出國報告（出國類別：訪問）

訪問日本原子能電力公司的核能電廠

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出國期間：97 年 11 月 24 日至 97 年 11 月 29 日
報告日期：98 年 1 月 6 日

摘　要

本次訪問日本原子能電力公司核能電廠的目的是「研習水化學新技術，交換研究心得，確實了解 BWR 電廠飼水鐵控制程序、方法及 PWR 的加鋅設備，增進國內核電廠的水化學與水質控制與管理能力，以提昇電廠營運效率」。

目　　次

摘　要

一、目　的

96 年於台北召開的[Symposium　on Water Chemistry and Corrosion of Nuclear Power Plant in Asia,2007]，會中日本原子能電力公司(JAPC)的 Dr. Meguro應邀演講[Current Status of Nuclear Power Plants and Water Chemistry Control for Their Structural Integrity in Japan]。[1]得知JAPC的東海與敦賀電廠(Tokai and Tsuruga Power Plants)在特徵上與國內核電廠很類似，且在水化學研究與應用方面有相當多優質的新型技術。當此核能復甦時期，應深入了解獲取寶貴經驗，實地訪問核電廠在獲得水化學與材料腐蝕之收益上更爲豐碩，故規劃前往JAPC核電廠訪問，對核能研究所的水化學研發而言有其重要及無可取代性。

日本目前所有的核能電廠如圖 1。[1, 2] JAPC的核能電廠均位在日本本州的中部，東海電廠在東邊靠近太平洋，敦賀電廠在西邊靠近日本海。[1~3](圖 1 及圖 2)。

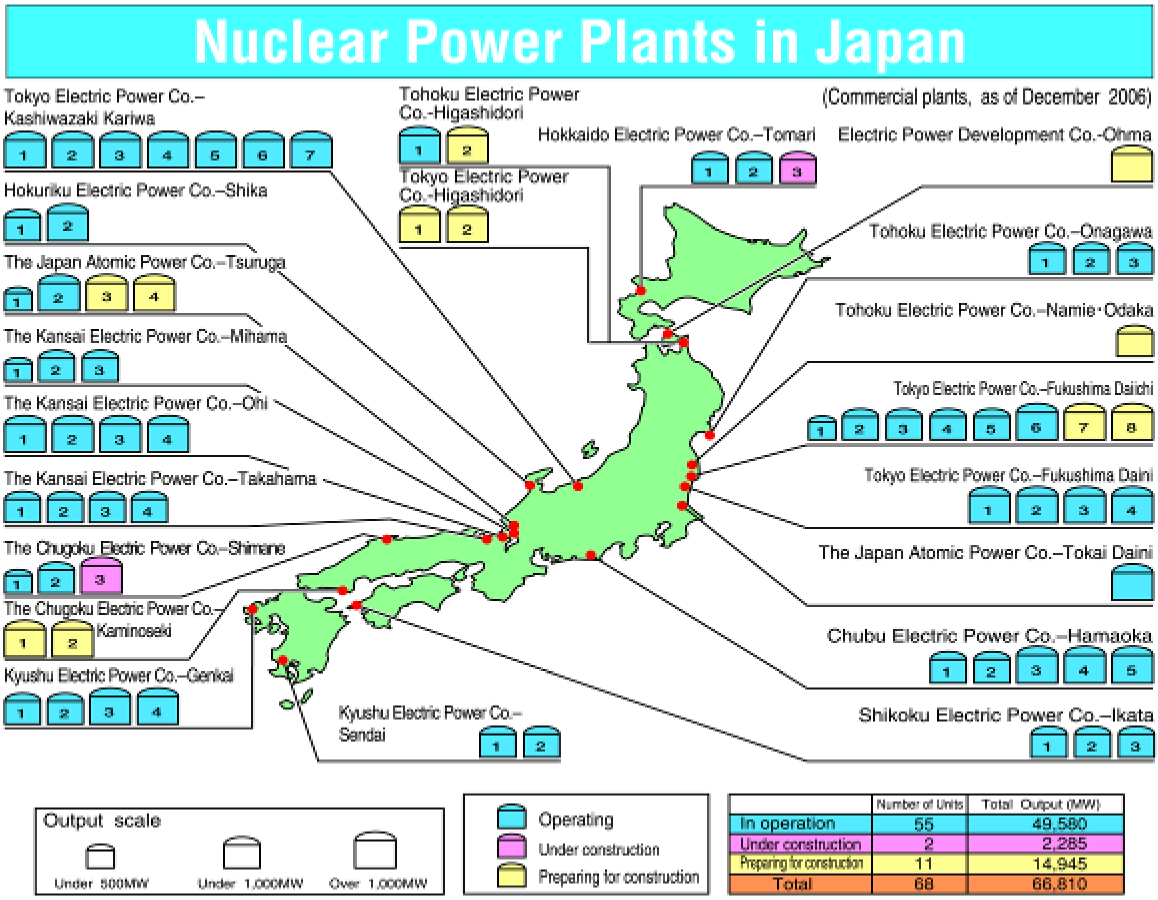


圖 1.日本的核能電廠分布

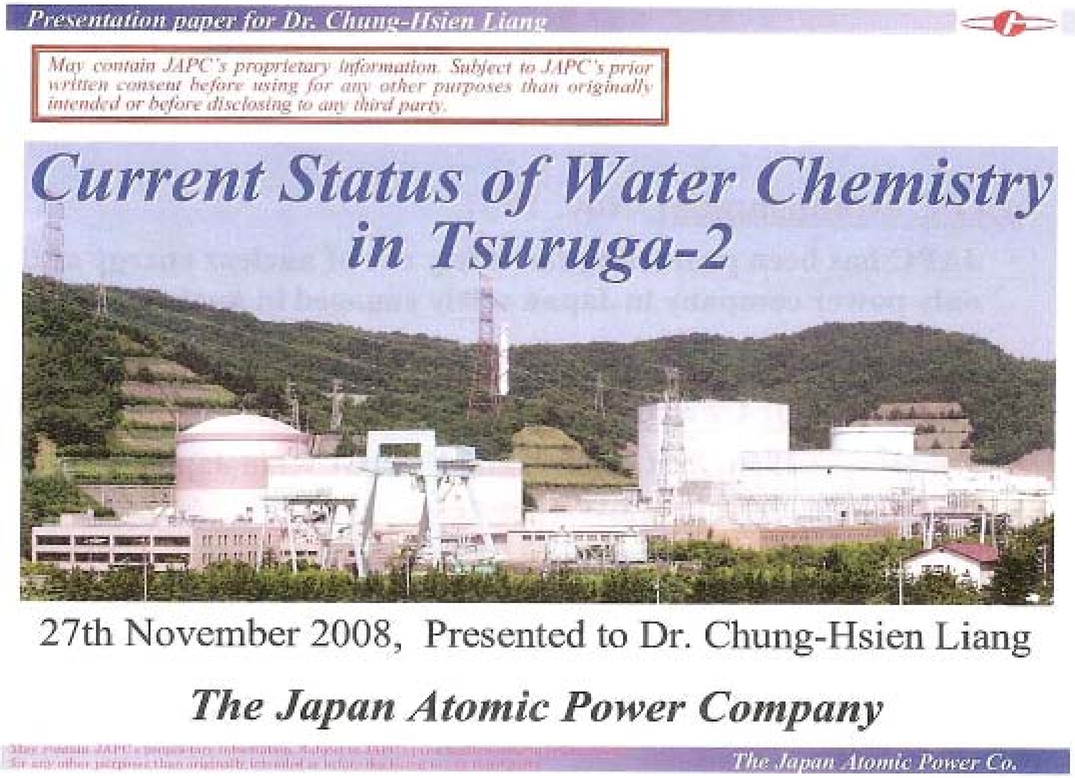


圖 2.日本原子能電力公司的核能電廠

二、過　程

此次公差，由97年11月24日至97年11月29日共計6天。11月24日抵達成田機場後，立即搭乘火車經成田-東京-上野-勝田(東海電廠附近)，路程約4小時。11月25日訪問東海電廠及技術交流。11月26日搭乘火車經由勝田(東海電廠附近)-上野-東京-米原-敦賀，路程約5小時。11月27-28日訪問敦賀電廠及技術交流。11月28日傍晚經敦賀-京都-大阪關西機場，路程約3小時。11月29日返抵國門。

行程					公差地點		工作內容
月	日	星期	地點		國名	地名	
			出發	抵達			
11	24	一	中正機場	東海	日本	東海	去程，到達東海電廠附近旅館
11	25	二		東海	日本	東海	訪問東海電廠
11	26	三		敦賀	日本	敦賀	旅程，由東海電廠出發到敦賀電廠附近旅館
11	27	四		敦賀	日本	敦賀	訪問敦賀電廠
11	28	五		大阪	日本	大阪	訪問敦賀電廠，傍晚到達大阪關西機廠附近旅館
11	29	六	大阪	中正機場			回程

三、心　得

(一)日本原子能電力公司及其核能電廠

日本原子能電力公司(Japan Atomic Power Company 簡稱 JAPC)是由 9 家電力公司、電力發展有限公司(Electric Power Development Co., Ltd.) 及另外 151 家公司，總共 161 家公司投資組成的核能電力公司。其中，東京電力占 28.23%，關西電力占 18.54%，中部電力占 15.12%，北陸電力占 13.05%，東北電力占 6.12%，九州電力占 1.49%，中國電力占 1.25%，北海道電力占 0.63%，四國電力占 0.61%，電力發展有限公司占 5.37%，其他 151 家公司投資 9.58%，共 100 %。JAPC 的最大股東是東京電力，但日力公司確是賣方(vendor)。因此 JAPC 必須定期與東京電力及日立公司開會。

JAPC旗下，目前運轉中的核能電廠有 3 個機組。含東海 2 號電廠 (Tokai No.2 Power Station)，是日本第一座大尺寸核能電廠 (BWR-5)，電力輸出 1,100,000 kW，1978 年 11 月商轉，電力供應給東北電力、東京電力等公司。敦賀 1 號機 (Tsuruga Power Station Unit 1)，是日本第一座輕水式核能電廠 (BWR-2)，電力輸出 357,000 kW，1970 年 3 月商轉，電力供應給中部電力、北陸電力、關西電力等公司。敦賀 2 號機 (Tsuruga Power Station Unit 2) (PWR)，電力輸出 1,160,000 kW，1987 年 2 月商轉，電力供應給中部電力、北陸電力、關西電力等公司。一座除役中的東海電廠，屬石墨減速-二氧化碳氣冷式反應器 (GCR)，是日本第一座除役的核能電廠。[4]除役首先移除反應器區外的周邊設施，之後反應器區安全儲存 10 年待輻射劑量達可允許拆除及移除的適當劑量，最終該廠址將作爲未來核能電廠用地。爲了確保安全自主足夠的電力供應，JAPC已計劃敦賀 3 & 4 號機 (APWR)，每個機 1,538,000 kW電力輸出，目前在場址準備階段。JAPC的組織、成員、現況、經營歷史等詳細資料請參考附錄之附件 1。

2007 年 JAPC 成立已 50 年。JAPC 於 30 年前建造 Tokai-2，目前它已運轉 30 年。2008 年 11 月是 Tokai-2 的生日，從建造開始 JAPC 就擁有它。

日本核能安全評估組織(Japanese Nuclear Regulation Agency, NISA)，要求日本電廠在運轉 30 年必須評估它們的核能電廠安全性，即 Plant Life Management：PLM。 因此，Tokai-2 在 2008 年 7 月已努力完成 PLM 文件送交 NISA。

此次參訪的主要目標為(1) Tokai 2 的凝結水除礦器離子交換樹脂床的進步型樹脂清洗系統(Advanced Resin Cleaning system, ARCS)及樹脂反洗廢水處理系統含電磁過濾器(Electromagnetic filter, EMF)及超過濾過濾器 (Ultrafiltration filter, UF) (2) Tsuruga-2 的發乏鋅氧化物注入系統 (Depleted Zinc Oxide injection device) (3)Tokai-2 及 Tsuruga-2 的 Hot Laboratory.。

(二)東海 2 號電廠的飼水鐵控制及其改善經驗[5]

Tokai-2 是一座BWR-5 電廠。其凝結水除礦器特徵如**圖 3**。與核一廠、核二廠類似，已是世界上少有，condemin前無前置過濾器(pre-filter)的BWR電廠。也因此，這類電廠的飼水鐵濃度都不低 (約 1.5-3 ppb)。而飼水鐵濃度與主環路再循還管路輻射劑量 (Primary loop recirculation，PLR dose rate)間成正比關係 **(圖 4)**。按此圖，要求的飼水鐵目標值為1.0 ppb。要達到此目標，必須樹脂表面進行週期清洗與再生。 Tokai-2 因此於 1985 引進小粒徑離子交換樹脂(small particle ion exchange resin)，1988 年起使用離子交換樹的浸泡再生方法(soak regeneration method)，1995 年 6 月起引進低架橋度離子交換樹脂脂(low cross-linked resin)[6]。多年前，也曾考慮在 condemin之前加裝中空纖維前置過濾器(Hollow Fiber Filter:HFF condensate filter (CF))。前述措施，在試驗階段均指出有效果，尤其是 HFF(核四廠也有 HFF設備)。最終，Tokai-2 的廠長因它們的價格太高而決定不引進這類設備與技術。JAPC開始尋找更具經濟利益及功能的技術與設備。

