28	22	17	12	6
1.0	57	48	41	34	24	48	40	34	28	18	41	34	29	23	15	34	29	23	18	11	24	18	15	11	5
1.1	50	42	36	30	21	42	35	30	24	17	36	30	26	21	14	30	24	21	16	10	21	17	14	10	5
1.2	45	38	33	27	20	38	32	27	22	15	33	27	23	18	12	27	22	18	15	9	20	15	12	9	5
1.3	41	35	30	26	17	35	29	24	21	14	30	24	21	17	11	26	21	17	14	8	17	14	11	8	4
1.4	38	33	28	23	16	33	27	23	19	12	28	23	20	16	10	23	18	16	12	8	16	12	10	8	4
1.5	35	30	27	22	15	30	26	22	17	12	27	22	18	15	10	22	17	15	11	8	15	12	10	8	4
1.6	34	29	24	21	15	29	24	21	17	11	24	21	17	14	9	21	17	14	11	6	15	11	9	6	4
1.7	33	28	24	20	14	28	23	20	16	11	24	20	17	14	9	20	16	14	10	6	14	11	9	6	4
1.8	32	27	23	20	14	27	22	20	16	11	23	20	16	12	9	20	16	12	10	6	14	11	9	6	4
1.9	30	26	22	18	14	26	22	18	15	10	22	18	16	12	9	18	15	12	10	6	14	10	9	6	4
2.0	29	26	22	18	12	26	21	18	15	10	22	18	15	12	8	18	15	12	10	6	12	10	8	6	3
2.5	28	23	21	17	12	23	20	17	14	10	21	17	15	11	8	17	14	11	9	5	12	10	8	5	3
3.0	27	23	20	17	12	23	20	17	14	5	20	17	14	11	8	17	14	11	9	5	12	9	8	5	3

Critical Value for Wilcoxon Rank Sum Test	$\frac{m}{2}(n+m+1)+z\sqrt{\frac{nm}{12}(n+m+1)}$	m is the number of measurements in the reference area (WRS test) n is the number of measurements in the survey unit (WRS test) N is the number of measurements in the survey unit (Sign test) z = 1.95 when α = 0.025 z = 1.645 when α = 0.05 z = 1.282 when α = 0.1
Critical Value for Sign Test	$\frac{N}{2}+\frac{z}{2}\sqrt{N}$	

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MARSSIM IS FLEXIBLE – TAKE ADVANTAGE OF IT!

(三) 西元 2013 至 2014 年目前規劃之 PTP 專業訓練課程：