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出國報告（出國類別：其他）

第九屆加速型中子源聯盟(UCANS9)國際會議(視訊報告)

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派赴國家/地區：臺灣，中華民國
出國期間：　　111 年 3 月 28 日~111 年 3 月 31 日
報告日期：　　111 年 6 月 14 日

摘要

本報告為參加世界小型加速器型中子源(Union of Compact Accelerator for Neutron Sources, UCANS) 第 9 屆國際會議的收穫與心得。本屆會議期程為從今年 3 月 28 日到 3 月 31 日，因受 CoVid-19 新冠肺炎疫情影響，本屆 UCANS9 改為線上直播會議。本所亦投稿一篇口頭論文，Status of Cyclotron Neutron Sources Development in Taiwan，介紹本所迴旋加速器中子源的發展規畫與執行近況。參與本次 UCANS9 會議， 對於目前本所正執行的中子源設施建置與相關中子研究工作，如加速器中子靶站、中子繞射設備概念設計，不同中子波導設計，聚焦型波導，或是新型平板中子偵測器等中子科技應用的範圍，獲取到有相當價值的資訊，與提供借鏡應用於研發工作中。

整體而言，此行參加 UCANS9 國際會議掌握到國際間小型加速器型之中子應用技術研發現況，拓展中子知識新視野，有益於提昇本所中子應用技術之發展。

目 錄

一、 目的

對於中子技術的研發及應用，自 1960 年代起蓬勃發展，早期中子源主要是以研究型核子反應器(Research Nuclear Reactors) 提供中子與配合執行，並在這期間各國亦興建了許多個研究型核子反應器，帶領中子技術跨入各科學領域，成為一重要科技研究設施。臺灣在此期間亦在國立清華大學建置一中子研究反應器(Tsing Hua Open-pool Reactor THOR) 於 1961 年啓用。但後來因其長壽高放核廢料處置及防止核擴散議題，研究型核子反應器的發展受阻，接替的是大型加速器散裂中子源(Spallation Neutron Source, SNS)的興起，如美國 SNS，日本 J-PARC，英國 ISIS、瑞士 SINQ 等大設施。但最近十年來，這些早期興建運轉的研究型核子反應器逐漸遇上除役年限已近之問題，為補上這類中子設施除役之空窗期與又不花大錢蓋散裂中子源，故近期皆在提倡以中小型加速器中子源取而代之。目前國際上使用加速型中子源的研究機構分布圖如下圖 1 所示，累計約有 18 個，美國有三個，歐洲有三個，亞洲為 11 個，圖中紅色表已在運轉中，藍色為設計建造中。目前該類設施均以長脈衝頻率或中階中子通量的中子源為主。加速型中子源是一種較為經濟且已有應用實績的中子源產生技術，由於加速型中子源的建造成本遠比研究型反應器低的很多，約莫是千分之一的造價，且未來長壽高放核廢料處置更新拆除的成本更是遠遠低於研究型反應器。