美國水化學專家 Mr. Asay於 1988 年開始研究 BWR condemin 的樹脂床的清洗方法，[7-9]，發展出進步型樹脂清洗系統(ARCS)。Tokai-2 於 2005 年引進ARCS並測試，效果良好**(圖 5)**。 Tokai-2 雖然曾裝置超音波樹脂清洗系統 (Ultrasonic resin cleaning，URC)，但自從電場起動開始(Start-up)就未曾使用過，原因雖不明。當然係URC的洗淨效果不佳。當Tokai-2 安裝 ARCS時就將URC系統移除，ARCS安裝在原先URC的位置上。雖然Tokai-2的凝結水除礦器入口(Condemin inlet，CDI) 的鐵Crud 濃度為 8-10 ppb(與核一廠、核二.廠相當)，但使用ARCS 後，本週期的飼水鐵可控制在<1ppb±0.1-0.2 ppb，甚至更低。配置ARCS的 condemin 其鏽垢移除效率(crud removal efficiency)很高。Tokai-2 的chemistry group認為中空纖維前置過濾器雖然是移除凝結水除礦器入口鐵鏽垢的最佳選擇，但ARCS

也不錯，因此ARCS 已是Tokai-2 的正常運轉中的系統之一，目前已不用之前的清洗方法。**(圖 6)**

Outline of Tokai-2

Start of commercial operation		28 November 1973
Electrical output		1,100MWe
Reactor	Type	BWR-5
	Thermal power	3,300MWt
Supplier		Hitachi/GE
Condensate demineralizer	Supplier	Ebara corp.
	Number of tower	10 (1 is stand-by)
	Product names	Cation: HCR-W2-C Anion: SBR-P-C-OH
	Amount of resin	Cation: 4.212m³/tower, Anion: 2.742m³/tower
	linear velocity	108m/h

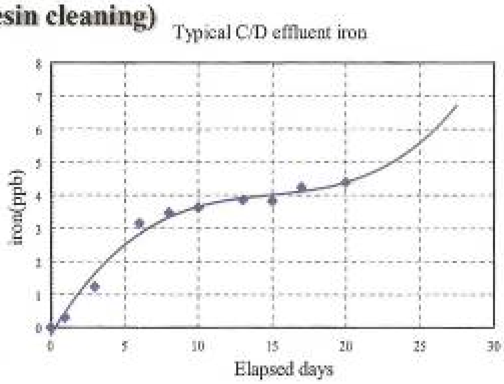
圖 3.東海 2 號電廠的概要

Relationship between Radiation Source and FDW CRUD

(Needs of resin cleaning)

【PLR dose rate prediction 】
6cycles (60,000EFPY) after from 2002 (0.7mSv/h)

FDW iron	PLR dose rate
3 ppb	0.8 mSv/h
1 ppb	0.55 mSv/h
0.5 ppb	0.5 mSv/h



When FDW iron have kept less than 1ppb, PLR dose late has been decreasing

⬇

We decided target value of FDW iron as less than 1ppb

Iron is deposited on resin surface gradually and deposited iron degrades C/D iron removing efficiency

⬇

Resin is needed to clean up its surface periodically.
-The wash and regeneration

圖 4 輻射源與飼水鐵濃度間關係

ARCS introducing plants

Utility company	NPP name	Number of ARCS	Introducing year
Virginia Power	Surry（PWR）	2	1988，1989
Entergy Operations	Grand Gulf（BWR）	1	1995-1996
Exelon Nuclear	Dresden（BWR）	1 (for unit 1,2)	1998
JAPC	Tokai-2（BWR）	1	2005

Iron in C/D inlet vs. FDW before and after ARCS

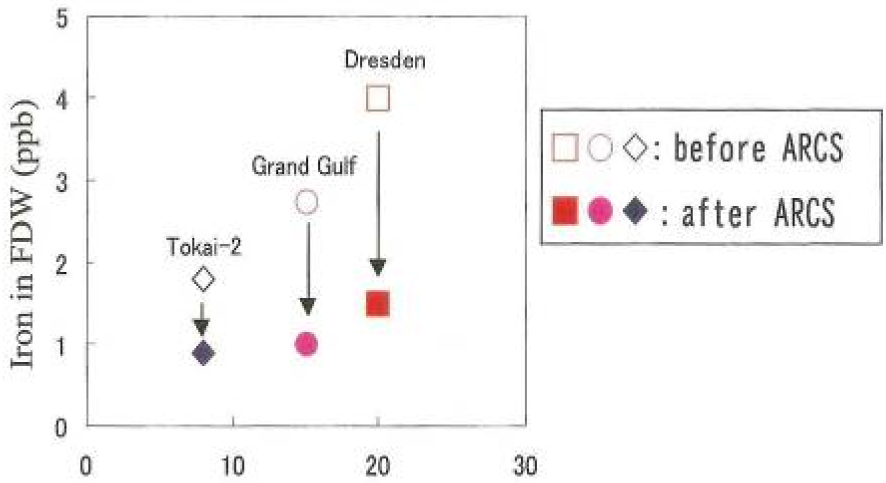
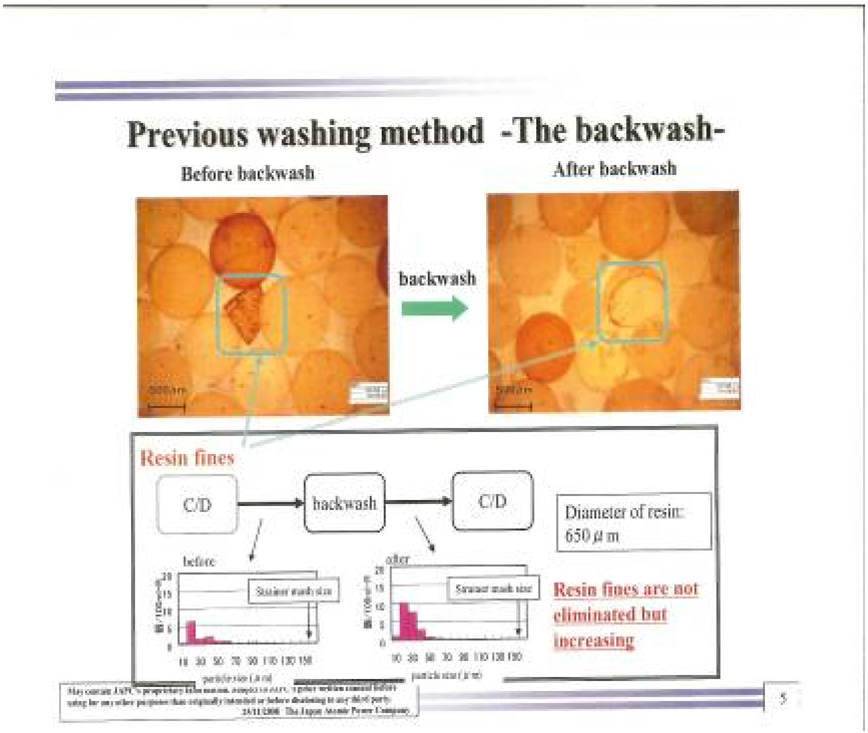


圖 5. 已安裝 ARCS 的電廠及其飼水鐵降低效果

東海電廠的化學組組長 Mr.Kodai 2008 年於柏林的國際水化學會議中發表Tokai-2使用ARCS 後的飼水鐵降低效果，且condemin反洗廢水也會減量、爐水硫酸根離子濃度也能降低。[10]。訪問Tokai-2 時，東海化學組也向本人詳述ARCS 經驗[5]，如下文。

Tokai-2 傳統先前的 Condemin 樹脂清洗方法(圖 6)，含空氣排除(Air scrubbing)與水反洗(Water backwash)，但無法移除樹脂床中的樹脂微粒(resin fine) 且會隨使用而增加，亦產生大量低放射性液體廢料量。傳統 Condemin 樹脂反洗造成飼水鐵偏高因而使輻射源增加、高的爐水硫酸根離子濃度而有應力腐蝕龜裂(Stress corrosion cracking，SCC)的風險及放射廢料量使經濟效益變差，因此改變清洗方法是解決之道(圖 7)。ARCS 的清洗原理(圖 8)係利用機械振動原理，採用兩種篩網(Screeen)其網目一爲 350 μm，另一爲 100μm 將顆粒鏽垢及樹脂微粒清除回復樹脂的吸附活性位置及吸附容量(Adsorption active site and capacity)，因而回到運轉線時能增加鏽垢移除效率。且洗淨用水能再使用減少反洗廢量。圖 9 係 ARCS 的外觀。現在用在 Tokai-2 中其外圍已加裝防振容器，無法直接看到 ARCS，僅能由壁上視窗觀看。使用 ARCS 後，飼水鐵濃度能降低成原先的 1/2 以下，樹脂不需要再生，且樹脂微粒與鏽垢移除率均有險著改善。(圖 10) 爐水硫酸根離子濃度也降低成爲原先的 80 %(圖 11)。而反洗廢水量降低約爲原先的 1/3，廢水操作時間也縮短了 3 倍。(圖 12)。

目前 Tokai-2 每一床 condemi resin 每 20 天 ARCS 清洗一次。飼水鐵濃度約爲 0.1-0.2 ppb。上一週期，改成每 60 天 ARCS 清洗一次，飼水鐵濃濃度約 0.4 ppb。Tokai-2 也已知明白雖然 ARCS 能降低爐水硫酸根濃度，但樹脂不再生運轉 19 個月後因陽離子交換樹脂惡化會增加 PSS(Poly styrene sulfate，係爐水硫酸根來源之一)，陰離子交換樹脂的 PSS 移除效率下降，使爐水硫酸根濃度漸漸增加，樹脂必須再生。Tokai-2 目前正評估原因及其機制。ARCS 能清除樹脂微粒及 樹脂上佔據的鏽垢，使樹脂的活性位置數目增加而增進鏽垢移除效率。實際上至少>90%，甚至達>99%。Condemin 入口不會因 ARCS 的使用而減少鐵濃度，但鏽垢移除效率的上升，甚至有時 Condemin 出口的鐵濃度會低到 0.02-0.08 ppb 之.程度。2008 年，飼水鐵曾出現 <0.1 ppb 如此有的水質。



