(　　　)電返國報字第　　　　號出國報告
行政院所屬各機關因公出國人員出國報告書
(出國類別：實習　)

低放射性廢料最終處置核種偵測技術建立

服務機關：台灣電力公司核能後端營運處
出國人職稱：核廢料前處理股長
姓　　名：史簡
出國地區：瑞典
出國期間：91/10/6～91/10/16
報告日期：92/1/8
（出國計畫：九十一年度第60號）

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行政院及所屬各機關出國報告提要

出國報告名稱：低放射性廢料最終處置核種偵測技術建立

頁數 30 含附件：☑是□否

出國計畫主辦機關/聯絡人/電話：台灣電力股份有限公司

出國人員姓名/服務機關/單位/職稱/電話：

史簡/台電公司/核能後端營運處/股長/02-23657216

出國類別：□1. 考察□2. 進修□3. 研究☑4. 實習□5. 其他

出國期間：91/10/6～91/10/16　　出國地區：瑞典

報告日期：92/1/8

分類號/目

關鍵詞：低放射性廢棄物、核種偵測

內容摘要：

低放射性廢棄物於執行最終處置時須依法規規定列明廢棄物內含之核種及其活度，我國早期並無相關法規可供遵循，惟台電公司仍依據美國聯邦法規 10CFR 61.55 廢棄物分類章節中表 1 及表 2 所列長、短半衰期核種，自民國 77 年 7 月開始陸續委託核能研究所進行多項研發計劃，建立起核一、二、三廠各廢棄物中 α 、 β 、 γ 核種活度數據庫及以 γ 核種為基底的比例因數，供計算廢棄物桶中難測的 α 、 β 核種活度，俾便日後廢棄物最終處置所需。

瑞典在低放射性廢棄物最終處置作業方面已執行多年，其廢棄物自產生開始，即建立完善的加馬核種資料庫，再利用目前世界各國大都採用之比例因數技術，來估算廢棄物內含之 α 、 β 核種及其活度；惟對於超鈾元素，瑞典係利用各核能電廠爐水取樣、分析，建立超鈾元素對 Pu-239/240 之比例因數，以估算廢棄物中超鈾元素之活度，此點係較特異之處，依據其它國家研發結果，超鈾元素 對 Co-60 或 Cs-137 亦有良好之比例關係，似乎並無利用到爐水分析資料之必要性，此兩種技術結果之差異性尚待進一步研討。

瑞典在整體低放射性廢棄物處置作業之運作經驗可供本公司借鏡、參考。

本文電子檔已上傳至出國報告資訊網（http://report.gsn.gov.tw）

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壹、出國目的

低放射性廢棄物於執行最終處置時須依法規規定列明廢棄物內含之核種及其活度，我國早期並無相關法規可供遵循，惟台電公司仍依據美國聯邦法規 10 CFR 61.55 廢棄物分類（Waste Classification）章節中表 1 及表 2 所列長短半衰期核種，自民國 77 年 7 月開始陸續委託核能研究所進行多項研發計劃，建立起核一、二、三廠各廢棄物中 α、β、γ 核種活度數據庫及以 γ 核種為基底的比例因數（Scaling Factor），供計算廢棄物桶中難測的 α、β 核種活度，俾便日後廢棄物最終處置所需。

行政院原子能委員會放射性物料管理局於民國 86 年 7 月始頒布「低放射性廢料分類補充規定」，未來低放射性廢棄物送至陸地最終處置場時，其交運文件必須述明該補充規定附錄表一、表二之核種濃度，亦必須按核種濃度分為 A、B、C、及超 C 四類，再依類別處置；該分類補充規定所要求提報之核種與美國聯邦法規 10 CFR 61.55 所列者相同，亦即台電公司以往研發成果仍可適用，惟因所建立之廢棄物 α、β、γ 核種活度數據庫係依據民國 79 年以後至各核能電廠廢料源實地取樣分析所完成，至於民國 79 年之前所產生且已水泥固化之廢棄物（大部份已運貯蘭嶼貯存場，小部份仍暫貯各核能電廠）則欠缺相關之核種資料，由於廢棄物桶堆疊暫貯於壕溝內，若大規模開啟壕溝蓋尋桶並取樣，在實務上亦不可行，為尋求合理且可接受之核種評估技術，台電公司乃委請核能研究所

貳、出國行程

起迄日期	地點	工作內容
91.10.06- 91.10.07		往程
91.10.08- 91.10.08	瑞典 FORSMARK	參訪中、低放射性廢棄物處置場 SFR 並討論廢料接收整體作業程序
91.10.09- 91.10.10	瑞典 OSKARSHAMN	參訪 ÄSPÖ HARD ROCK 實驗室、CLAB 中期貯存設施及 CANISTER 實驗室
91.10.11- 91.10.13	瑞典 STOCKHOLM	赴 SKB 公司拜會並瞭解其低放射性廢棄物整體營運情形
91.10.14- 91.10.14	瑞典 NYKOPING	赴 STUDSVIK 公司瞭解粒狀樹脂熔融處理技術
91.10.15- 91.10.16		返程

參、工作內容

一、瑞典放射性廢棄物營運體系

(一)背景與組織

瑞典位於歐陸的北緣，面積約44萬平方公里，氣候惡劣，岩礫星佈，土壤貧瘠而林木蒼鬱，當出海冒險的維京時代沒落後，基督教文明傳來，瑞典人變為較和平的貿易商人，而同時也本著自身的地理條件發展出根基深厚的農工企業。森林與木材工業、礦產與金屬工業以及水力發電是瑞典的三大資源；然而前兩項資源卻又必須依靠鉅量的能源來維持，因此水力發電成為瑞典的經濟命脈，再加上瑞典冬季酷寒，電器取暖又增加尖峰的用電需求，由於電力需求的不斷增長，瑞典在70年代就著手發展核能發電，1972年首座核能電廠開始商轉，到目前一共有12座核能機組（其中一座已停止商轉，等待除役），分佈於四個廠址。如同其他核能國家一樣，反核的聲浪隨著機組的增加而昇高，核能工業界在1980年遭受到最嚴重的打擊，當年的公民投票決定瑞典應該從1995年開始關閉核能電廠，並且在2010年完全廢止核能發電，所幸瑞典的核能工業界並未因此而消沈，除了不斷的與民眾溝通外，核能工業界也積極的向民眾展示核能發電的安全性與可行性，由於電廠營運績效良好及用過核子燃料中期貯存設施（CLAB）暨中、低放射性廢棄物最終處置場（SFR）相繼完工運轉，藉由妥善的規劃

與營運管理，以事實有效地反駁了放射性廢棄物仍然無法解決的質疑，核能工業界的努力，又漸漸改變了民眾對核能發電的看法，由最近的民調顯示，民眾贊成核能發電的比例亦逐漸攀升，再加上瑞典核能發電比例約佔全國總發電量的50%，在沒有替代能源情況下，一般相信在2010年之後，瑞典還會繼續使用核能。瑞典有四家電力公司採核能發電，總共12部機組，分屬：

A.Ringhals 核電廠（4 部機）－Vattenfall AB（公司）

B.Barsebäck 核電廠（2 部機，其中 1 部機已停止運轉）－Sydsvenska Värmekraft AB

C.Oskarshamn 核電廠（3 部機）－OKG AB

D.Forsmark 核電廠（3 部機）－Forsmarks Kraftgrupp AB（註：亦為中、低放射性廢棄物最終處置場 SFR 所在地）

按瑞典法律規定，該四家電力公司具有確保核能廢棄物安全管理和處置的責任，因此，該四家公司乃共同設立 SKB 公司（Swedish Nuclear Fuel and Waste Management Company），由其負起用過核子燃料與其他核能廢棄物的營運體系以及接收與處置設施的規劃、興建、運轉及擁有。

瑞典政府在核能管制方面，由瑞典輻射防護所（the Swedish Radiation Protection Institute,簡稱 SSI）負責輻射防護管制，而由瑞典核能檢察署（the Swedish

Nuclear Power Inspectorate，簡稱 SKI）負責核能安全管制。

瑞典政府每三年要審查一次 SKB 提出的研究發展與示範（RD&D）計畫；因而前述兩單位（SSI 及 SKI），共同經由瑞典國家放射性廢棄物營運咨議委員會（KASAM）提供各項審查意見。

(二)瑞典放射性廢棄物處理及營運現況

1.運轉廢棄物

核能電廠運轉會產生兩種放射性廢棄物，一種是用過核子燃料，它具有高放射性及長半衰期；另一種是運轉廢棄物，它具有中、低強度放射性及短半衰期，而 SFR 只接收運轉廢棄物；至於放射性活度非常低之廢棄物，如輕微污染之工具、工作服或鞋套，由於其幾乎不含放射性，在瑞典，這類廢棄物通常都是就地在核電廠內的淺地層處置場處置。

用過核子燃料中期貯存設施－CLAB 的運轉也會產生中、低放射性廢棄物，這些廢棄物亦會送往 SFR 處置。

2.拆廠廢棄物

在反應器運轉期間，壓力槽內及周圍之反應器組件，會因腐蝕或受中子活化，而產生放射性物質，其中一部份放射性物質（腐蝕產物或中子活化產物）借由冷卻水而分散到核電廠的其他組件，等到核電廠除役、拆廠，部份組件就成為放射性廢棄物，需