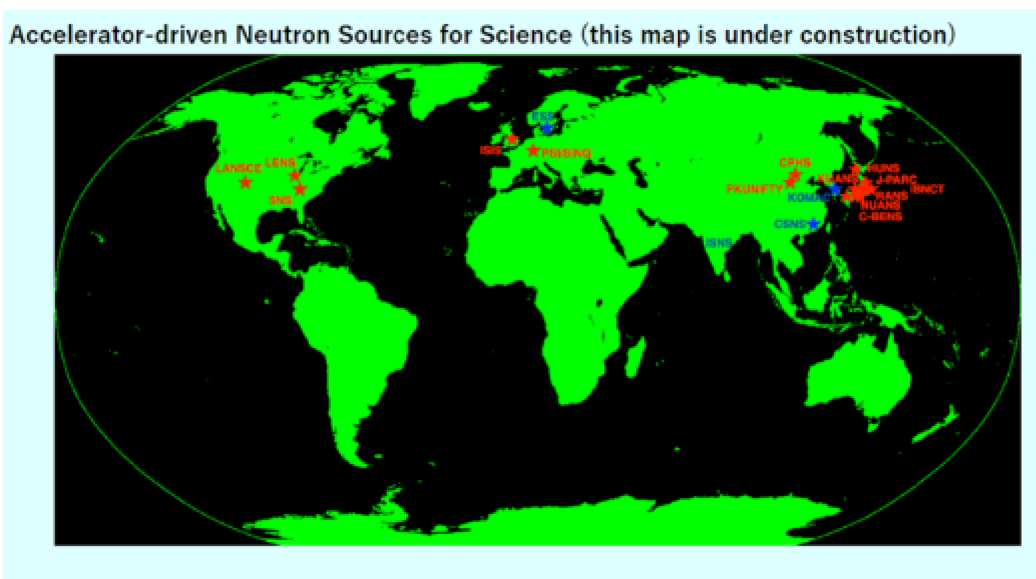


圖 1 國際上加速型中子源實驗機構分布圖(資料來自 IAEA 網站)

核能研究所早期有一實驗型研究用反應器(Test Research Reactor, 簡稱 TRR) 於民國 77 年(1988)除役，原規畫接替的 TRR II 的計畫，執行數年後因種種因素，該計畫於民國 91 年(2002)退場。國科會(科技部前身)於民國 94 年(2005)一起與澳洲核能研究機構(ANSTO)簽訂中子束應用合作協議興建一中子分析實驗站，由國立中央大學物理系李文獻教授主導建置一三軸冷中子非彈性散射分析儀 (Spin-polarized Inelastic K-space Analyzer, 簡稱 SIKA)於民國 104 年(2015)完成，目前已開放國內外學術單位使用，本項中子設施目前由科技部委由國家同步輻射中心的中子小組負責營運、操作及維護等工作。現今國內有關中子技術的學術研究需求，目前主要是依賴國立清華大學的 THOR 研究型反應器或澳洲 ANSTO 的中子設施，因此台灣能夠運用之中子科學研究還是有所限制。

由於加速型中子源技術成長有利於建置中小型中子研究應用實驗平臺，本所亦提出利用現有之 30MeV 迴旋加速器建置中子源，於原子能二期計畫中執行[中子源開發與應用]研究計畫。另因新冠肺炎疫情影響造成國內核醫藥物供應不穩，本所建置一 70MeV 迴旋加速器以供應核醫藥物與應用於中子，質子與核醫藥物開發等研究工作的構想已獲上級單位的支持同意執行，將於民國 112-115 年間執行此建置計畫，本所於民國 110 年先執行科技部科發基金 [國家質子與中子應用實驗室:70MeV 迴旋加速器建置概念設計] 計畫。待 70MeV 迴旋加速器建置計畫完成且取得營運許可後，中子應用實驗室將可對國內學術界與業界在相關材料分析應用開發上提供助益。

加速型中子源是一種較為經濟且已有應用實績的中子源產生技術，由於小型加速型中子源的建造成本遠比研究型反應器低的很多，約莫是千分之一的造價，且較無高放核廢料處置問題，更新拆除的成本更是遠遠低於研究型反應器，被列為建置新中子源之注目選項之一。國際小型加速型中子源聯盟(Union of Compact Accelerator for Neutron Sources, UCANS)成立於西元 2010 年，其宗旨為提供一國際合作交流平台，規劃每間隔 1 至 2 年便舉行一次國際研討會，促使國際上以中小型加速器研究機構進行中子研發的學者及專家，有一會議場合及期間可進行技術與經驗交流，今年是第 9 屆，主辦單位為日本理化研究所(RIKEN)，因新冠肺炎疫情影響原訂於日本舉行的會議改為線上會議。本次參與第九屆國際加速型中子源聯盟(UCANS9)國際線上會議，本所亦投稿一篇口頭論文，Status of Cyclotron Neutron Sources Development in Taiwan，介紹本所迴旋加速器中子源的發展規畫與執行近況。而報名參與此線上會議的本所同仁總計有 5 名，分別是燃材組雍敦元、 董

曉明、 鄭勝隆等與物理組李灝銘及陳孝輝等，該 5 位皆為參與中子應用實驗室建置計畫之成員，藉由參與此 UCANS9 國際線上會議，有助本所掌握到國際間小型加速器型之中子技術研發現況與應用技術之最新發展，拓展中子知識新視野，且有益於提昇同仁現正執行本所的中子設施建置計畫之效能。