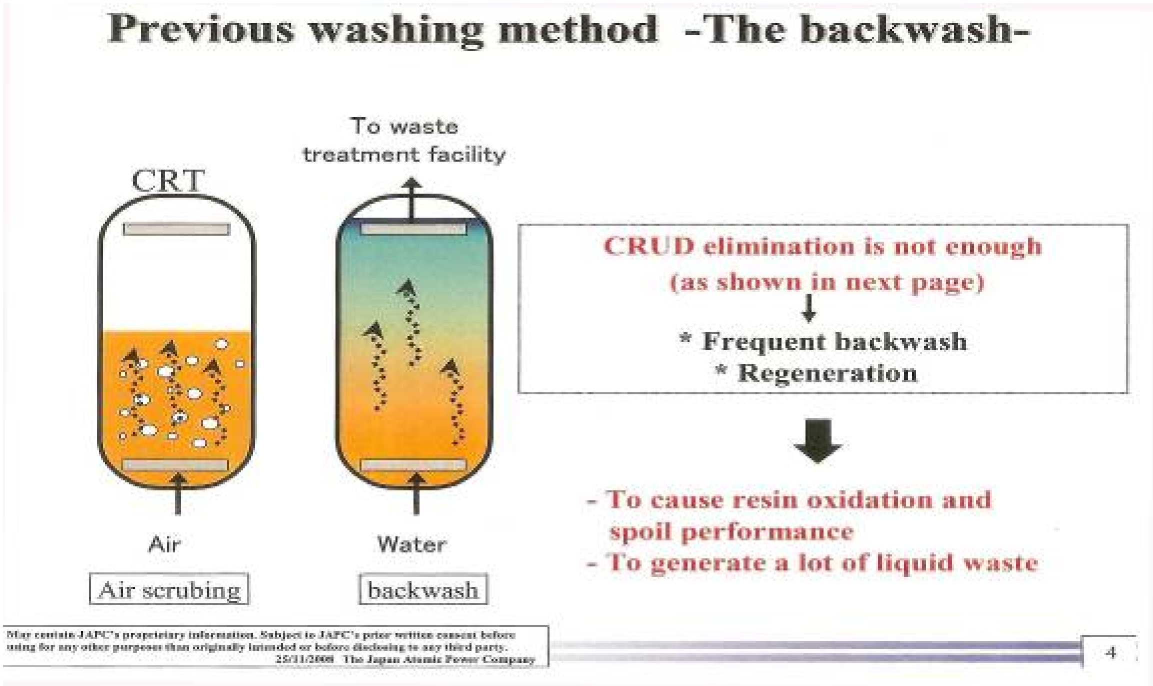


圖 6.Tokai-2 於 ARCS 安裝前的 Condemin 樹脂清洗方法

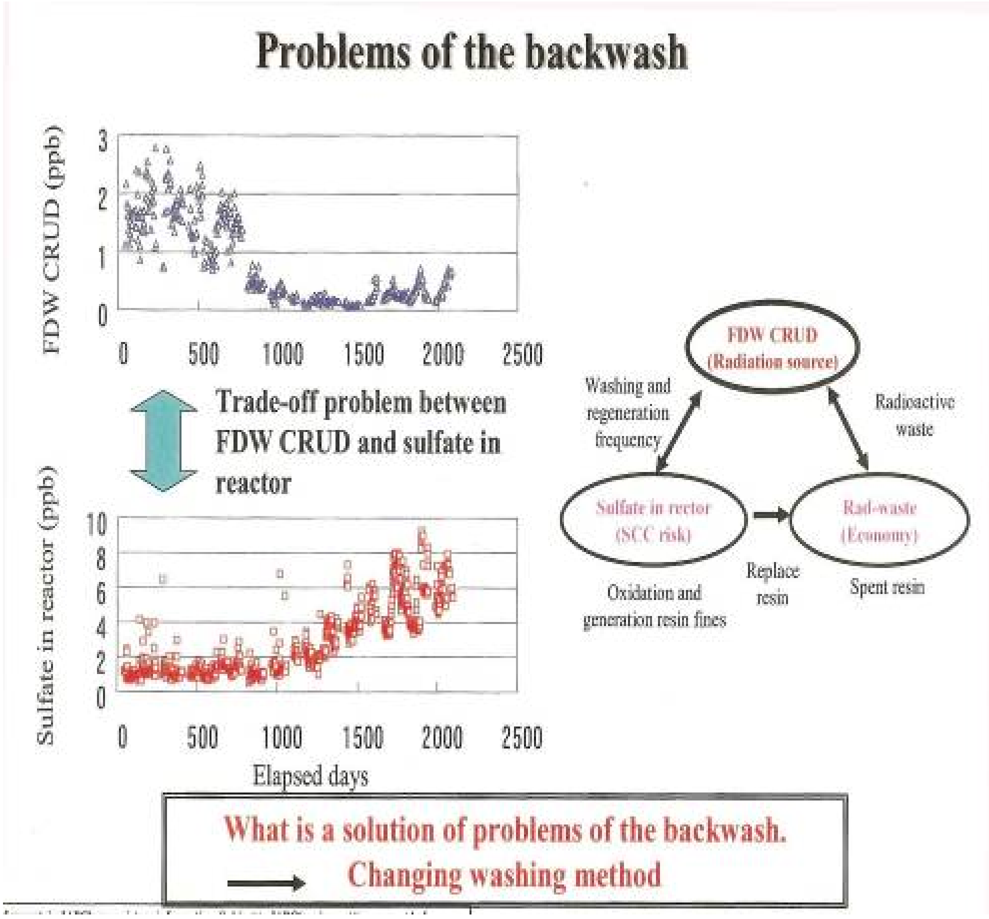


圖 7.傳統樹脂反洗的問題

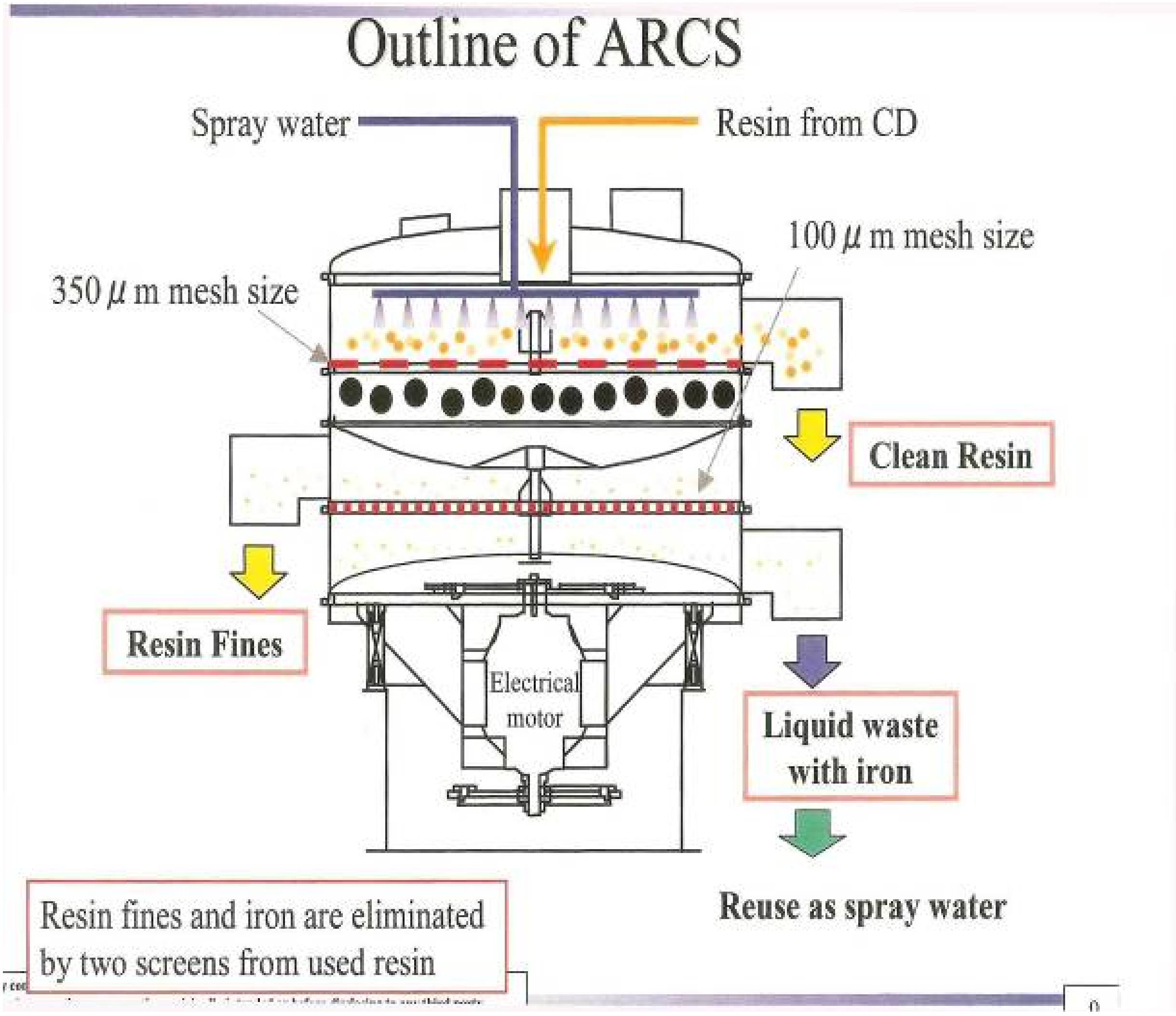


圖 8.ARCS 的清洗原理

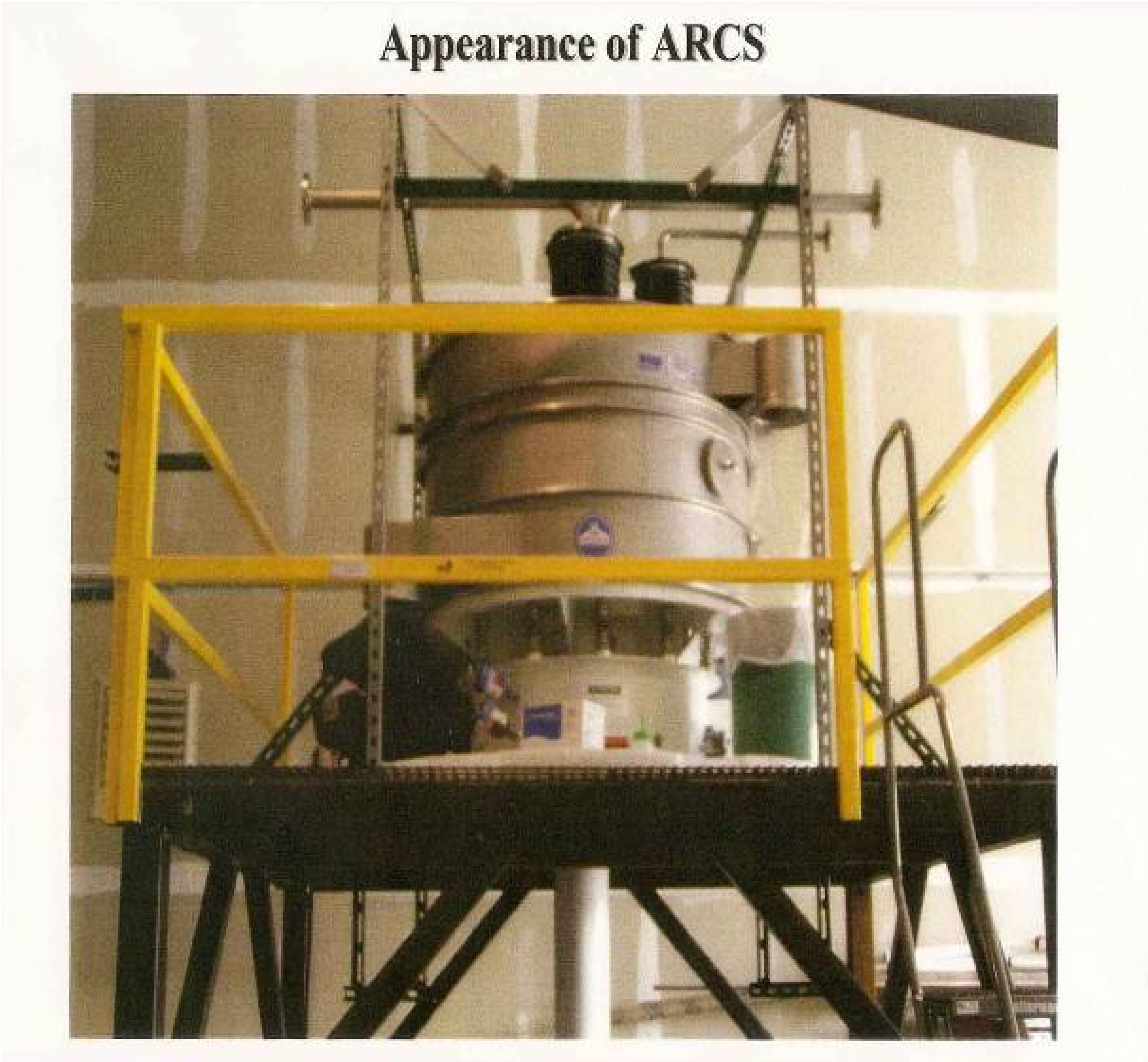
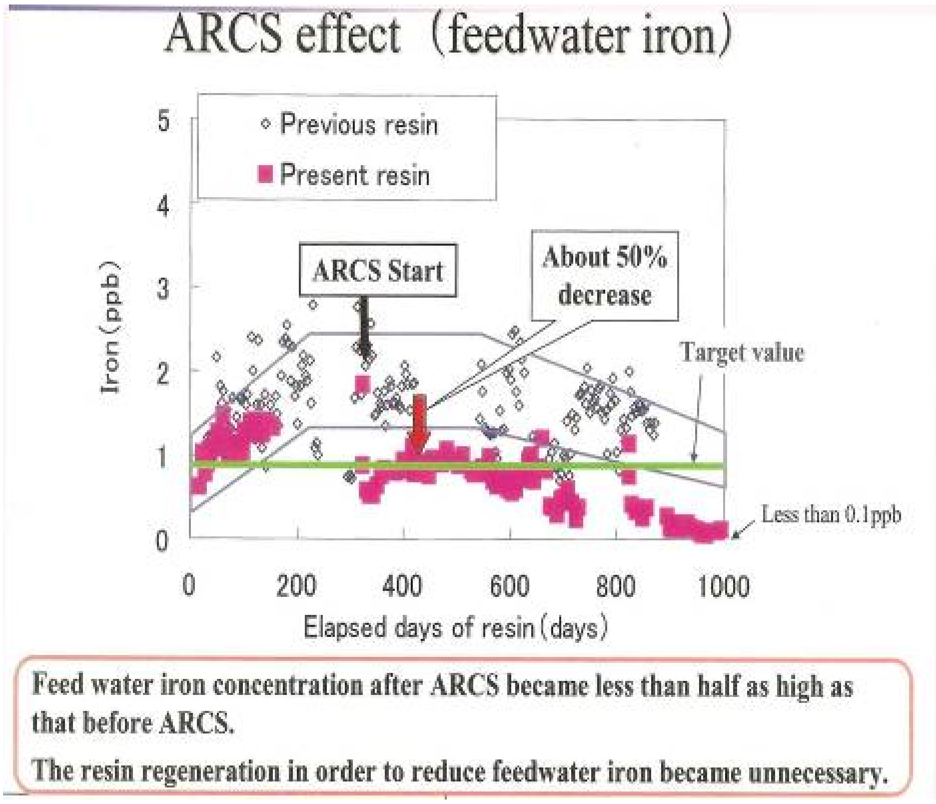