作進一步處置。這些除役廢棄物大部份屬中，低強度放射性廢棄物，主要為短半衰期核種，SFR 未來可擴充來容納除役拆廠廢棄物。

3.醫、農、工、研究機構各界產生的低放射性廢棄物

在瑞典，此類廢棄物大都會送到 Studsvik Radwaste 處理（焚化或熔融）、包裝，然後送往 SFR 處置。

瑞典核能電廠產生之可燃或金屬廢棄物，亦會送往 Studsvik Radwaste 焚化或熔融處理，焚化後之灰則裝入鋼桶後送去 SFR 處置，至於熔融後之金屬 Ingot 符合 Free Release 標準者則售與 Scrap Dealer，至於尚未符合自由釋出標準者，則暫時貯存，待放射性衰減至符合釋出標準時再出售。

4.低放射性廢棄物暫時貯存

核電廠及 Studsvik 所產生的低放射性廢棄物在運送前會暫存設施內特定的場所，在 Oskarshamn 核電廠及 Studsvik 是暫存於岩洞裡；在 Barsebäck，Forsmark 及 Ringhals 核電廠則建有貯存倉庫。

5.放射性廢棄物營運體系

瑞典其相關核能設施位置圖如附件一，至於其放射性廢棄物處置作業概念如附件二；核電廠所產生的用過核子燃料先運往水池式用過核子燃料中期貯存設施 CLAB（1985 年開始運轉）暫存，再送往用過核子燃料最終處置場（據告可能延至 2015 年啟

用）作最終處置；而核電廠所產生的運轉廢棄物及醫、農、工、研究機構各界產生的低放射性廢棄物均送往中、低放射性廢棄物最終處置場 SFR（1988 年啟用）處置，封閉後不再需要監管。

二、參訪中、低放射性廢棄物處置場（SFR）、ÄSPÖ HARD ROCK 實驗室、用過核子燃料中期貯存設施（CLAB）及 CANISTER 實驗室。

(一)中、低放射性廢棄物處置場（SFR）

1.基本資料

SFR 與 Forsmark 核電廠位於斯德哥爾摩北方約 160 公里處，原址以前是鐵礦場，人煙稀少，SFR 與電廠之間由一條 2 公里長的碴岩公路連接，共用一個運輸碼頭，整個處置場位於海床底下 50 公尺深的結晶岩岩體中，場址上方的波羅地海海水深度為 5 公尺。

SFR 的設計，分為地上設施（如附件三）與地下設施（如附件四）兩部份：

(1)地上設施包括：

①辦公室及維修廠房

②接收廠房

③通風廠房

(2)地下設施包括四條各 160 公尺長，但寬度及設計各異的岩窖（Rock Vault），以及一個高 70 公尺的岩穴（Rock Cavern），在這岩穴下部則建造一個

筒倉（Silo），按圖說明如下：

①控制中心，可遙控裝卸在岩窖中之廢棄物容器。

②運輸容器之卸載區。

③筒倉（Silo）。

a.高 50 公尺，外徑 32 公尺，內徑 26 公尺，整個筒倉內部並以混凝土牆分格成 2.5 公尺寬的正方形垂直空間；筒倉外壁與岩穴間的空隙，都用膨潤土填充。本筒倉只接受以金屬桶或金屬/混凝土模組（Concrete or Metal Container；Mould）盛裝的中強度放射性廢棄物。

b.整個筒倉共可存放 42 層的廢料模組，每當放置三層，就以混凝土漿澆置（grouted），整個作業都由控制中心遙控進行。

c.整個筒倉裝滿後，頂部將以水泥蓋板覆蓋，然後上部空間以回填材料回填。

④接收經脫水、固化處理廢樹脂的岩窖（BTF，有兩個），屬中強度放射性廢棄物，以混凝土護箱（Concrete Container）盛裝，具有相當的結構強度，在本岩窖中係以堆高機執行處置作業。

⑤專門接收低強度放射性廢棄物的處置岩窖（BLA）廢棄物經壓縮、包封處理後，裝入一般標準貨櫃，然後以堆高機執行處置作業。

⑥具混凝土結構的岩窖（BMA）

a.岩窖內的混凝土結構以混凝土牆分格成數個處置室（pit），接收以金屬桶或金屬/混凝土模組（Concrete or Metal Container；Mould）盛裝，但有可能產生氣體的中強度放射性廢棄物。

b.每個處置室（pit）一旦放滿，其頂部使用水泥蓋覆蓋，所有操作均賴安置於處置窖上的橋式吊車遙控執行。

SFR 第一階段計畫之設計容量為 63,000m^3，自 1983 年開始建造，至 1988 年完工運轉，迄今（2001 年）已接收處置了 27,500 m^3 放射性廢棄物，整個處置場運轉及維護人員約為 12 人，總投資費用約 740 百萬瑞典幣（1988 年幣值），每年運轉費用約需 30 百萬瑞典幣。未來仍需擴建，以因應拆廠廢棄物所需。

2.SFR 核種估算技術

SFR 運轉執照規定，送往處置之放射性廢棄物於封場時的總核種濃度上限值為 10^6Bq，基於此一必要限制，SKB 在評估各個核種活度時，採取兩種方法，一種是比較實際的估算（realistic estimation），即利用手邊既有之廢棄物資料來預估；另一種是較保守的估算（conservative estimation），此一保守估算所獲得的各個核種活度，將用來：(A)評估處置場核種外釋劑量，(B)將各個核種總活度相加，看看是

否會超過處置場允許的封場總活度 10^6Bq。

(1)SFR 實際估算核種活度的來源資料包括：

①各核能設施（核能電廠）產生廢料之加馬核種資料庫。

②研究機構（studsvik）產生廢料之加馬核種資料庫。

③比例因數值。

④超鈾核種部份，係由各核能機組爐水取樣分析而得。

在實際估算過程中，為了計算 α 、 β 核種之活度，亦如同本公司，係採用比例因數之技術；惟除了分裂產物對 Cs-137 及腐蝕產物對 Co-60 外，與本公司不同的是對超鈾元素，SKB 係採用電廠爐水取樣分析，建立超鈾元素對 Pu-239/240 之關係，而本公司對超鈾元素則係採對 Cs-137 或 Co-60 之比例關係來估算，依世界其他各國之經驗，超鈾元素對 Cs-137 或 Co-60 之比例關係應是可接受的，瑞典的作法是獨具一格。

在對關鍵核種 Co-60 及 Cs-137 方面，其比例因數作法與本公司大致相同，比較特別的是超鈾元素對 Pu-239/240 之比例因數建立部份，由於一般建立比例因數是取各類廢棄物樣品，再以放化分析其內所含之有關核種及活度；對於超鈾元素，若取爐水樣品加以分析其核種及活度，對應

至其下游產生之各類廢棄物，要如何判斷在各類廢棄物中超鈾元素含量（或比例）?SKB 研究的結果，對超鈾元素在各類廢棄物之分佈是仿照 Co-60 分佈之比例而定，惟或許有人會問，為何不採用 Cs-137 分佈之比例？因為 Cs-137 是活化產物，應比腐蝕產物 Co-60 有更好之比例關係，但是 SKB 是依據經驗法則作此判斷，至於其真正之原因，則未有定論，可能歸因於核種遷移（transport）結果。

(2)保守估算部份

簡單的說，就是對前述採用實際廢棄物核種分析數據計算獲得之活度總量再加上一個放大因子，以 SFR 為例，大約是 10 倍左右。

此次參訪 SKB，獲得“Low and Intermediate Level Waste in SFR-1”報告一份（計 314 頁），應對瑞典 SFR 廢棄物處置情形能有進一步的瞭解。

(二)用過核子燃料中期貯存場（CLAB）

CLAB 位於瑞典 Oskarshamn 核能電廠（屬 OKG 電力公司所有）鄰近，於 1977 年申請設置，1980 年獲准興建並於 1985 年完工運轉，為了營運方便，由 SKB 委託 OKG 電力公司運轉維護。CLAB 採水池式貯存技術，目前貯存容量為 5,000 噸(鈾)，大約可貯存 20,000 BWR 燃料元件及 2,500 PWR 燃料元件，現正進行擴建中，預計 2003 年底可完工。CLAB 相關資料

詳如附件五。

CLAB 地面上的建築物有接收廠房、輔助廠房、電機廠房與辦公大樓，地面下就是貯存廠房，詳如附件六所示。貯存廠房頂部離地面約 25 公尺，長約 120 公尺，寬 20 公尺，高約 27 公尺，由四個貯存池所構成，每個貯存池可容納 3000 立方米的水，池水溫度最高保持在 36℃，有兩個冷卻循環，採海水為熱沈。

(三)Äspö Hard Rock 及 Canister 實驗室

1.Äspö Hard Rock 實驗室可說明 SKB 公司最重要的研究計劃，在此地下實驗室可針對用過核子燃料之最終處置的各項測試進行研究，各項計劃參與之國家多達 9 個，透過國際合作，除可促使資源有效利用外，更可提昇技術層次。已完成及正在進行之計劃包括：The ZEDEX experiment、The LOT experiment、The demonstration repository、The prototype repository、The backfill experiment 及 The retrieval experiment；其計劃內容之簡要描述請參考附件七。