二、 過程

UCANS9 國際研討會主辦單位為日本理化研究所(RIKEN) ，但因受 CoVid-19 疫情影響，本屆改為線上直播會議，本屆會議期程為從今年 3 月 28 日到 3 月 31 日計 4 天，同時考量到與會者來自全球各地，會議折衷定在日本時間下午 5 時到 12 時 (臺灣時間下午 4 時到 11 時)，對應到標準中央時區為下午 8 時到下午 2 時。本次 UCANS9 會議之主要議程 (program)如下表 1 說明，更詳細的大會演講及海報則補充在附錄一。本所亦投稿一篇口頭論文(oral presentation)，Status of Cyclotron Neutron Sources Development in Taiwan，介紹本所迴旋加速器中子源的發展規畫與執行近況，口報告安排時段在 3 月 30 日下午 8 時 05 分 O8 場次，由物理組陳孝輝博士代表報告，相關論文摘要及簡報在附錄二。

表 1：UCANS9 會議之議程

JST (Japan)	UCT	28 March	29 March	30 March	31 March
17:00	8:00	Opening session **Keynote lecture 1**	Session D: CANS Application (I-5, O14-18)	Session F: Target development 2 (I-8, O23-28)	Session H: Accelerator developments (O34-37)
18:00	9:00	Session A: CANS projects and facility development 1 (I-1,2 O1-4)	**Keynote lecture 2** Session E: Instrumentation and measurement 2 (I-6,7, O19-22)	**Keynote lecture 3** Session G: CANS projects and facility development 2 (I-9,10, O29-33)	Session I: Moderator development and Monte carlo method (I-11,12, O38-43) -20:25
20:00	11:00	Session B: Target Development 1 (I-3, O5-7)			Closing
21:00	12:00	Session C: Instrumentation and measurement 1 (I4, O8-13)	Poster session 1: CANS facility developments, Moderator developments, Target developments (P1-15) -22:50	Poster session 2: CANS applications, Accelerator developments, Instrumentation developments (P16-30)	
22:00	13:00				
23:00	14:00	-23:10	Int. Committee meeting	-23:20	
24:00					

三、　心得

本會議心得報告針對參與本所中子研究計畫規劃執行的中子分析應用技術為主，在內容方向上以中子分析技術為主，包含中子繞射技術與分析應用，中子影像分析技術以及相關中子應用技術等。另本次會議亦有多篇論文摘針對國際間已發展及規劃中的加速器中子源發表其最新進展，因收獲的資訊量較多，本心得報告作者之一李灝銘博士等人以[第九屆世界小型加速器型中子源國際會議之中子靶站彙整] 為題，完成另一篇專題技術報告撰寫。