圖 9. ARCS 的外貌及實體



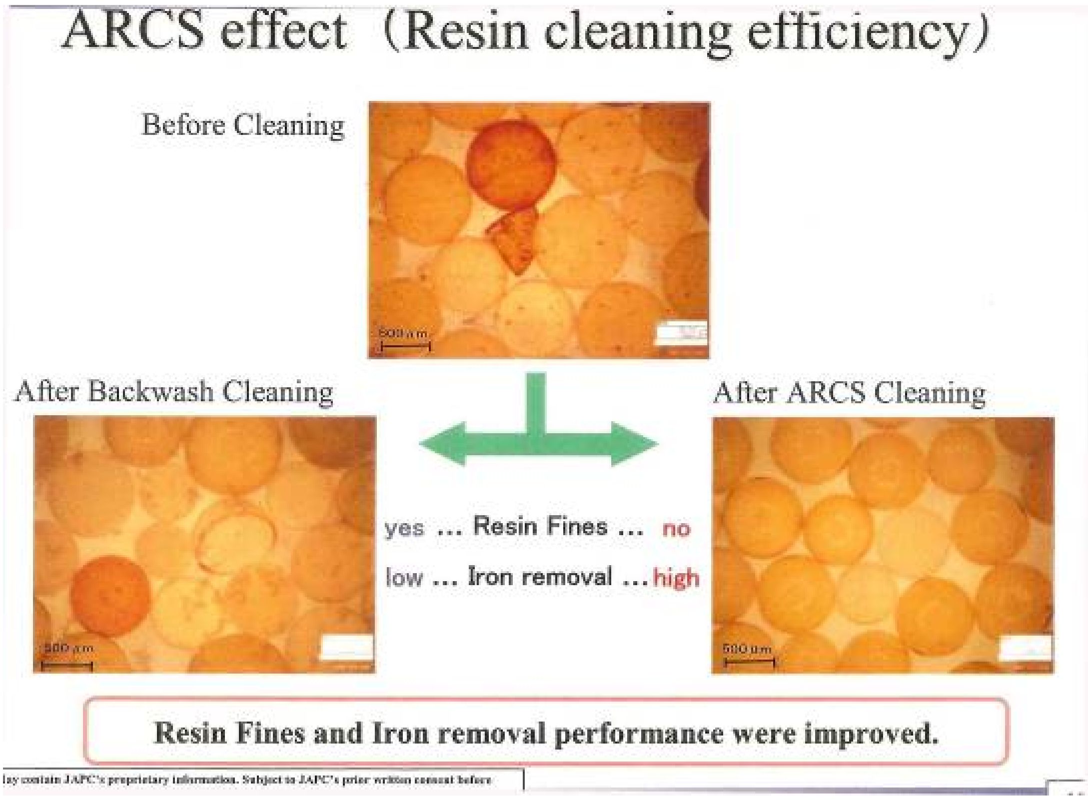


圖 10. ARCS 的飼水鐵降低效果

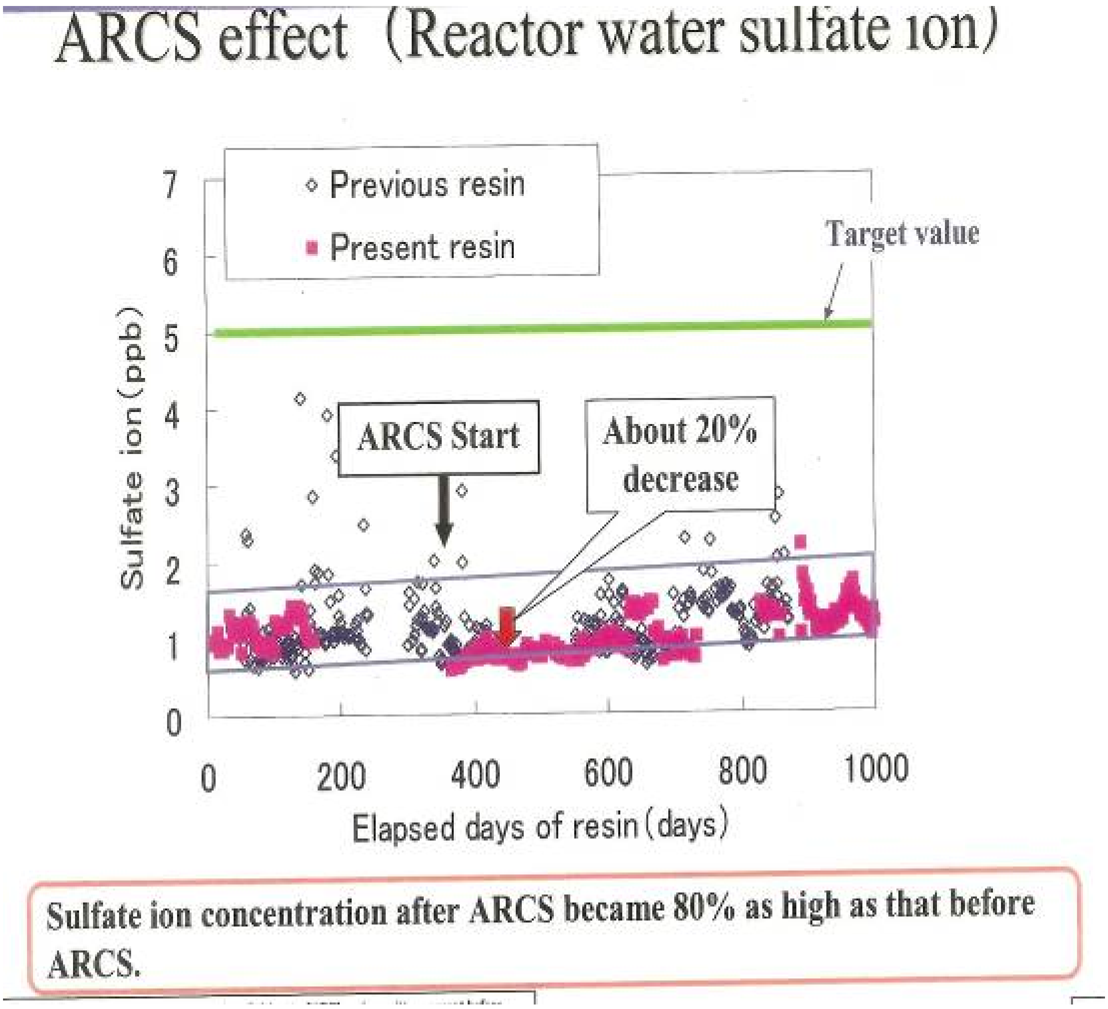


圖 11.ARCS 的爐水硫酸根離子濃度降低效果

ARCS effect（Liquid waste）

☆Decrease of Liquid waste（Resin cleaning）

	Back Wash	After ARCS
Cleaning waste water	31,500m^3/year	11,250m^3/year

☆Reduce of operator processing time

	Back Wash	After ARCS
Time for waste water processing	18 hours/time	6 hours/time

圖 12. ARCS 的反洗廢水量的將低效果

(三) 東海 2 號電廠放射性廢水處理系統及其效果[5]

東海 2 號電廠於商轉初期的放射性廢水處理系統與核一廠、核二廠類似，使用預敷式過濾器(Precoat filter)處理機械、設備洩水(Equipment drain)，含樹脂反洗廢水、泵封水(pump seal water)等。但預敷式過濾器產生大量過濾器淤泥，主要爲纖維與粉狀樹脂。且廢液中的微細鏽垢很難由預敷式過濾器中的樹脂移除，造成輻射劑量抑低困難。因此 Tokai-2 研究使用永久磁鐵(Permanent magnet)或電磁鐵過濾器(Electromagnetic filter，EMF)於放射性廢液處理系統中。

日本Organo.公司[11-12]及日立公司[13]均獲有 EMF的專利，但在Tokai-2 安裝前，其經驗都是用在凝結水除礦器的前置過濾器。**Tokai 2** 在商轉後 8 年(1986) 在放射性廢水處理系統開始安裝EMF及UF(Ultrafiltration filter)。[14-16] 而JAPC 的Tokai-2 and Tsuruga-1 是Organo 公司的EMF唯一用在廢料處理系統中的例子。[17] 目前Tokai-2 的放射性廢料處理系統中，機械、設備洩水，ARCS的樹脂反洗廢水、泵封水等均使用含 2 組EMF及 6 組UF的放射性廢水處理系統，已不再使用預敷式過濾器。而爐水淨化系統反洗廢水及過濾器(RWCU C/F)送到用過粉狀樹脂槽(Spent Powdex tank)暫存 24 小時後，水與過濾器分離後送到濃縮系統。EMF及UF不能處理導電度>50 μS/cm 的水。[18]。過濾器儲存在槽中等待最終處理階段。

Organo 公司供應給Tokai-2 的EMF構造如圖 14。螺旋狀鐵磁性材料填充在 EMF 容器中，電磁螺線管線圈(electromagnetic solenoid coil)在容器外圍。當線圈被電轉動下，內部鐵磁性材料激發成強磁性，機械洩水液體廢料通過EMF容器時，鏽垢被鐵磁性材料移除。[11-12] Organo公司期望用在Tokai-2 放射性廢水處理系統中的**EMF**，鏽垢移除率能夠達到 75%。

UF由 US ABCOR 公司供應，型號爲HFA-300 FEG 型。[14] 構造如圖 15。使用在Tokai-2 的EMF及UF的特徵如圖 16。圖 17 指出 Tokai-2 使用EMF &UF的效果，EMF的除污因子(Decontamination factor，DF= inlet iron/outlet iron) 約 3-10。EMF入口鐵濃度約數拾ppm ，出口約數ppm.。UF 的DF可達 1000 以上，因此 UF出口的鐵濃度<. 10 ppb.。在使用EMF之前，預敷式過濾器廢料量年產生量約數拾 m^3/year。但在使用EMF之後已無預敷