2.Canister 實驗室設立之目的是為了研發用過核子燃料處置容器之封存技術，亦即對封蓋之焊接及檢驗進行各項測試，以確保其處置容器（Canister）之密封性。此實驗室於 1996 年開始建造，完成於 1998 年；其簡要之介紹如附件八，未來 SKB 公司將配合用過核子燃料處置計劃之進展，設立一個封存工廠

（Encapsulation Plant），此實驗室將轉為訓練中心以訓練封存工廠之工作員工。

三、參訪 STUDSVIK RADWASTE 研究機構

瑞典 Studsvik Radwaste 雖屬一研究機構，但在廢棄物處理方面，仍積極地開拓市場，利用其既有之設備（焚化爐及金屬熔融廠）提供放射性廢棄物產生者減容處理服務。

在瑞典，醫、農、工業界產生的放射性廢棄物係送至 Studsvik 處理；國外之廢棄物亦可送去處理，但是處理過程產生具放射性之廢棄物仍需送回原產國。

(一)放射性廢棄物（含廢樹脂）處理技術——THOR（THermal Organic Reduction）

Studsvik 在美國南卡羅萊納州設立一座處理低放射性廢棄物之工廠，利用 THOR（THermal Organic Reduction）技術以有效處理各類廢棄物，包括廢樹脂、活性炭、石墨、污泥、廢油、溶劑及除污溶液，其放射性強度可允許至 100R/hr。

THOR 技術處理廢樹脂，首先樹脂進入系統後，經過裂解，其中有機物質被轉變成合成氣體以提供燃燒能量，剩下的富含碳及金屬氧化物的低密度殘渣，再經由蒸氣重組反應，其中碳被 Superheated Steam 氧化成二氧化碳與水，而金屬氧化物則留存下來，可被置入高健全桶（HIC），送往處置。

附件九是 THOR 之流程圖；在美國，Studsvik 公

司已與 Washington Group International , Inc.簽訂一項處理美國能源部放射性廢棄物的合約，將利用 THOR 技術代能源部處理放射性廢棄物。

(二)金屬熔融處理

由於瑞典法規訂有熔融後金屬自由釋出（Free Release）之標準亦允許熔融後金屬可暫存 20 年，因此廢金屬送至 Studsvik 除污、熔融後，經取樣、分析，確認其 Ingot 已達到釋出標準者，即售與廢金屬回收廠家；對不合標準且具回收價值者，若經評估暫存 20 年間，其放射性強度可衰變至釋出標準，亦可以暫存方式處理。附件十是 Studsvik 金屬熔融處理的概念示意圖。

肆、心得與建議

一、政治與現實有時是難兩全的，雖然基於政治妥協使瑞典Barsebäck核電廠關了一部機組，但是因為瑞典不主張用石化燃料及煤發電且核能發電量佔了全國發電量將近五成，在沒有其他替代能源之下，短期間內是不可能非核化的，瑞典在核能營運方面仍蓬勃發展中。

二、瑞典在整體低放射性廢棄物處置作業上，已建立完整之架構，由廢棄物產生、處理、包裝再送往處置，按步就班，資料亦稱完備且甚公開，完全達到資訊透明化，從而建立起大眾的信心，頗值得參考。

三、瑞典係採用海床下處置低放射性廢棄物，工程浩大且所費不貲，我國未來之處置型態，除非是無法找到適當的地區，是否要採用類似之處置方式，應認真加以評估、考量。

四、由於SKB目前在Oskarshamn附近之Simpevarp地方進行用過核子燃料深地層處置場適合性之調查作業，鑽孔取樣，造成鄰近地區頗有微詞，所以SKB花費鉅資在當地電視台播放宣傳影帶且允諾未來如果因為設置處置場，致使周邊房價、地價下跌時，將予以補償；值得注意的是，SKB提出之補償條件是有造成損失事實時始予以補償，而不是因為設置處置場而提撥工程款之若干比率給予補償，其代表之意義是不同的。

五、SKB各廢棄物相關設施皆有導覽、解說人員，此類人員大都是曾經在該設施工作多年，對設施瞭若指掌，工

作起來較有專業性亦具說服力，此外，公關人員若不具所溝通工作之專業知識，應接受一定時間之專業知識訓練，始足以擔當重任，此點應可供本公司參考。

伍、附錄

附件一：瑞典相關核能設施位置圖

附件二：放射性廢棄物處置作業概念圖

附件三：SFR 地上設施

附件四：SFR 地下設施

附件五：CLAB 資料

附件六：CLAB 廠房圖示

附件七：Äspö Hard Rock 實驗室計劃簡介

附件八：Canister 實驗室介紹

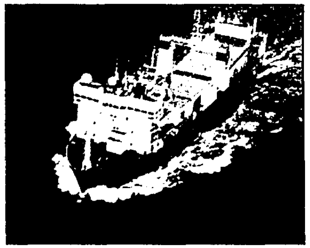
附件九：THOR 流程圖

附件十之一：金屬熔融處理概念圖(一)

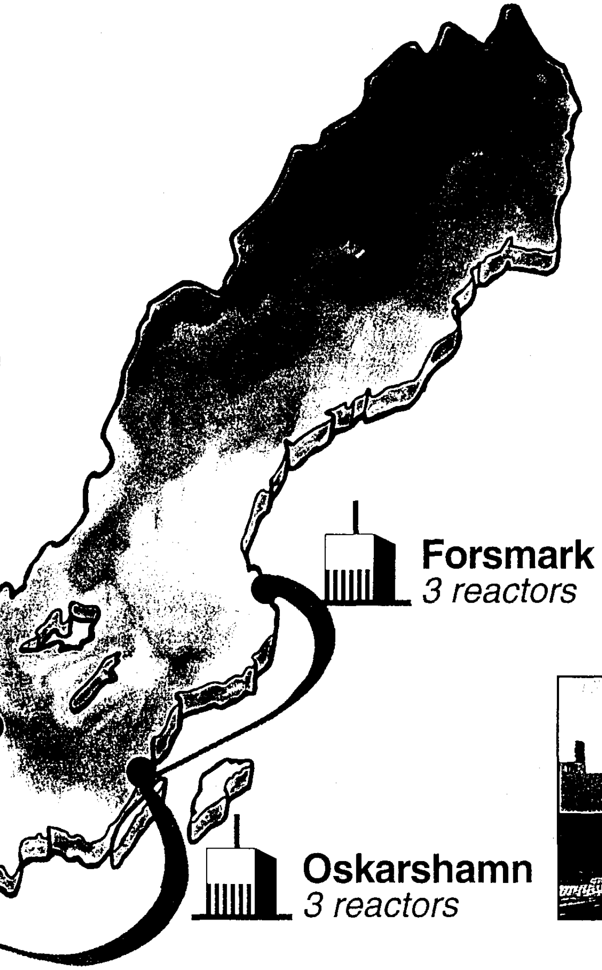
附件十之二：金屬熔融處理概念圖(二)

附件十之三：熔融後金屬錠暫存，以待放射性強度衰變

Facilities



M/S Sigyn



SFR

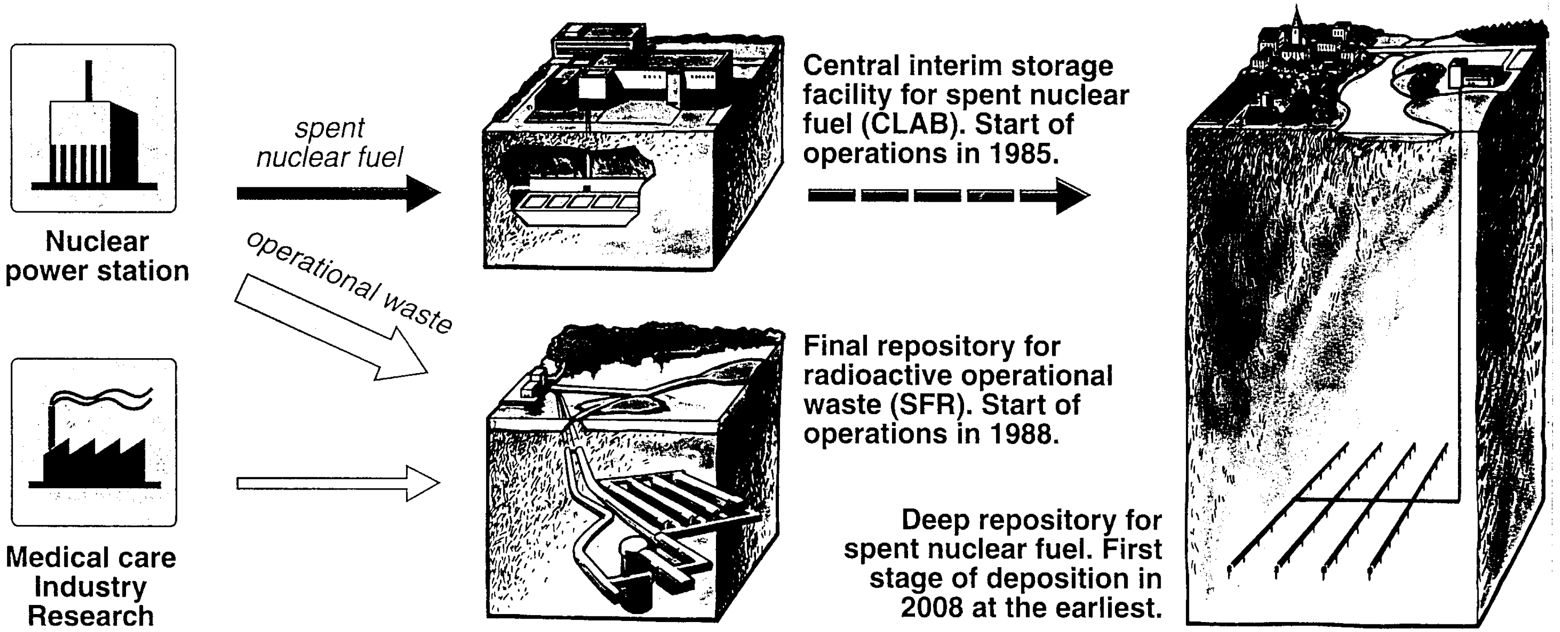
CLAB

Äspö Hard Rock Laboratory

附件一：瑞典相關核能設施位置圖

SKB

The Swedish system



Nuclear power station

spent nuclear fuel

operational waste

Medical care Industry Research

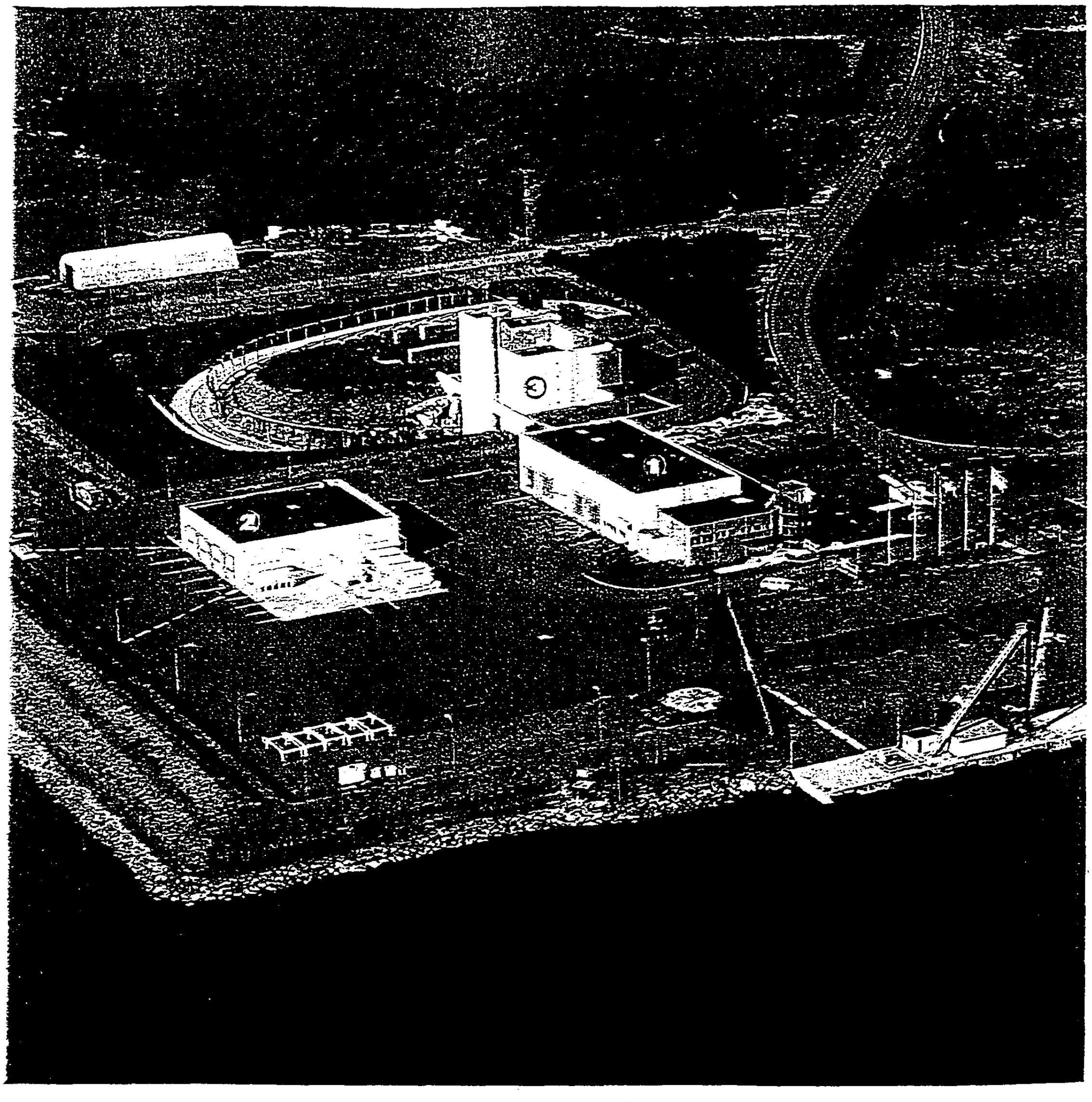
Central interim storage facility for spent nuclear fuel (CLAB). Start of operations in 1985.

Final repository for radioactive operational waste (SFR). Start of operations in 1988.

Deep repository for spent nuclear fuel. First stage of deposition in 2008 at the earliest.

附件二：放射性廢棄物處置作業概念圖

SFR consists of an above-ground section and an underground section. The above-ground section consists of three buildings: office and workshop building (1), terminal building (2) and ventilation building (3). The transport containers that arrive at SFR are placed in the terminal building, before being driven down into the repository. The ventilation building supplies the rock caverns with air.

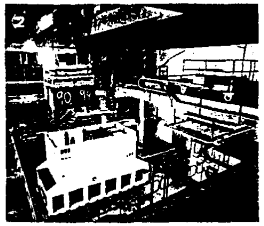


附件三：SFR 地上設施

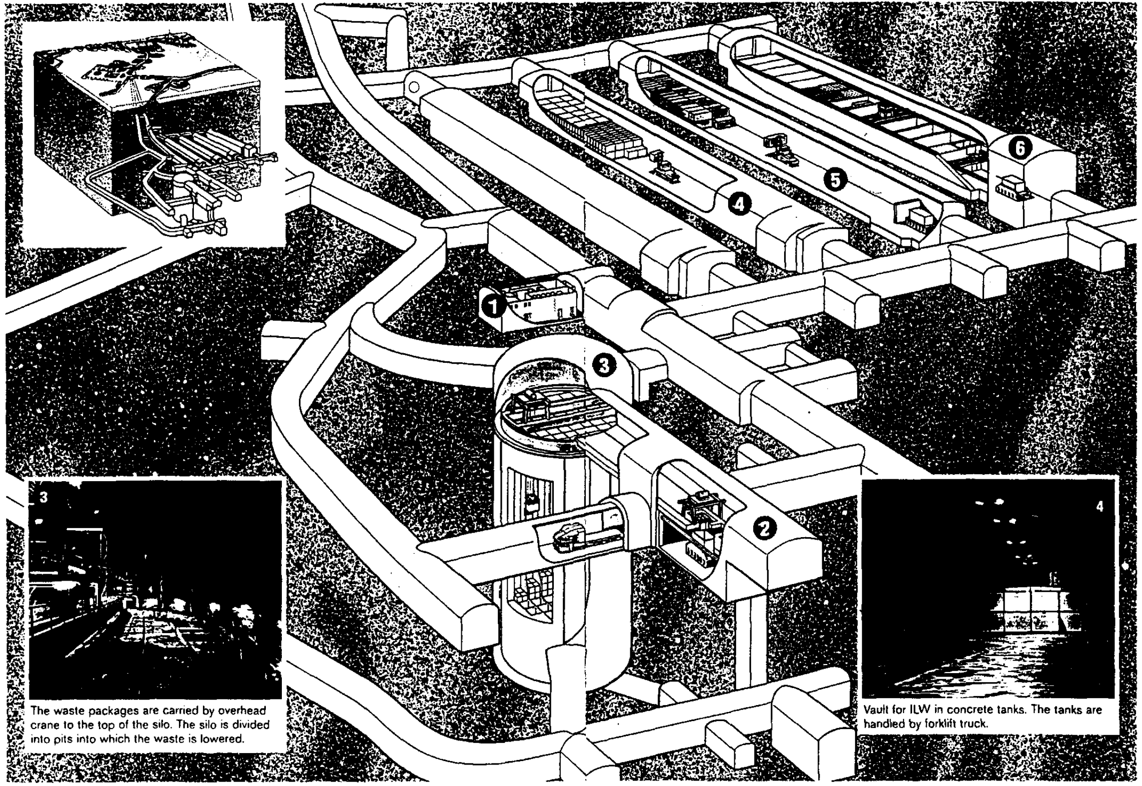
The Facility

Unloading of transport casks with operational waste at SFR. Shipments of low- and intermediate-level waste (LLW and ILW) from Ringhals, Barsebäck, Oskarshamn and Studsvik to SFR take place by sea on M/S Sigyn, which is specially designed for transporting spent nuclear fuel and radioactive waste. Length: 90 m. Breadth: 18 m. Draught: 4 m. Payload: 1,400 tonnes.

Control room with workstations for remote-controlled unloading. The picture shows monitoring of unloading in the rock vault, which is divided into pits.



Unloading of the transport cask takes place in an unloading niche. It is performed by remote-controlled equipment.



The waste packages are carried by overhead crane to the top of the silo. The silo is divided into pits into which the waste is lowered.