式過濾器廢料。EMF& UF已達到放射性廢料的改善。

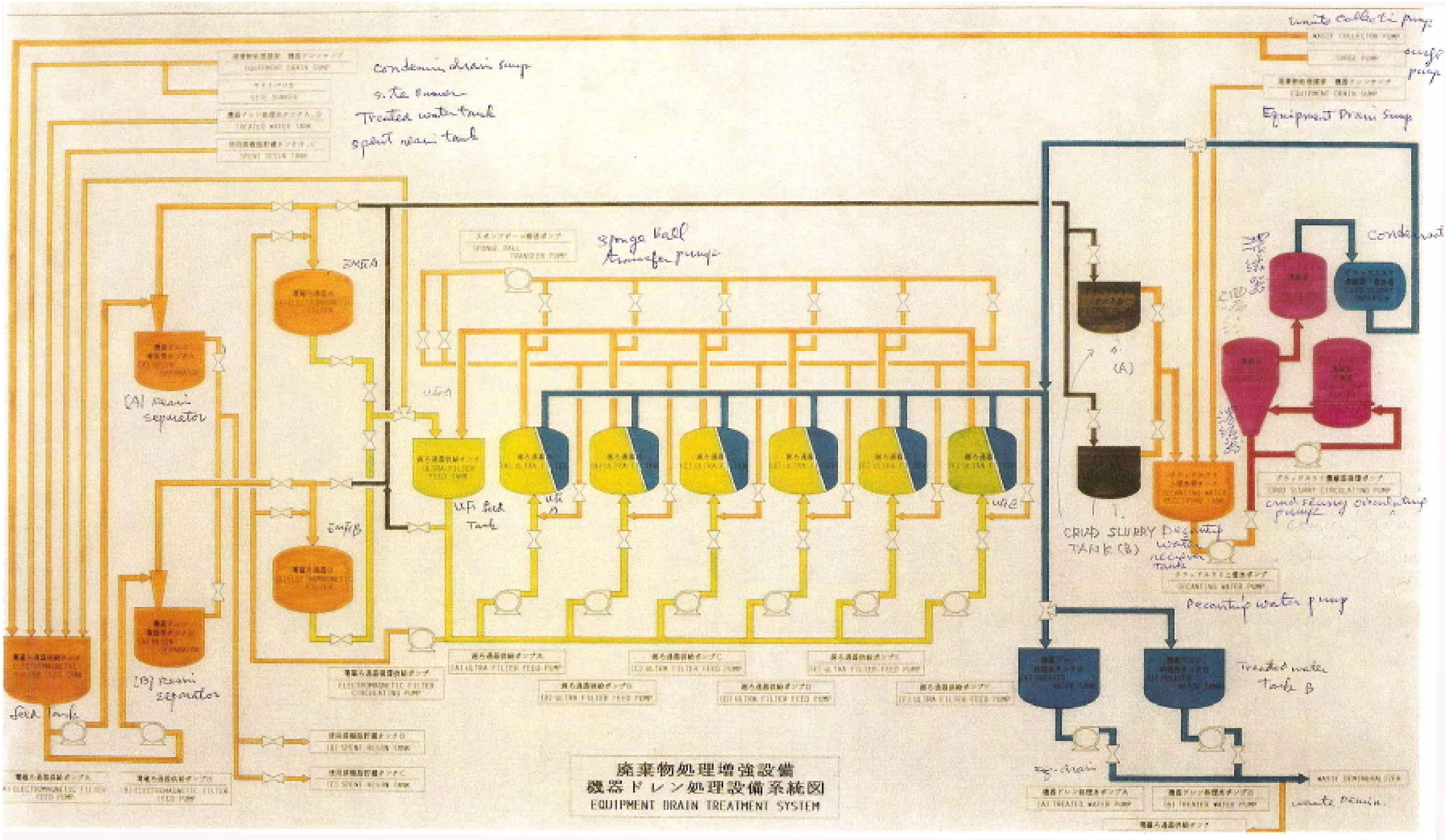


圖 13.Tokai-2 的放射性廢液處理系統

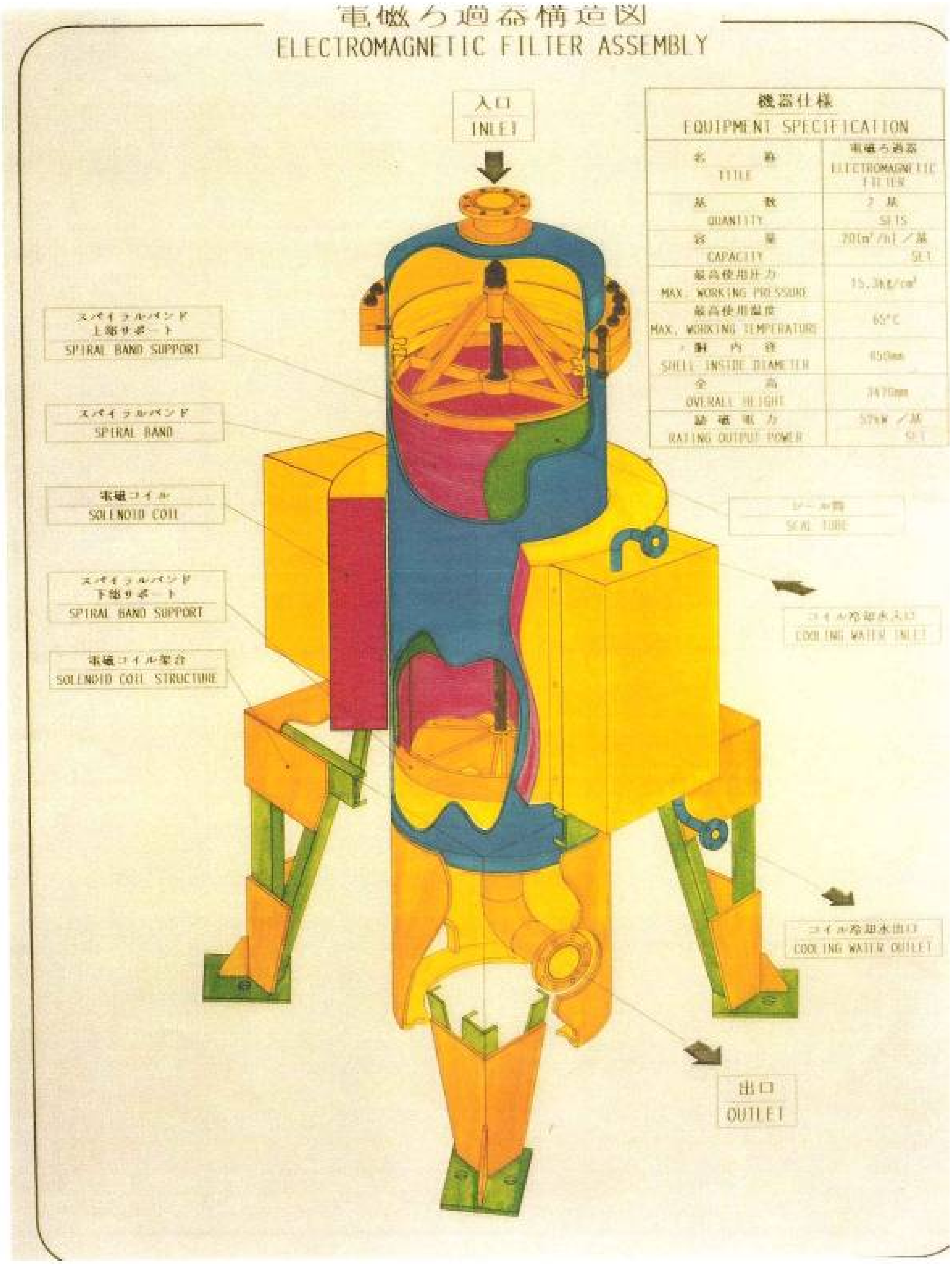

電磁ろ過器構造図
ELECTROMAGNETIC FILTER ASSEMBLY
入口
INLET
機器仕様
EQUIPMENT SPECIFICATION
名称
TITLE
電磁ろ過器
ELECTROMAGNETIC FILTER
基数
QUANTITY
2基
SETS
容量
CAPACITY
201m³/h/基
SET
最高使用圧力
MAX. WORKING PRESSURE
15.3kg/cm²
最高使用温度
MAX. WORKING TEMPERATURE
65°C
胴内径
SHELL INSIDE DIAMETER
850mm
全高
OVERALL HEIGHT
3470mm
MAX. WORKING TEMPERATURE
RATING OUTPUT POWER
57kW/基
SET
スパイラルバンド
上部サポート
SPIRAL BAND SUPPORT
スパイラルバンド
SPIRAL BAND
電磁コイル
SOLENOID COIL
スパイラルバンド
下部サポート
SPIRAL BAND SUPPORT
電磁コイル架台
SOLENOID COIL STRUCTURE
シール筒
SEAL TUBE
コイル冷却水入口
COOLING WATER INLET
コイル冷却水出口
COOLING WATER OUTLET
出口
OUTLET

圖 14. EMF 構造

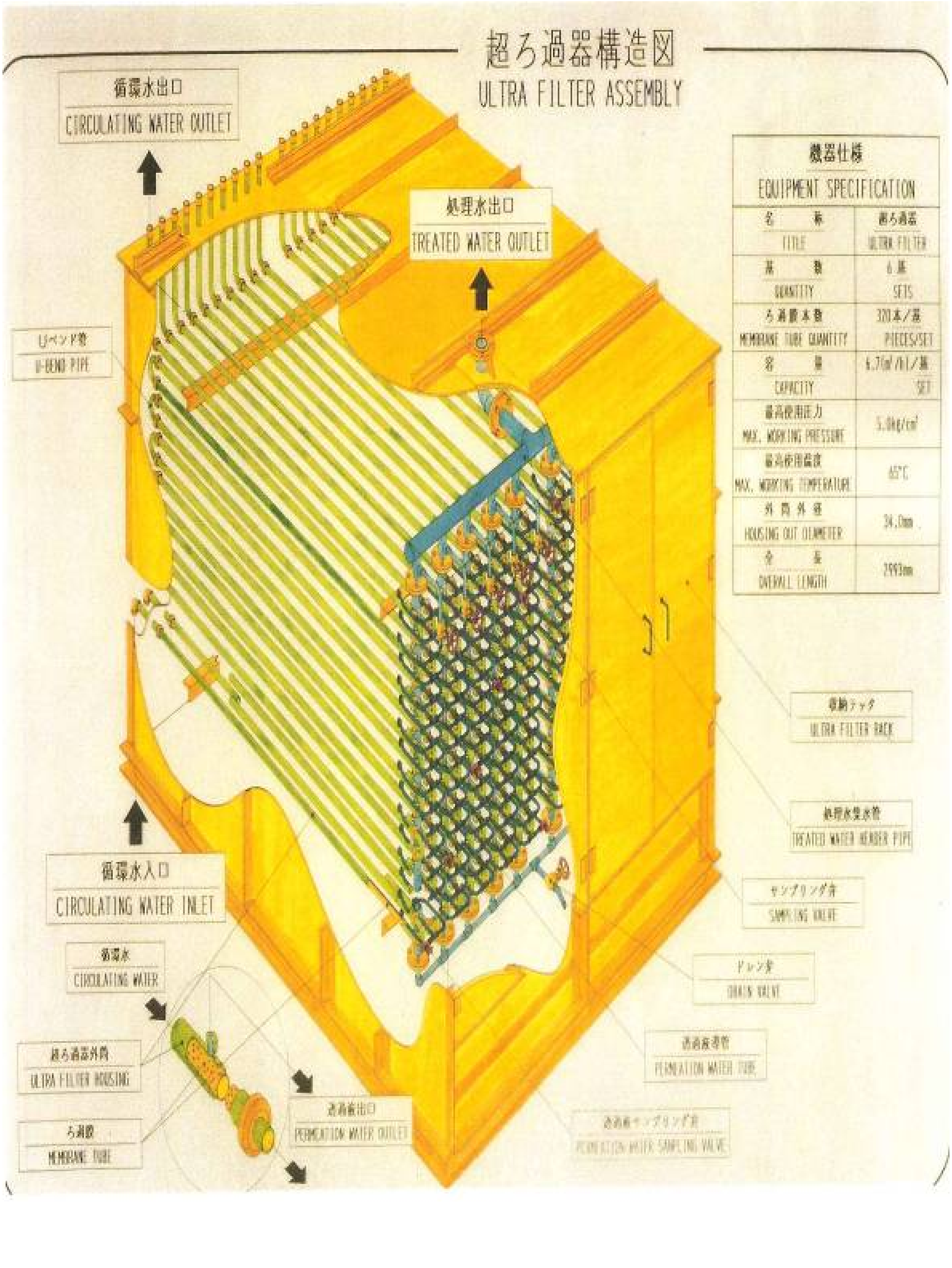

超ろ過器構造図
ULTRA FILTER ASSEMBLY
循環水出口
CIRCULATING WATER OUTLET
処理水出口
TREATED WATER OUTLET
機器仕様
EQUIPMENT SPECIFICATION
名称
TITLE
超ろ過器
ULTRA FILTER
基数
QUANTITY
6基
SETS
ろ過膜本数
MEMBRANE TUBE QUANTITY
320本/基
PIECES/SET
容量
CAPACITY
最高使用圧力
MAX. WORKING PRESSURE
5.0kg/cm²
最高使用温度
MAX. WORKING TEMPERATURE
65°C
外筒外径
HOUSING OUT DIAMETER
34.0mm
全長
OVERALL LENGTH
2993mm
Uベンド管
U-BEND PIPE
ULTRA FILTER RACK
処理水集水管
TREATED WATER HEADER PIPE
サンプリング弁
SAMPLING VALVE
循環水入口
CIRCULATING WATER INLET
循環水
CIRCULATING WATER
ドレン弁
DRAIN VALVE
超ろ過器外筒
ULTRA FILTER HOUSING
透過液導管
PERMEATION WATER TUBE
ろ過膜
MEMBRANE TUBE
透過液出口
PERMEATION WATER OUTLET
透過液サンプリング弁
PERMEATION WATER SAMPLING VALVE

圖 15.UF 構造

Electromagnetic Filter

Number of unit	2 (units)
Capacity	20 (m3/hr/unit)
Solenoid coil	
Rating output power	52 (KW/unit)
Size	
Shell inside diameter	850 (mm)
Overall height	3,470 (mm)
Materials	304 SS

Ultra Filter

Number of unit	6 (units)
Number of membrane tube	320 (tubes/unit)
Capacity	6.7 (m3/hr/unit)
Tube Size	
Housing outside diameter	34 (mm)
Overall length	2,993 (mm)
Materials	
Outside housing	304 SS
Membrane tube	Porosity reinforcement plastic

圖 16. EMF& UF 特徵

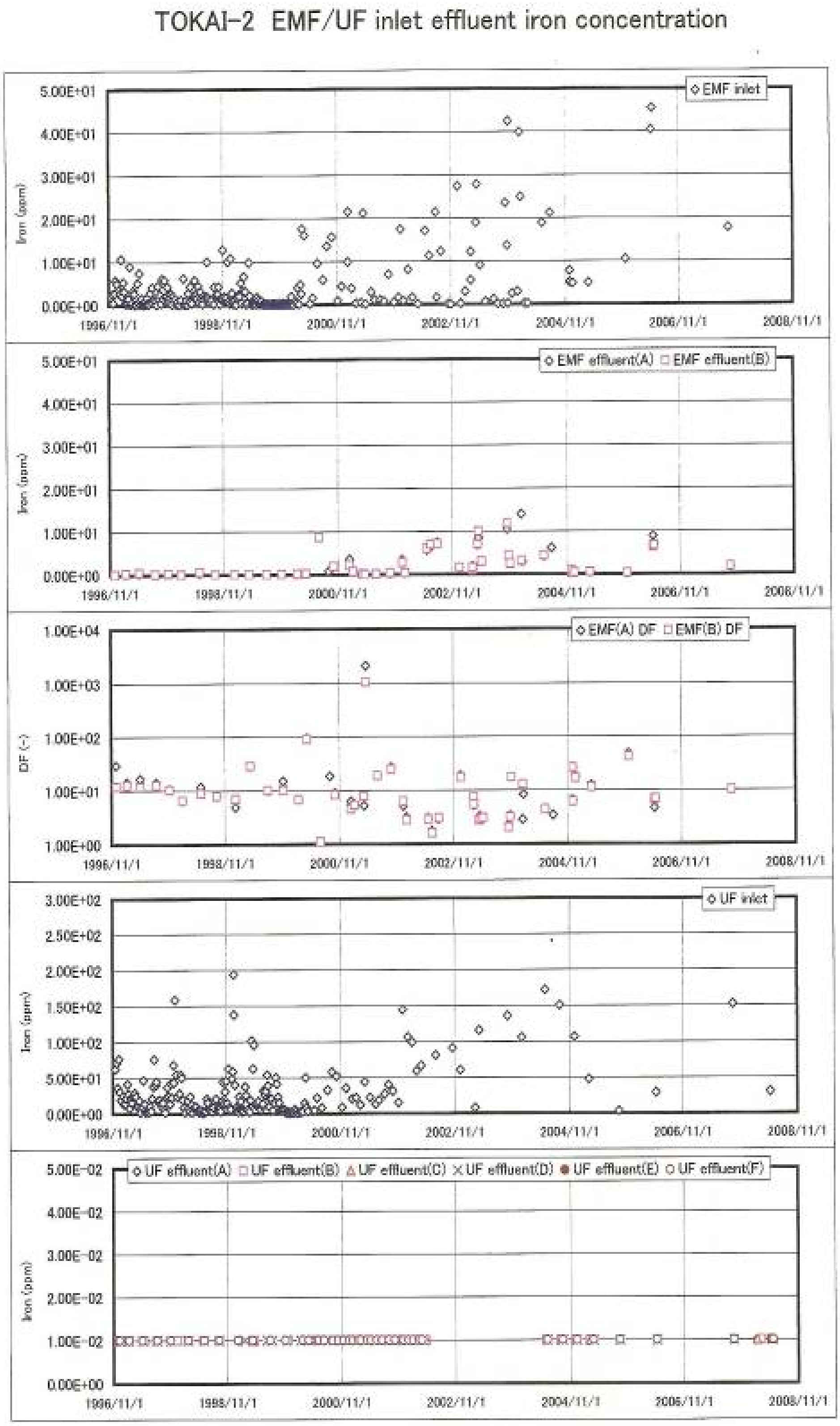


圖 17.Tokai-2 的 EMF &UF 的效果

(四) 敦賀 2 號機的一次及二次冷卻水水化學改善經驗[3]

1.一次水化學

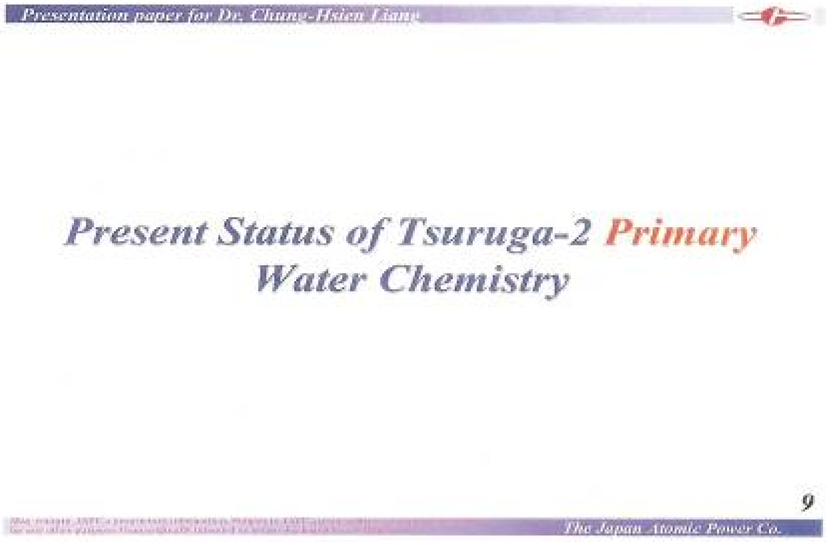
圖 18 指出 1998~2008 Tsuruga 2 一次水化學控制策略的演進。主要在輻射劑量的降低改善。包括(1)B/Li控制：由調和型(Li<2.2ppm)改進成修飾型(Li<3.5 ppm) 使運轉中一次冷卻水的pH由 6.9 上升到 7.2-7.4，減少管路的腐蝕及府蝕鏽垢量。(2)大修停機中鏽垢移除改善：採用添加H_2O_2，加速管路表面含輻射源氧化膜的氧化與溶出，再配合水處理系統的純化速度增加。(3)加鋅使一次系統的輻射劑量率降低。