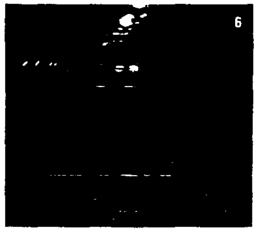
Vault for ILW in concrete tanks. The tanks are handled by forklift truck.

The final repository for radioactive operational waste, SFR, is situated near the Forsmark Nuclear Power Station. SFR is a central facility for final disposal of short-lived LLW and ILW originating in Sweden. The geological conditions in the crystalline bedrock make this a suitable medium for hosting a final repository for radioactive waste. The rock at Forsmark is of good quality and well-suited for an underground rock facility. SFR is situated in crystalline bedrock at a depth of more than 50 metres below the seabed, which is in turn under 5 metres of water. The facility is connected to the ground surface by two parallel kilometre-long access tunnels. The disposal chambers consist today of four 160-metre-long rock vaults of varying design, plus a 70-metre-high rock cavern in which a concrete silo has been built. The silo is intended to contain most of the radioactive materials to be disposed of in SFR.

LLW enclosed in unopened freight containers is emplaced in one of the four rock vaults. The waste in this part of the facility can be handled without any special radiation shielding and this is done by an ordinary forklift truck. Three of the rock vaults receive ILW, which requires radiation shielding. Dewatered filter resins in concrete tanks are deposited in two of these ILW vaults. These waste packages are handled by a radiation-shielded forklift truck. The third vault contains more hard-to-handle waste, which is emplaced in pits. When the pits have been filled, they are sealed with concrete lids. The waste in this vault is handled with a remote-controlled overhead crane.

A cylindrical rock cavern houses the concrete silo, which is 50 metres high and has an inside diameter of 26 metres. The silo repository is intended for ILW and is mainly used for filter resins from purification of reactor water. The space between the silo wall and the rock is filled with bentonite, a clay material which swells and prevents groundwater flow. Internally, the silo is divided into square vertical pits measuring 2.5 metres on a side. The pits are separated by concrete walls. After the waste packages have been lowered into the pits, the waste is grouted with concrete. All handling in the silo is automated and remote-controlled.

Vault for LLW in ordinary freight containers, which are handled by forklift truck.



ILW in drums or moulds is emplaced in the rock vault, which is divided into pits. As the pits are filled, concrete lids are placed on them. Handling in this vault is done by remote-controlled overhead crane.

Principal data for SFR

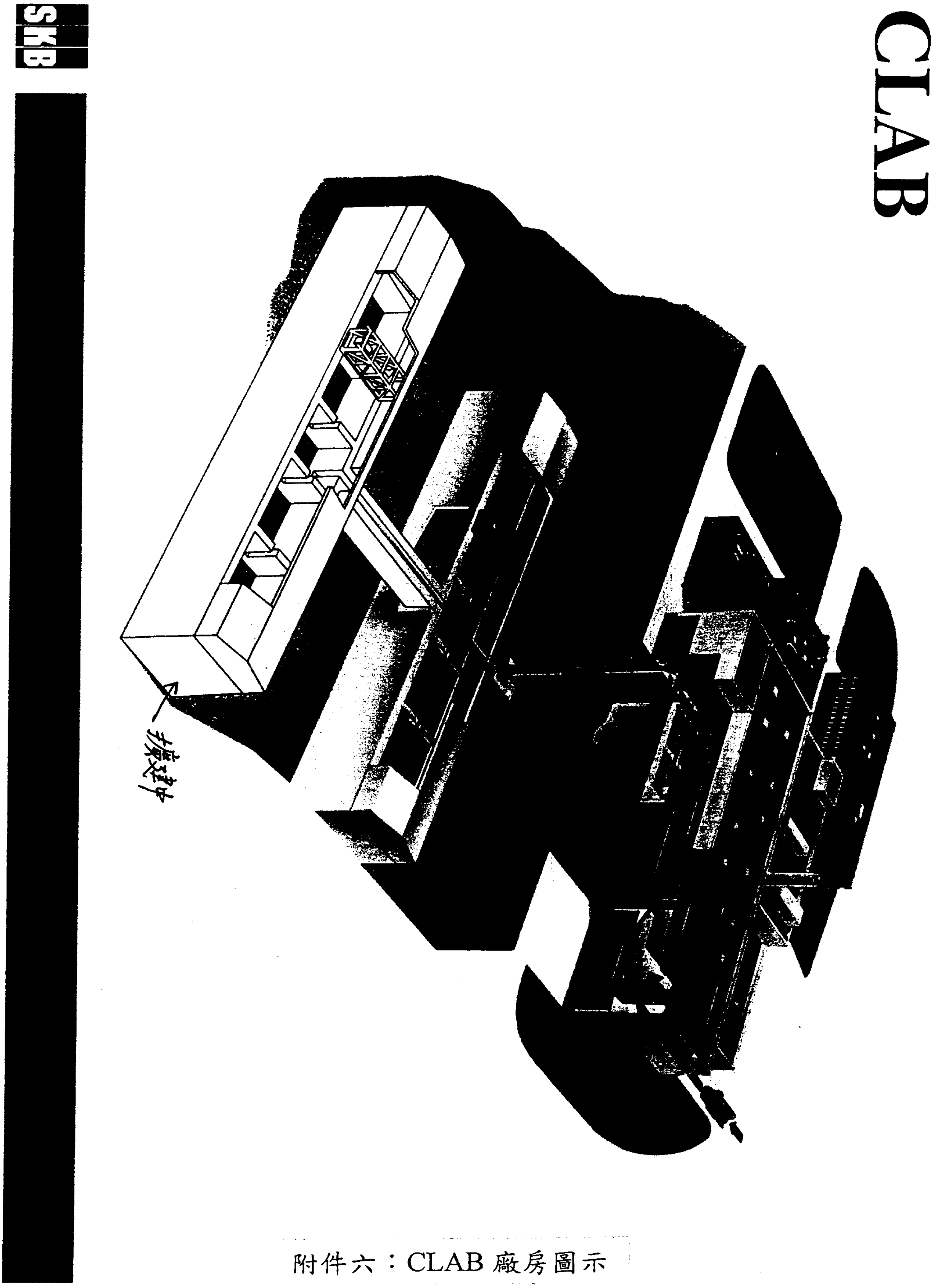
Start of construction:	1983
Start of operation:	1988
Disposal capacity:	63,000 m³
Receiving capacity:	1,000–2,000 m³/år
Operation and maintenance personnel:	about 12 persons
Surface section:	Office and workshop building, terminal building, ventilation building
Underground section:	4 rock vaults, 1 silo, operations centre
Owner:	SKB
Operation and maintenance:	Forsmarks Kraftgrupp
Cost of construction:	SEK 740 million
Cost of operation:	approx. SEK 30 million/year
Total cost:	approx. SEK 1,500 million (incl. closure)

附件四：SFR 地下設施

附件五：CLAB 資料

Vital statistics for CLAB

Start of operations:	1985
Repository capacity:	5,000 tonnes of uranium (approx. 20,000 BWR assemblies + 2,500 PWR assemblies)
Transportation:	Approx. 80 casks/year ≈ 240 tonnes
Planned expansion:	3,000 tonnes
Pool temperature:	max 36°C in normal operation
Personnel:	Approx. 100
Operation costs:	Approx. SEK 75M/year
Construction costs:	SEK 1,700M (1988)

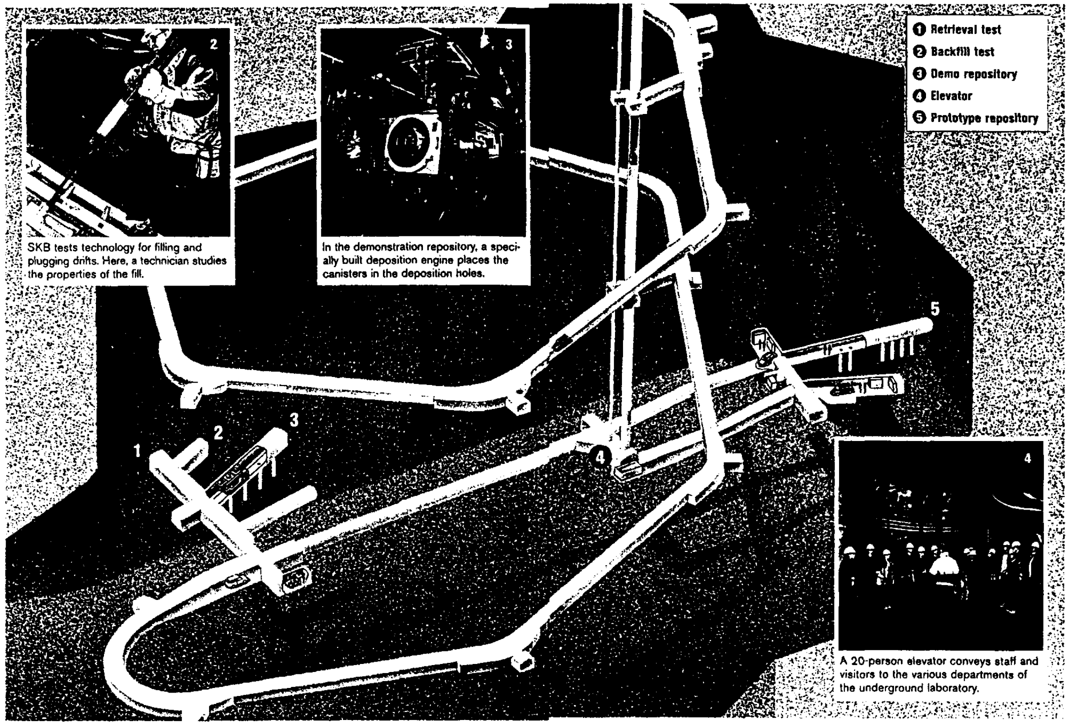


附件六：CLAB 廠房圖示

Practical technology

The dress rehearsal for practical application of deep-repository technology at SKB's Hard Rock Laboratory at Äspö, near Oskarshamn, has now picked up in intensity. Over the next few years, methodology and technologies for deep-repository storage of spent nuclear fuel will be rigorously tested.

The Äspö Hard Rock Laboratory (HRL) is perhaps SKB's most important research and development resource. Here, we can test techniques for site investigation and deposition in a realistic environment. The following is a brief summary of the more significant technique-oriented experiments completed or currently under way at the Äspö HRL.



SKB tests technology for filling and plugging drifts. Here, a technician studies the properties of the fill.

In the demonstration repository, a specially built deposition engine places the canisters in the deposition holes.

A 20-person elevator conveys staff and visitors to the various departments of the underground laboratory.

The ZEDEX experiment

Tunnelling inevitably affects the surrounding rock; new fractures alter both stress status and the flow of water through the rock. The area through which the drift is driven is known as the disturbance zone. This experiment aims at establishing the size of the disturbance zone round a drift that has been blasted rather than drilled.

The experiment was carried out in two parallel drifts at a depth of 420 metres, one blasted, the other excavated by a tunnel-boring machine. We measured the properties of the rock both before, during and after blasting.

The experiment showed that a disturbed zone is formed regardless of whether the drift is blasted or bored. Blasting induced new fractures all round the drift. The deepest fractures, extending to about 80 centimetres, were observed in the floor; in the walls, they were about 30 centimetres deep. Boring affected the rock to a far lesser degree. In the bored drift, the fractures extended to less than three centimetres into the walls, floor and ceiling.

The LOT experiment

We also wanted to establish the effect on bentonite clay of long-term storage in an environment similar to that of a future deep repository. To this end, we are now conducting what we term the LOT experiment – the Long Term Test of Buffer Material.

In this test, copper tubes, encased in bentonite, were located in boreholes in the floor of the drift. Each tube was fitted with an electrical heating element to simulate the heat generated by the disposal canister.

The experiment was designed to establish how temperature and minerals affect the bentonite and whether bacteria are able to survive there. On completion of the test, the bentonite will be drilled out of the holes and sent for laboratory testing.

Pilot tests have already been performed in which bentonite was heated for 15 months. During that period, the properties of the bentonite were not found to have changed in any unforeseen manner. Bacteria are not active in bentonite.

The demonstration repository

Tests of machines and technology in a realistic environment are crucial to the end result. In the demonstration repository we test how the canisters, which weigh at least 25 tonnes, may be positioned in the deposition holes along with their bentonite casing.

For these tests, we developed a radiation-shielded, remote-controlled deposition engine that runs on rails.

The prototype repository

A prototype repository is being built to test how the deep repository can be expected to function over a twenty-year period. In particular, it is important to determine the mutual reactions of the canister, bentonite, fill and rock.

The prototype is an exact copy of a real-life repository, although with only six holes. Sensors are installed in the boreholes, the clay and canisters to measure pressure, temperature and a wide variety of chemical para-meters. After about five years, the exterior of the repository will be excavated so as to give us an idea of how the various materials have been affected. After a further 10 to 15 years, the interior section will also be excavated.

The backfill experiment

SKB is also testing the method to be used for filling and plugging the drifts. It is essential that the permeability to water of the backfill material and plug is approximately the same as that of the surrounding rock. The drifts could otherwise prove an effective escape route for any radioactive substances that might find their way out through the canister and buffer.

In the Äspö laboratory, we backfilled and plugged a thirty-metre test section of a blasted drift. The inner section of the drift is filled with a mix of 30 percent bentonite and 70 percent crushed rock.

The admixture of bentonite to the rock ensures that the mixture will swell and seal off any cavities between the backfill material and ceiling of the drift. The outer section of the drift is filled with crushed rock only. The test area is sealed off with a thick concrete plug.

The interior of the drift is provided with some 200 gauges and sensors that will enable us to monitor the sealing capacity of the fill and plug over the course of the next few years. The results will show whether this approach functions in practice and how well the models used as our basis of calculation conform with reality.

The retrieval experiment

The deep repository approach assumes that we will proceed in stages. To start with, only about one tenth of the spent nuclear fuel will be deposited – the method will then be evaluated, meaning that if the results are negative we must be able to expose the canisters and retrieve them from the boreholes.

Here, the main problem is removing the bentonite that keeps the canisters in place, and it is this that we will be testing in the Äspö retrieval experiment. First, we will deposit a canister, fitted with an electric heater, into a borehole lined with blocks of bentonite, where it will be allowed to remain for between two and five years to ensure that the bentonite is saturated with water. In the meantime, we will develop a method for exposing and retrieving the canister.

Today we believe that the best method of retrieving canisters is to wash away the bentonite with a saline solution. The slurry thus formed can then be sucked out of the borehole.

Äspö HRL – key figures

Drift lenght:	3600 meters
Greatest depth:	460 metres
Extracted rock volume:	150,000 m³
Staff:	35

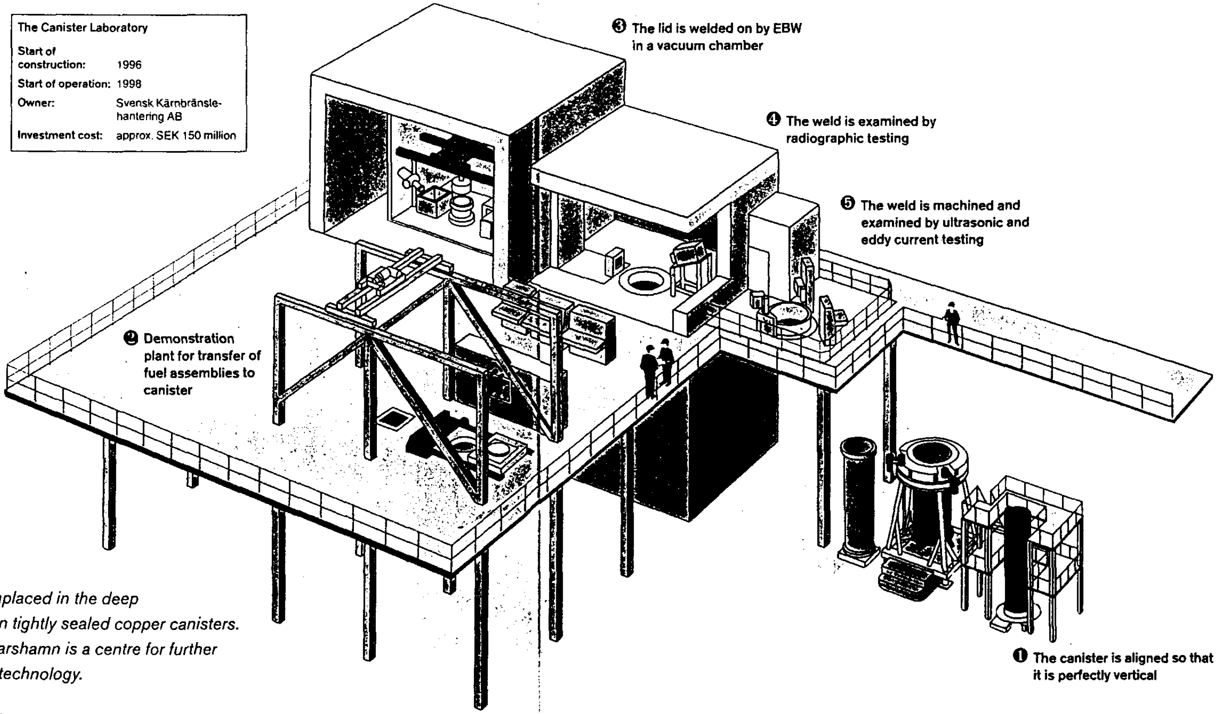
附件七：Äspö Hard Rock 實驗室計劃簡介

Canister Laboratory


The Canister Laboratory, inaugurated in November 1998, is a centre for technology development and training.


Research on sealing of the canisters is being done with both electron beam welding and friction welding.

The Canister Laboratory	
Start of construction:	1996
Start of operation:	1998
Owner:	Svensk Kärnbränslehantering AB
Investment cost:	approx. SEK 150 million



Before the spent nuclear fuel is emplaced in the deep repository, it will be encapsulated in tightly sealed copper canisters. SKB's Canister Laboratory in Oskarshamn is a centre for further development of the encapsulation technology.

At the Canister Laboratory we are first and foremost working to develop the technology for welding the lid on the copper canister and checking that the welded joints are truly leaktight. Here we work solely with copper canisters and dummy fuel assemblies. There is no spent fuel in the facility.

Reliable technology

The Canister Laboratory has one of the world's most powerful electron beam welders for joining the canister to its lid. This welding method involves fusing the parts together by means of a powerful electron beam. The welding equipment at the Canister Laboratory has a power rating of 100 kW. This is so powerful that 30 cm of steel can be cut through in five seconds.