圖 19 上圖顯示 Tsuruga-2 的一次水化學參數值，溶氫濃度(DH)的**控制**相當精準在 25-26 ppb 範圍內，顯示其優異的電廠操作 (核三廠為 25-32ppb)。下圖指出日本 PWR 每機組的平均人員輻射曝露(Occupational Radiation Exposure，ORE)在世界上相當高，Tsuruga-2 為居中間，因此降低人員輻射曝露是日本 PWR 的重要目標，也因此 Tsuruga-2 於 2004 年開使一次系統的加鋅研究與試驗，結果顯示加鋅後一次系統的輻射劑量率降低約 20 %，SG channel head 估計降低 0.05 man -Sv。(圖 20，21)。

Tsuruga-2 是日本首次嘗試PWR的加鋅計畫與試驗。JAPC 建議其他PWR電廠組成一個合作研究群，且委託給AREVA 公司提供的計畫。**AREVA** 與JAPC訂合約，於 3 年前開始支援Tsuruga 2 的加鋅計畫。合約內容包括 DZO supply(Depleted Zinc Oxide) ，然後JAPC(Tsuruga 2)將它溶解在醋酸(acetic acid)中，生成醋酸鋅加入一次系統中，加鋅設備由日機裝製造(圖 20 的下圖 與 圖 21 的 上圖)。合約計畫內容包括審查實施計畫、供應 DZO 審查Tsuruga 2 的試驗結果、劑量降低的評估及副作用。[19]結果類似國外經驗，但Tsuruga-2 現在已開始連續加鋅。

2.二次水化學

Tsuruga 21998 年加裝 HFF 當做凝結水除礦器(condensate polisher)的前置過濾器，降低雜質進入 SG 內(圖 22)。而過去 SG 罅隙(crevice)所發生的 Cu-沉澱，也已將含 Cu 的冷凝管更換，已無此問題。且在 2004 開始採用 High AVT 控制下，已將 SG 中聚積之含鐵淤泥降降低成 1/4 的程度。(圖 22，23)



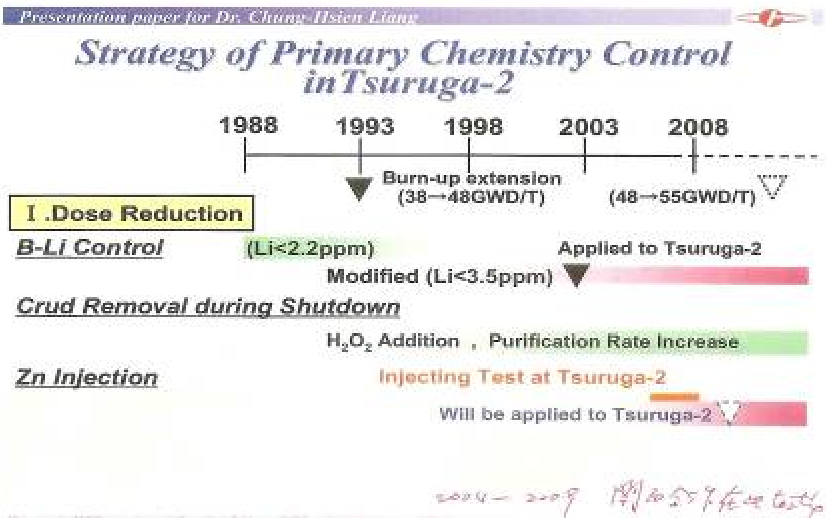


圖 18. Tsuruga-2 的一次水化學演變

Presentation paper for Dr. Chung-Hsien Liang

Primary Water Chemistry in Tsuruga-2

	RCS (LBH:Loop B Hot side)		
	Spec.	C.V.*	D.V.**
Li(ppm)	0.2-3.5	1.9-3.5(1)	—
DH(cm3/kg-H2O)	25-35	25-26	—
Cl(ppb)	≦50	—	＜5
F(ppb)	≦50	—	＜5-30
DO(ppb)			＜5
Zn(ppb)	—	5±2(2)	—

(1) Modified B-Li Control
(2) Zinc Injection Test

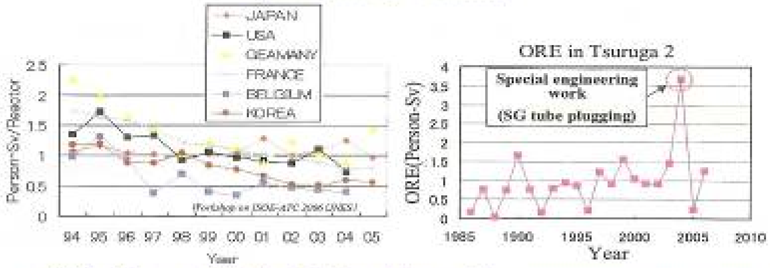
*Control Value
**Diagnostic Value

11

The Japan Atomic Power Co.

Presentation paper for Dr. Chung-Hsien Liang

PWR Average Occupational Radiation Exposures (ORE) per Unit by Country



- ORE of Japanese PWRs is the highest in the world.
- Therefore, reducing ORE is one of important issue in Japanese PWR.
- ORE in Tsuruga-2 situates in the middle range of Japanese PWRs.
- The increase of ORE in 2004 is caused by special engineering work(SG tube plugging).

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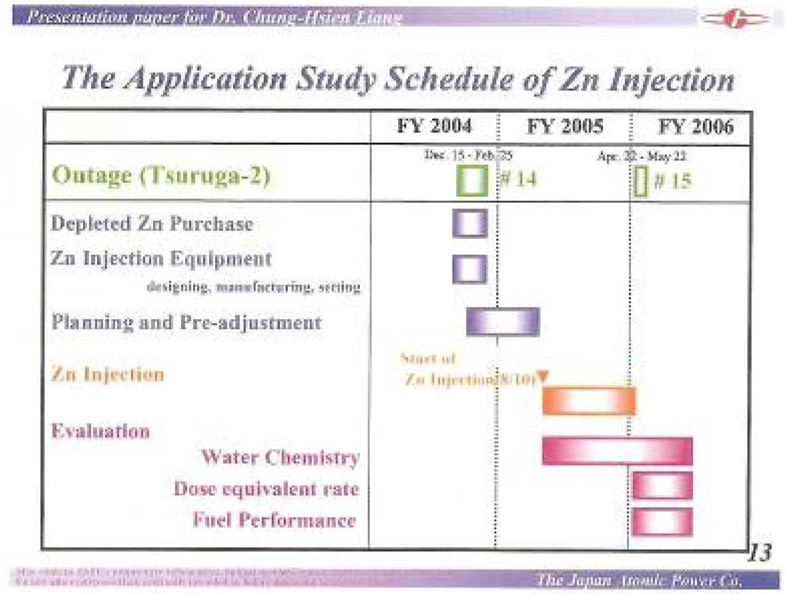
The Japan Atomic Power Co.

圖 19.Tsuruga-2 的一次水化學參數值與人員集體輻射曝露



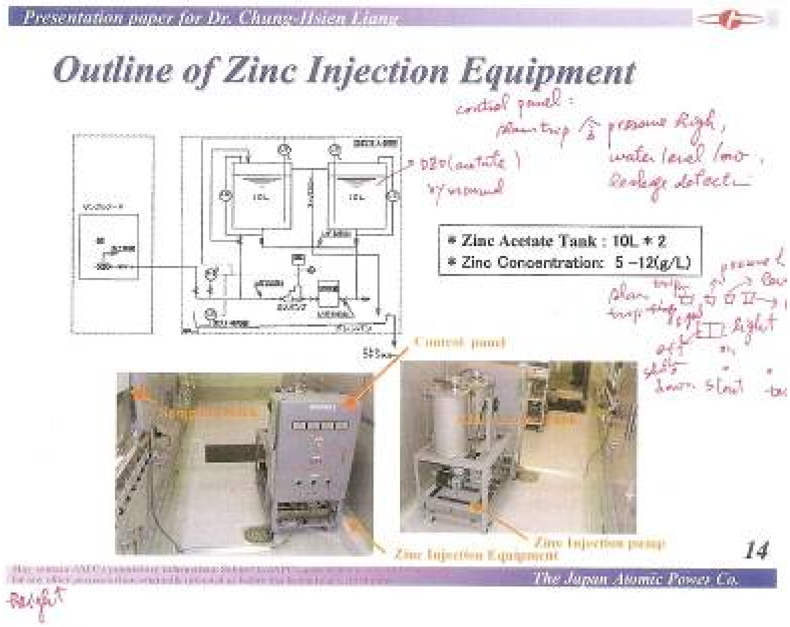
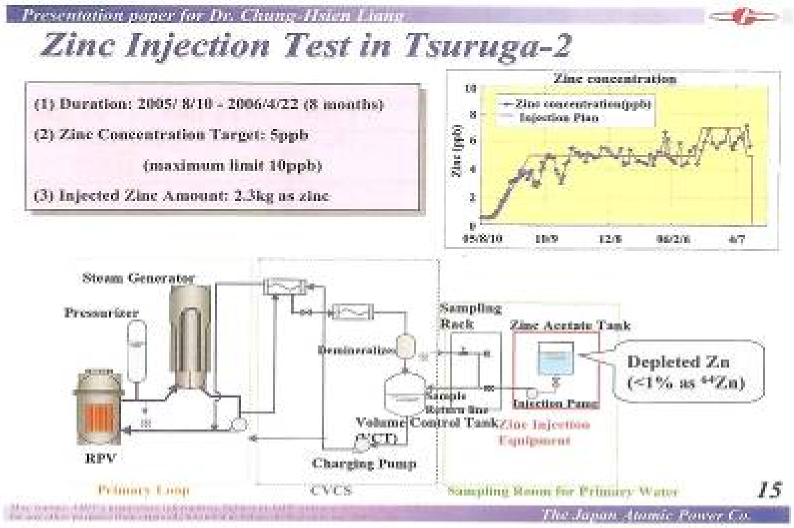


圖 20 Tsuruga-2 一次系統的加鋅研究時程與加鋅設備



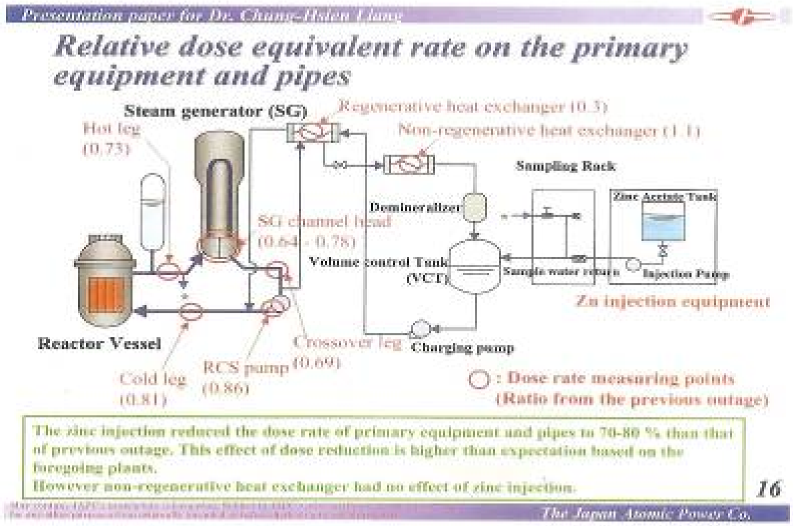
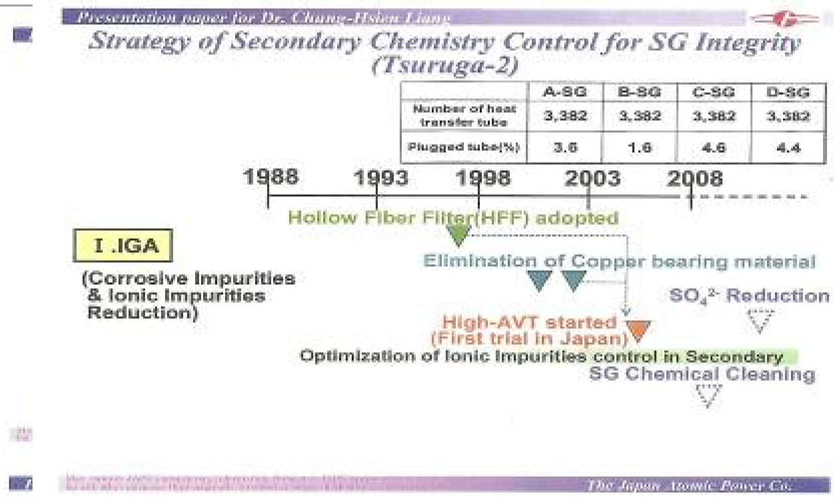


圖 21. Tsuruga-2 一次系統的加鋅測試及輻射劑量的降低效益



Presentation paper for Dr. Chung-Hsien Liang

Secondary Water Chemistry in Tsuruga-2

		Spec.	C.V.*	D.V.**
Feedwater	pH	8.7-12	9.6-10(1)	—
	Fe(ppb)	<20	—	<1-2
	Cu(ppb)	—	—	<0.01
SGBD	pH	8.5-12	9.5-9.9	—
	Na(ppb)	<40	—	<0.5
	Cl(ppb)	<100	—	<1
	SO4(ppb)	—	—	<1

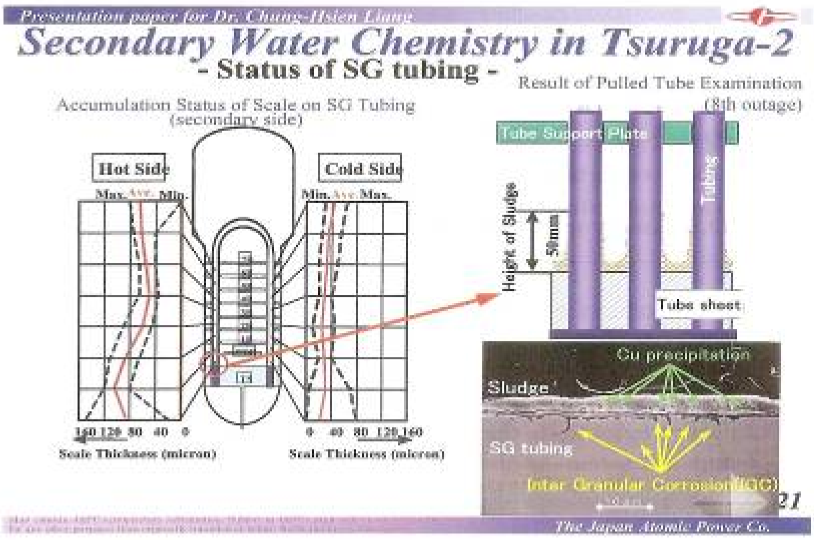
(1) High-AVT Treatment with NH_3

*Control Value
**Diagnostic Value

20

The Japan Atomic Power Co.