The method is tried-and-tested and is used today in the manufacture of many industrial products. It is being further developed in the Canister Laboratory to suit our purpose of welding copper.

Metal becomes malleable

At TWI in the UK we are also studying the Friction Stir Welding (FSW) technique, which is a kind of friction welding method.

A specially designed rotating tool is used in FSW. As the tool rotates and moves along the joint, heat is generated which, in combination with the high pressure of the lid against the canister, fuses the metal parts together. The temperature becomes so high that the metal becomes soft and malleable.

But unlike electron beam welding (EBW), FSW does not melt the material.

Powerful X-rays

To inspect the welds we use one of the most powerful X-ray machines on the market. It is 60 times as powerful as an ordinary industrial X-ray machine.

To protect the personnel against X-rays, the equipment is surrounded by thick concrete walls. The canister, which has a weld more than three metres long, rotates slowly while the X-ray tube bombards a 0.4 mm wide section at a time. It takes about an hour to inspect a weld.

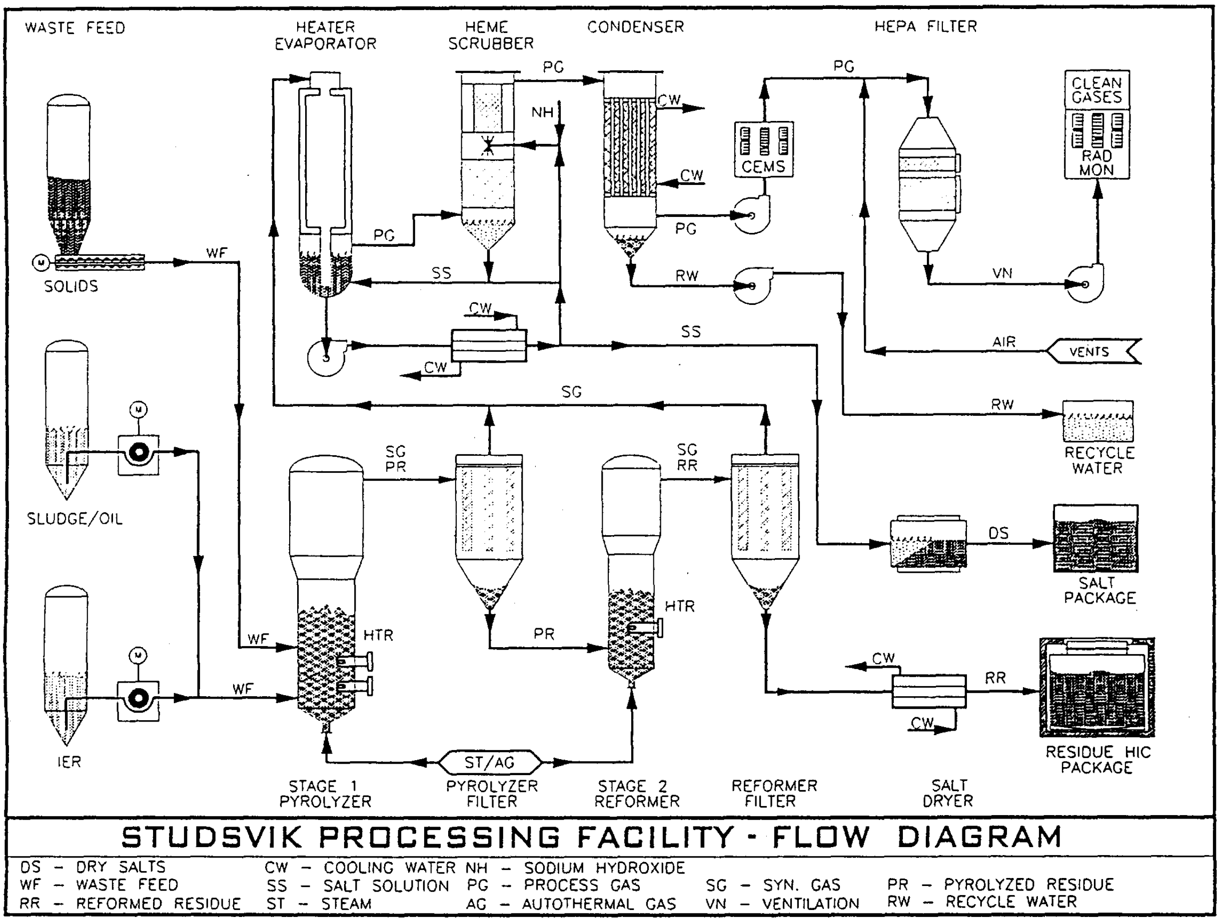
The welds are also inspected ultrasonically. Ultrasonic inspection provides a very clear image of the weld. The method enables us to determine the depth of any defects.

Several testing methods

Inductive testing (eddy current testing) is yet another method we use to check the quality of the weld. The reason we make use of several different methods is that they complement each other by allowing us to see different types of defects. The different methods can also confirm the accuracy of each other's results. Another important task in the Canister Laboratory is making sure that the machines and other equipment that will be used in the encapsulation plant work as intended. We must be sure of this so we can in turn be sure of achieving the quality and production pace needed in the finished encapsulation plant.

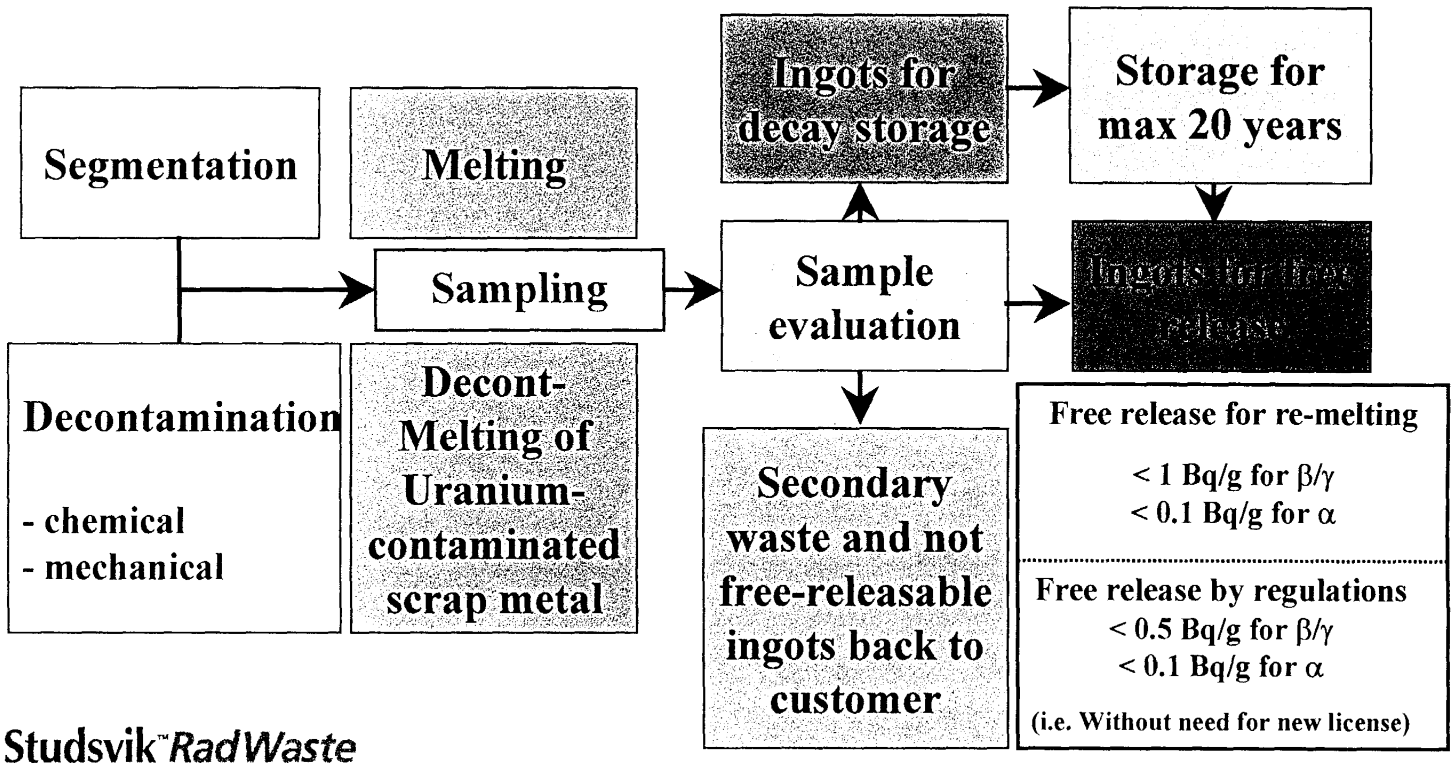
The Canister Laboratory will later serve as a training centre for the personnel who will eventually work in the encapsulation plant.