圖 22. Tsuruga-2 的 SG 完整性二次側水化學控制策略及水化學



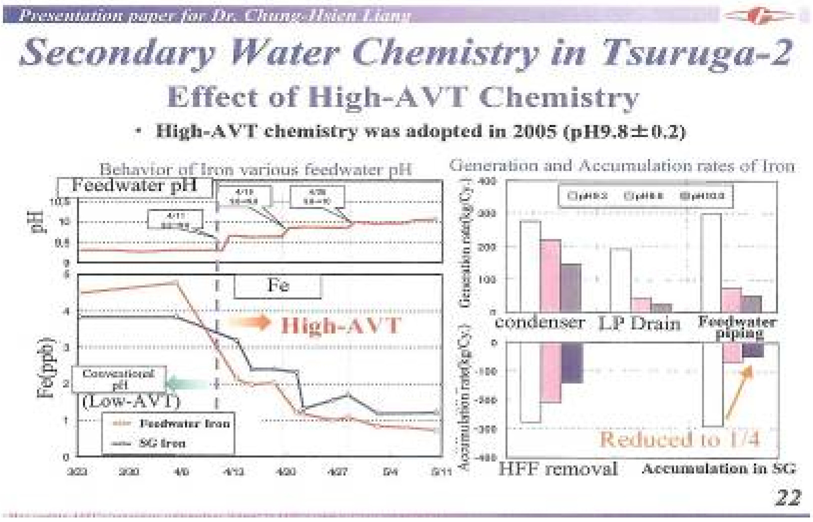


圖 23 Tsuruga-2 二次水化學效益

(五) Hot Laboratory

JAPC 的 Tokai-2 及 Tsuruga-2 電廠的 Plant Engineering Group 主要是化學背景成員，擔負電廠中化學、材料、維護工作。最特殊的是旗下都有一間 Hot laboratory。Hot laboratory 除了負責電廠中含放射性樣品的一次水化學分析外，且有 X 射線螢光分析(X-ray Fluorescence，XRF)、X 射線繞射分析 (X-ray Diffraction，XRD)、掃瞄電子顯微鏡 (Scanning Electron Microscopy，SEM)等儀器，分析飼水、爐水鏽垢，甚至管線表面氧化膜、燃料棒表面氧化膜的組成、型態等。且 Group 任何成員都會操做這些儀器。這在國內，甚至日本都是唯一的。

四、建　議　事　項

1. 國內水化學應重視 **BWR** 飼水鐵的控制

BWR 飼水鐵的控制，不但是電廠營運的重要化學指標，決定未來加鋅能否實行，也影響爐內管路表面的輻射劑量率，最終也決定電廠從業人員的集體輻射曝露。而核一廠場、核二廠與 Tokai-2 類似，都屬凝結水除礦器前無前置過濾器的稀有 BWR 電廠，因此飼水鐵的控制先天不良。但 Tokai-2 安裝 ARCS 後已解決此問題，飼水鐵控制相當良好。WANO 應核二廠的請求，於 2008 5/18-23 派 Tokai-2 的 Mr.Sasaki 到核二廠並發表 Tokai-2 的 ARCS 經驗。核二廠已表示未來有興趣安裝 ARCS，但因使用 ARCS 後，放射性廢液處理系統的來源廢水 –凝結水除礦樹脂反洗廢水中的懸浮鏽垢顆粒濃度會增加，反而增加放射性液體廢料處理系統的負擔，因此 ARCS 安裝的規劃階段必須與廢液處理系統改善一併考慮。

2. 水化學研究的重視

JAPC 相當重視水化學(化學與材料)因此電廠的營運也相當優異。新型水化學控制與管理策略之計畫持續發展，已具世界的領先地位。國內水化學研究群，目前首先應參與國際活動包括亞洲、國際相關會議吸收心技術；其次應結合各產業增進本土化水化學能力，提昇核能產業中的水化學地位。除研究外更應著重在實用工程面上。

3. 水化學研究的人才培養

Tokai-2 與 Tsuruga-2 的 plant engineering group.成員平均分布在 50、40、30 各年齡層，無斷層問題。這是國內水化學研究群必須努力改進之處，但也要國內相關單位長官的支持。

五、附　錄

1. 附件一、JAPC Corporate Profile 2008-2009, The Japan atomic Power Company

JAPC POWER STATIONS

Stable, High-Quality Electricity Supply

JAPC works hard to operate
its plants safely and provide a high quality, stable power supply.

JAPC POWER STATIONS

Tokai No. 2 Power Station
Japan's first large-scale nuclear power plant

Tokai No. 2 Power Station continues its record in Japan for total power output from a single Boiling Water Reactor (BWR).

Electric output: 1,100,000 kW
Reactor type: Boiling water reactor (BWR)
Fuel: Low enriched uranium (approx. 132 tons)
Start of commercial operation: November 1978

Power supplied to:
Tohoku Electric Power Co.,Inc.
The Tokyo Electric Power Co., Inc.

Fiscal Year 2007
Total power generation: 8.79 billion kWh
Capacity factor: 91.0%

Achievements (since the commercial operation)
Accumulated power generated: 209.23 billion kWh
Average capacity factor: 74.0%
Average availability factor: 74.9%

In 1998, Tokai No. 2 Power Station obtained ISO 14001 environmental management certification, first among nuclear power plants in Japan.

Tsuruga Power Station Unit 1
Japan's first light water reactor

Tsuruga Power Station Unit 1 is the first nuclear power plant equipped with a light water reactor.

Electric output: 357,000 kW
Reactor type: Boiling water reactor (BWR)
Fuel: Low enriched uranium (approx. 52 tons)
Start of commercial operation: March 1970

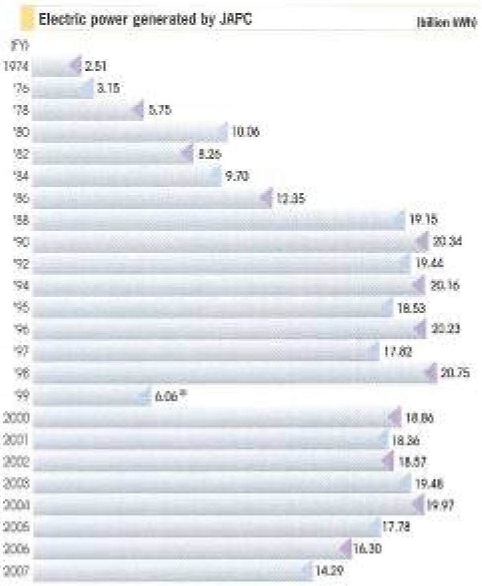
Power supplied to:
Chubu Electric Power Co., Inc.
Hokuriku Electric Power Co., Inc.
The Kansai Electric Power Co., Inc.

Fiscal Year 2007
Total power generation: 1.719 billion kWh
Capacity factor: 54.8%

Achievements (since the commercial operation)
Accumulated power generated: 80.13 billion kWh
Average capacity factor: 67.4%
Average availability factor: 70.2%

In 1998, Tsuruga Power Station Unit 1 obtained ISO 14001 environmental management certification, first among nuclear power plants in Japan.

09

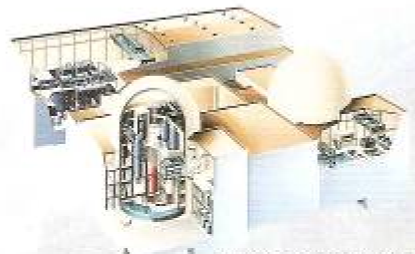


*Due to the long-term operation halt of Tsuruga Power Station Unit 2 and Tokai No.2 Power Station.

Construction of Tsuruga Power Station Units 3 and 4

To ensure a stable and self-sufficient supply of energy and help curb global warming, the extension project of Tsuruga Power Station Units 3 and 4 has been planned, and site preparatory work is now in progress. Placing special emphasis on safety measures, reliability, operation and maintenance, the new units will be equipped with a more advanced pressurized water reactor (PWR) than Unit 2, based on our previous experience in operation maintenance and latest technology. Tsuruga Power Station Units 3 and 4 will be equipped with economical twin-type PWR (two units in one facility).

Electrical Output: 1,538,000 kW each
Reactor Type: Advanced Pressurized Water Reactor



Tsuruga Power Station Units 3 and 4 (conceptual design)

Tsuruga Power Station Unit 2
Establishment of domestic nuclear technology

Tsuruga Power Station Unit 2 was built using domestic nuclear technology. Incorporating Japan's first Prestressed Concrete Containment Vessel (PCCV), it has significantly improved its earthquake resistance, and made a range of other improvements.

Electric output: 1,160,000 kW
Reactor type: Pressurized water reactor (PWR)
Fuel: Low enriched uranium (approx. 89 tons)
Start of commercial operation: February 1987

Power supplied to:
Chubu Electric Power Co.,Inc.
Hokuriku Electric Power Co., Inc.
The Kansai Electric Power Co., Inc.

Fiscal Year 2007
Total power generation: 3.784 billion kWh
Capacity factor: 37.1%

Achievements (since the commercial operation)
Accumulated power generated: 171.95 billion kWh
Average capacity factor: 80.1%
Average availability factor: 80.4%

In 1998, Tsuruga Power Station Unit 2 obtained ISO 14001 environmental management certification, first among nuclear power plants in Japan.

Based on Our Long-Accumulated Expertise

As part of its pioneering efforts in providing nuclear energy, JAPC continues the decommissioning of Tokai Power Station and establishing the nuclear fuel cycle for efficient use of uranium resources.

Decommissioning Tokai Power Station

Tokai Power Station is undergoing the first decommissioning of a nuclear power plant in Japan. Decommissioning began with removal of the peripheral facilities outside the reactor area. The reactor area will be safely stored for 10 years until radiation levels have diminished to an appropriate level for the dismantling and removal of the reactor. Finally, the site will be ready for a future nuclear power plant.

Tokai Power Station
— Japan's first commercial nuclear power plant

Tokai Power Station uses a modified Calder Hall unit, a carbon dioxide gas-cooled reactor developed in the UK. The unit also incorporates an original quake-resistant design developed in Japan.

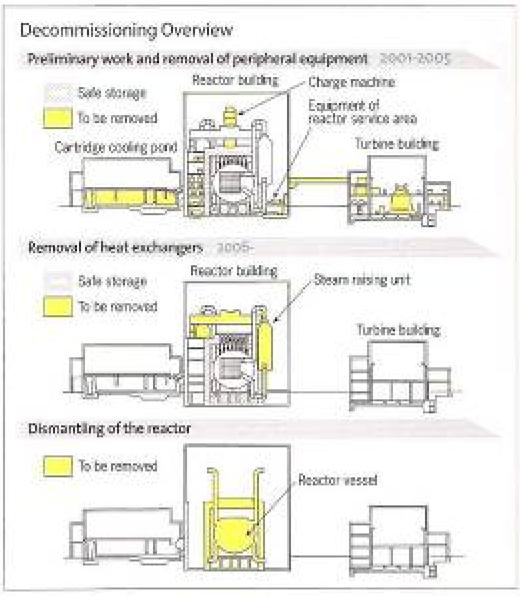
Electric output: 166,000kW
Reactor type: Graphite-moderated, carbon dioxide gas-cooled reactor (GCR)
Fuel: Natural uranium (approx. 187 tons)
Operation period: 31 years and 8 months
Total electricity generated: 29,006,720kwh
Average capacity factor: 62.9%
Average availability factor: 77.5%

Milestones

July 25, 1966: Operation initiated.
Mar. 31, 1998: Commercial operation ceased.
Oct. 4, 2001: Reactor dismantling application submitted.
Dec. 4, 2001: Decommissioning work initiated.
June 30, 2006: Decommissioning plan approved.
Aug. 17, 2006: Removal of the heat exchanger initiated.
Sep. 8, 2006: Approval of radiation measurement and assessment methods in compliance with the clearance system.