附件八：Canister 實驗室介紹


WASTE FEED
HEATER EVAPORATOR
HEME SCRUBBER
CONDENSER
HEPA FILTER
CLEAN GASES
RAD MON
CEMS
PG
NH
CW
RW
VN
SS
AIR
VENTS
SG
SG PR
SG RR
RECYCLE WATER
DS
SALT PACKAGE
HTR
PR
WF
RR
RESIDUE HIC PACKAGE
SOLIDS
SLUDGE/OIL
IER
M
ST/AG
STAGE 1 PYROLYZER
PYROLYZER FILTER
STAGE 2 REFORMER
REFORMER FILTER
SALT DRYER
STUDSVIK PROCESSING FACILITY - FLOW DIAGRAM
DS – DRY SALTS
WF – WASTE FEED
RR – REFORMED RESIDUE
CW – COOLING WATER
SS – SALT SOLUTION
ST – STEAM
NH – SODIUM HYDROXIDE
PG – PROCESS GAS
AG – AUTOTHERMAL GAS
SG – SYN. GAS
VN – VENTILATION
PR – PYROLYZED RESIDUE
RW – RECYCLE WATER

附件九：THOR 流程圖

Studsvik RadWaste concept for melting and free release of radioactive scrap metal for re-cycling

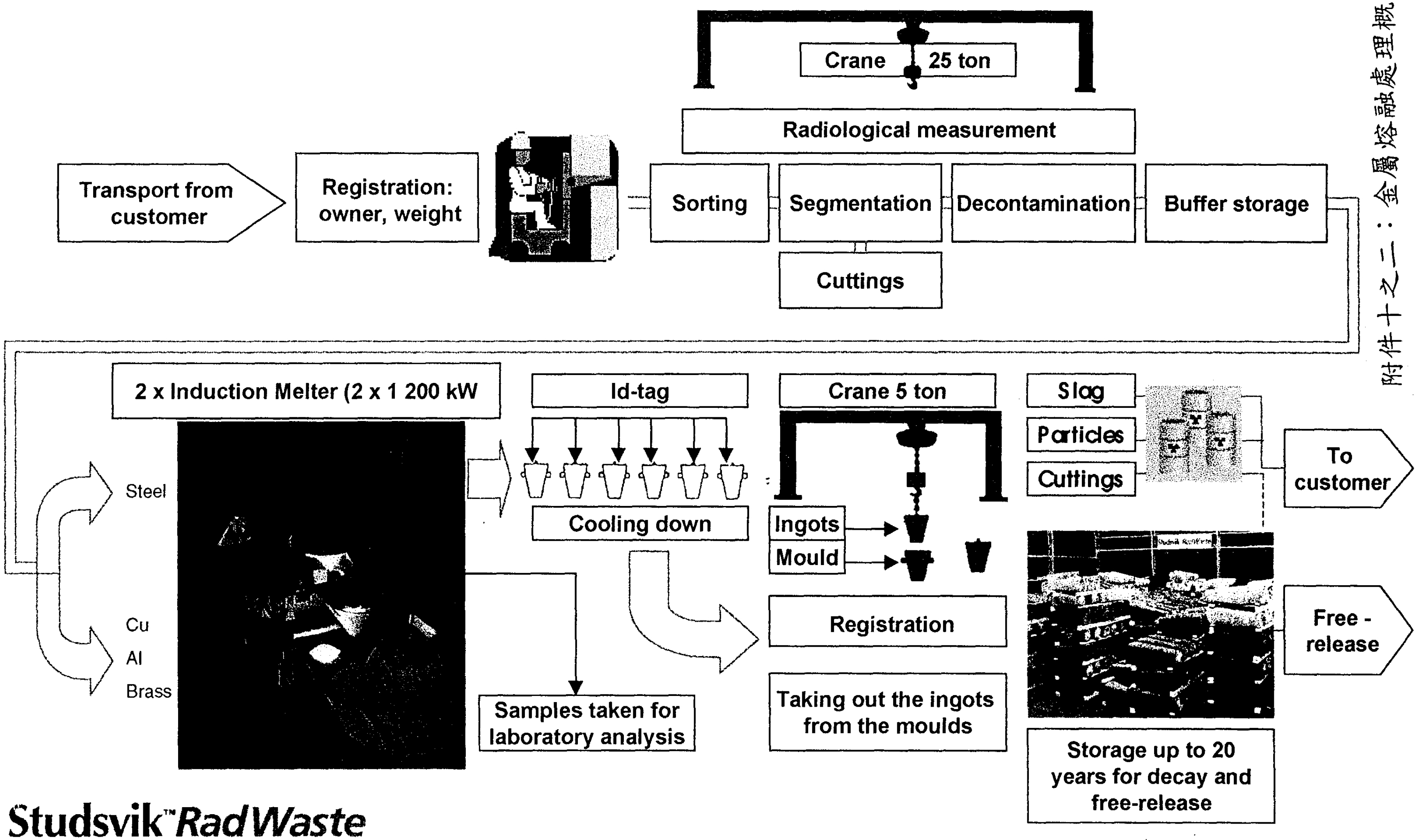


Studsvik™ RadWaste

附件十之一：金屬熔融處理概念圖(一)

附件十之二：金屬熔融處理概念圖(二)

Logistics for Scrap Metal Handling



Crane 25 ton

Radiological measurement

Transport from customer

Registration: owner, weight

Sorting

Segmentation

Decontamination

Buffer storage

Cuttings

2 x Induction Melter (2 x 1 200 kW

Steel

Cu

Al

Brass

Id-tag

Cooling down

Samples taken for laboratory analysis

Crane 5 ton

Ingots

Mould

Registration

Taking out the ingots from the moulds

Slag

Particles

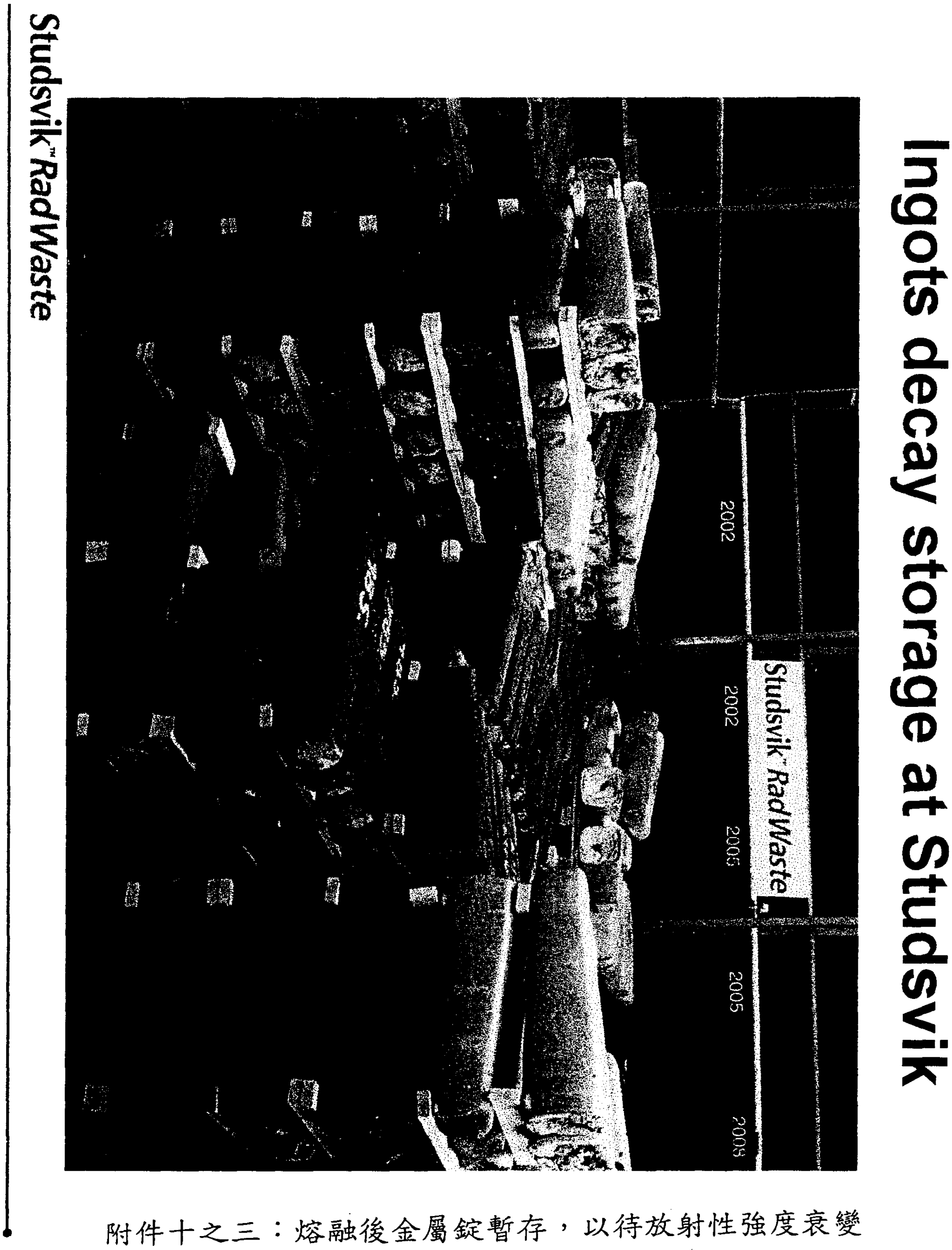
Cuttings

To customer

Free - release

Storage up to 20 years for decay and free-release

Studsvik™ RadWaste



Ingots decay storage at Studsvik

Studsvik™ RadWaste

附件十之三：熔融後金屬錠暫存，以待放射性強度衰變