Dismantling by a remotely operated machine

Fuse cutting



Clearance system for Recycling of Dismantling Material

Decommissioning of nuclear power facilities generates a huge amount of dismantling material such as iron and concrete. JAPC is now engaged in Japan's first recycling project, in compliance with the government's newly institutionalized clearance system. The system allows us to recycle or reuse the dismantling material, after it has first been confirmed safe by the government, in the same way as general industrial waste.

Recycled Clearance Products
Recycled products, such as benches, tables, and shielding blocks, are manufactured by foundries in Tokai-mura and used in JAPC facilities and other nuclear related facilities.

Expertise in Decommissioning Technology

With the decommissioning of the Tokai Power Station, JAPC is carrying out an important first in Japan's nuclear history: the safe, efficient decommissioning of a commercial nuclear plant. In our pioneering role, we are working to establish technologies for remote dismantling, mass/ radiation assessment, radioactive waste disposal, and project control system development. JAPC strives to accumulate expertise and knowledge to contribute to future decommissioning operations.

Corporate Profile

Business Outline

(As of March 31, 2008)

Established: November 1, 1957
Authorized capital: ¥120,000 million
Paid-in capital: ¥120,000 million
Power plants: 3 plants (installed capacity: 2,617,000kW)
Total revenue: ¥180,088million (FY2007)
Total assets: ¥648,729 million
Number of employees: 1,351

Corporate Objects

1. In order to develop and make nuclear power generation commercially feasible, our objects are to conduct the following businesses:
   1) The construction and operation of nuclear power plants and the supply of electricity generated thereby; and
   2) Other businesses connected and relevant to the above.

2. We may contract to provide services as regards the research, design, project management, construction, plant operation and other relevant technical aid, etc, concerning nuclear power plants.

Directors & Auditors

(As of June 30, 2008)

President
Yukinori Ichida

Executive Vice Presidents
Hideaki Suzuki — Kinju Atarashi
Susumu Kawashima

Managing Directors
Takashi Yori — Takashi Nitta
Shoji Matsumoto — Fumiyuki Kashima
Hiroyuki Iokibe

Directors
Shinji Kato — Akira Takatsuji
Hiroshi Masuda — Tadamichi Sato
Taiki Ichimura — Yoshitaka Tatsumi

Directors (part-time)
Fumio Kawaguchi — Fujio Shinki
Shigemi Tamura — Yoshihiko Nakagaki
Shosuke Mori — Toshiaki Yashima

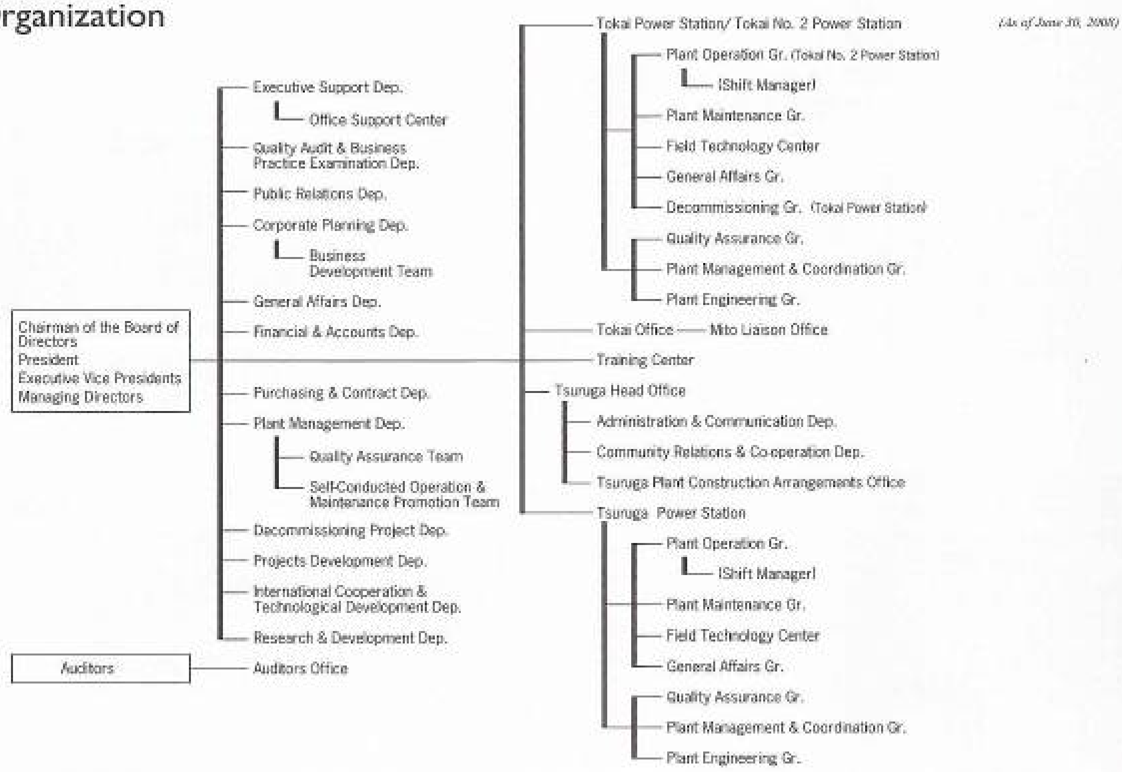
Senior Auditor
Masao Aoyagi

Auditor
Kiyondo Nagai

Outside Statutory Auditors
Yoji Obashi — Hiroshi Saito

Organization

(As of June 30, 2008)



Business Review

Business Results & Assets

	2004	2005	2006 (FY)	2007 (FY)
Operating revenue (Electric operating revenues) (Millions of yen)	173,509	149,581	155,655	178,418
Ordinary profit (Millions of yen)	1,475	1,408	2,841	3,512
Net income (Millions of yen)	1,001	553	1,961	2,117
Net income per share (Yen)	83.49	46.10	163.49	176.45
Total assets (Millions of yen)	582,873	595,417	625,436	648,729

Stockholders

(as of March 31, 2008)

Stockholders	Shares held	Voting %
Electric power companies:		
Hokkaido Electric Power Co., Inc.	75,600	0.63
Tohoku Electric Power Co., Inc.	733,992	6.12
The Tokyo Electric Power Co., Inc.	3,387,088	28.23
Chubu Electric Power Co., Inc.	1,814,498	15.12
Hokuriku Electric Power Co., Inc.	1,565,658	13.05
The Kansai Electric Power Co., Inc.	2,225,188	18.54
The Chugoku Electric Power Co., Inc.	150,563	1.25
Shikoku Electric Power Co., Inc.	73,600	0.61
Kyushu Electric Power Co., Inc.	178,924	1.49
Subtotal (9 companies)	**10,205,111**	**85.04**
Electric Power Development Co., Ltd.	644,800	5.37
Subtotal (10 companies)	**10,849,911**	**90.42**
Others (151 companies)	**1,150,089**	**9.58**
Grand Total (161 companies)	**12,000,000**	**100.00**

The JAPC Group Companies

Nuclear Services Co.

Established: November 1, 1973
Paid-in capital: ¥171 million **President:** Hirokatsu Yamaguchi
Operation: Operation and maintenance of nuclear power stations and incidental facilities; design, execution, and control of construction expansion, improvement, maintenance, repair, removal of nuclear power stations and incidental facilities and contracting services; radiation control etc

Genden Business Services Co.

Established: September 10, 1985
Paid-in capital: ¥20 million **President:** Sadatoshi Iki
Operation: Management of community relations centers and recreation facilities; assisting in operation of nuclear power stations and incidental facilities; sales, storage, and rental of equipment related to operation and management of nuclear power stations and incidental facilities; non-life insurance agent, etc.

Genden Information System Co.

Established: July 1, 1996
Paid-in capital: ¥20 million **President:** Kazumitsu Shirakawa
Operation: Management and maintenance service for computers and networks; development and maintenance of application software; lease and sales of computers, printers, package software; document management service; nuclear power plant core management and engineering; electrical communication system construction, etc.

Related Company

Recyclable-Fuel Storage Co. (RFS)

Established: November 21 , 2005
Paid-in capital: ¥3,000 million **President:** Makoto Kubo
Operation: Storing and managing spent nuclear fuel from the power plants of Tokyo Electric Power Co., Inc. and Japan Atomic Power Company, and related operations

Related Organizations

Genden Ibaraki Foundation

Established: December 24, 1997
Chairman: Fumiyuki Kashima
Business activities: Promoting regional culture and scientific technology; supporting cultural organizations and artists; cultivating art appreciation; helping foster new cultural works

Genden Fukui Foundation

Established: December 11, 1997
Chairman: Susumu Kawashima
Business activities: Promoting regional culture; cultivating art appreciation; helping foster new cultural works; commending outstanding cultural activities

History

1957 Nov. 1 JAPC is established.
Daigoro Yasukawa is appointed President; Tamaki Ipponmatsu, Vice President.
Dec. 5 Tokai-mura, Ibaraki Prefecture is selected as prospective plant site.
1959 Mar. 16 Application is filed for permission to establish Tokai Power Station.
Dec. 14 Permission is granted to engage in electric power business and to establish Tokai Power Station.
Dec. 22 Purchase contract for Tokai Power Station reactor is signed with General Electric Co. (U.K.).
1960 Jan. 16 Construction of Tokai Power Station begins.
1962 Nov. 9 Eastern tip of Tsuruga Peninsula is selected as site of Tsuruga Power Station.
1965 Oct. 11 Application submitted for establishment of Tsuruga Power Station.
1966 Apr. 22 Permission is granted for establishment of Tsuruga Power Station reactor. Construction of Tsuruga Power Station begins.
May 14 Purchase contract for Tsuruga Power Station reactor is signed with General Electric Co. (U.S.A.).
July 25 Tokai Power Station starts commercial operation.
1970 Mar. 14 Tsuruga Power Station starts commercial operation.
1971 Dec. 21 Application submitted for establishment of Tokai No. 2 Power Station.
1972 Dec. 23 Permission is granted for establishment of Tokai No.2 Power Station reactor.
Dec. 28 Contract is signed with General Electric Co. (U.S.A.) for purchase of major equipment for Tokai No.2 Power Station.
1973 June 1 Construction of Tokai No.2 Power Station begins.
1978 Nov. 28 Tokai No.2 Power Station starts commercial operation.
1979 Mar. 28 Application submitted for establishment of Tsuruga Power Station Unit 2.
1980 Feb. 26 Basic agreement relating to construction work on fast breeder reactor "Monju" is signed with the Power Reactor and Nuclear Fuel Development Corporation.
1981 Apr. 1 Tsuruga Power Station is shut down because of No.4 feed water heater failure.
1982 Jan. 22 Commercial operation of Tsuruga Power Station is resumed.
Jan. 26 Permission is granted for establishment of Unit 2 reactor at Tsuruga Power Station.
Apr. 20 Construction starts on Tsuruga Power Station Unit 2.
1983 Feb. 17 Contract is signed with Mitsubishi Heavy Industries Ltd. and Mitsubishi Corporation for purchase of major equipment for Tsuruga Power Station Unit 2.
1986 July 16 The Federation of Electric Power Companies of Japan decides to have JAPC take charge of the construction, operation, and related R&D activities of the first demonstration FBR.
1987 Feb. 17 Tsuruga Power Station Unit 2 starts commercial operation.
1989 Mar. 30 Technical Cooperation Agreement on research and development of demonstration FBR is signed with the Power Reactor and Nuclear Fuel Development Corporation.
1992 Aug. 3 The BWR at Tokai No.2 Power Station achieved accumulated generation of 100 billion kWh, the world record for a BWR.
1995 Jan. 6 Preliminary environmental impact assessment begins for Tsuruga Power Station Units 3 and 4.
1998 Feb. 2 Tokai No. 2 Power Station and Tsuruga Power Station were the first to receive ISO 14001 certification among Japanese nuclear power plants.
Mar. 31 Tokai Power Station ceased commercial operation.
Aug. 19 Tsuruga Power Station Unit 2 generates total electric power of 100 billion kWh, first among Japanese power plants.
1999 June 28 Cooperative agreement is concluded with the Japan Nuclear Cycle Development Institute regarding the research on the practical application of the fast-breeder reactor.
2000 Feb. 22 Preliminary request for development of Tsuruga Power Sation Units 3 and 4 submitted to Fukui Prefecture and Tsuruga City.
2001 Jan. 16 "Environmental Impact Assessment Methodology" for Tsuruga Power Station Units 3 and 4 submitted.
Oct. 4 "Reactor Dismantling Application" regarding the decommissioning of Tokai Power Station submitted.
Dec. 4 Initiation of the decommission of Tokai Power Station.
Dec. 25 Submission of "Environmental Impact Appraisal Report" for the construction of Tsuruga Power Station Units 3 and 4.
2002 Feb. 22 Primary public hearing for the construction of Tsuruga Power Station Units 3 and 4.
Aug. 2 Tsuruga Power Station Units 3 and 4 Plan included in the national government's basic energy development plan.
Dec. 25 Primary approval for Tsuruga Power Station Units 3 and 4 obtained from the governor of Fukui Prefecture and Mayor of Tsuruga City.
2004 Mar. 30 An application for the Establishment License Amendment of Tsuruga Power Station Units 3 and 4 submitted.
July 2 Preliminary construction for Tsuruga Power Station Units 3 and 4 begins.
2005 Nov. 21 JAPC and TEPCO jointly establish Recyclable-Fuel Storage Company (RFS) in Mutsu-shi, Aomori Prefecture.
2006 June 30 Decommissioning plan for the Tokai Power Station approved based on the amendment to national laws on nuclear reactors.
Sep. 8 Radiation measurement and assessment methods in compliance with the clearance system approved.
2007 Mar. 22 Recyclable-Fuel Storage Company (RFS) applies for Japan's first approval of spent fuel storage operation.
May 31 Corporate principles adopted.

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