(一) 中子繞射分析技術與中子影像技術

一、北京清華大學物理系報告: 低略角度聚焦小角度中子散射近期發展

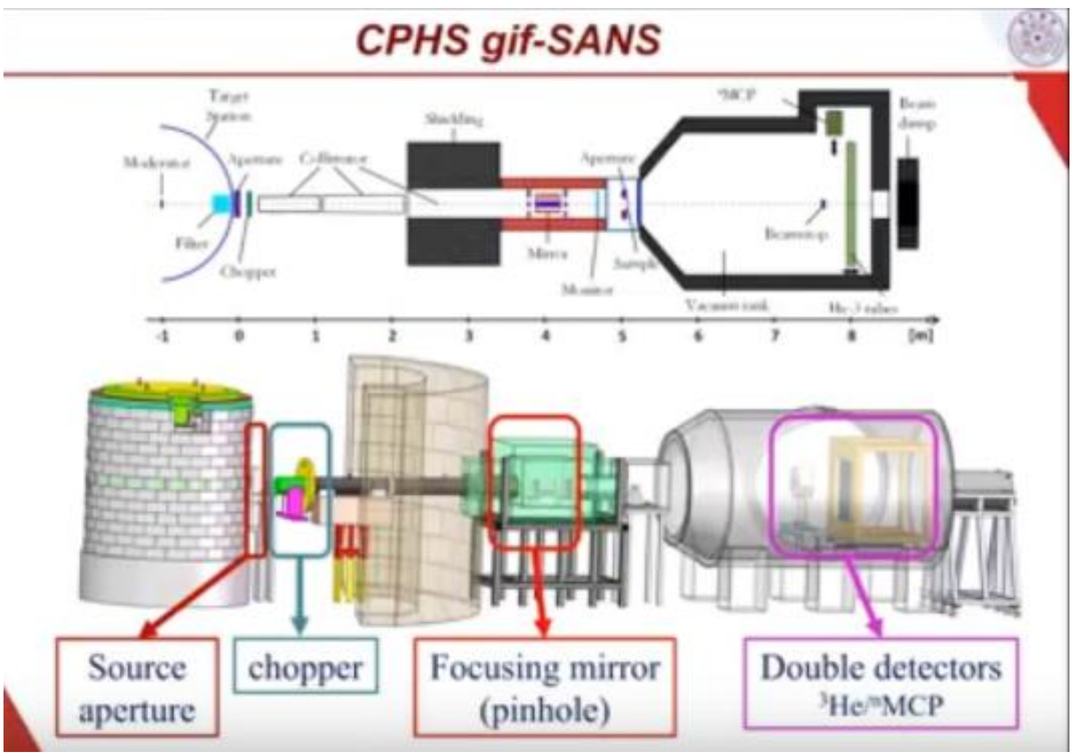


圖 2 低掠角聚焦小角度中子散射儀距離位置圖與外觀示意圖

本報告示以傳統小角度中子散射(Small Angle Neutron Scattering, SANS)儀為基礎，中子先行經路徑前段之波長或能量選擇器，再進入北京清華大學設計開發的聚焦裝置(Focusing Mirror)可縮小傳統小角度中子散射儀的距離，一般所需 10 ~ 15 米的距離以調整光束入射角度，本報告可減少至 10 米以內，且經由聚焦的中子數可具有可調分析能力。依據不同分析 Q 值，選擇分析套件設備。

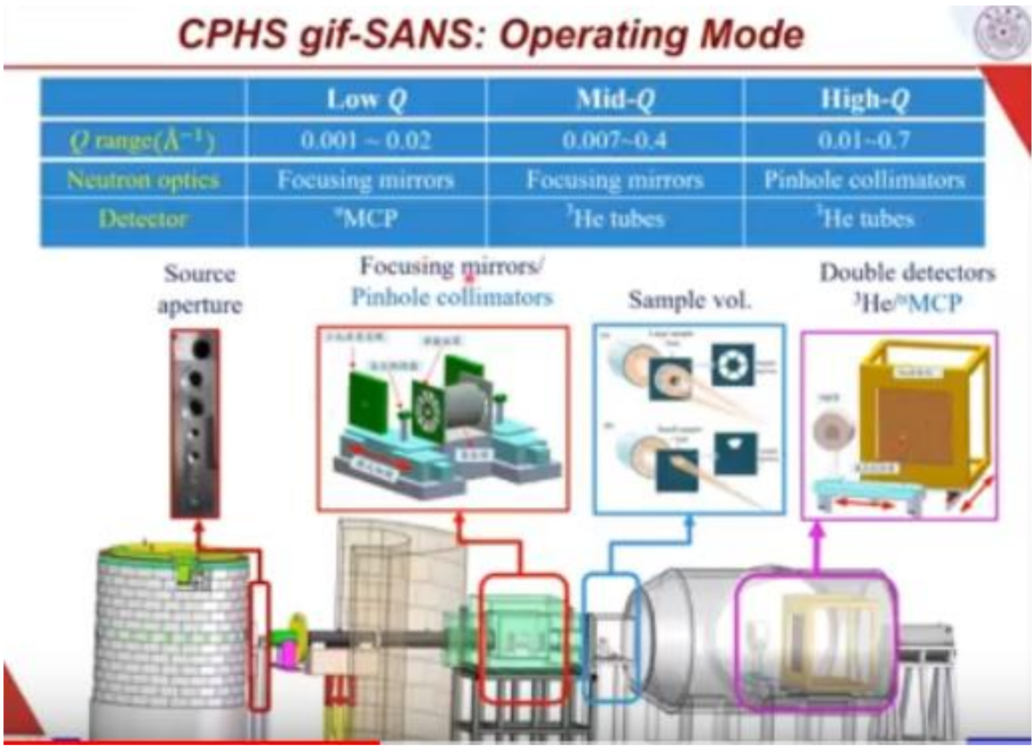


圖 3、低掠角聚焦小角度中子散射儀操作模式

清華大學研究團體提出一稱為 gif-SANS 的操作模式，可在中子源端進行光束通量控制，可以調整不同大小尺寸的光圈，再到聚焦超級玻璃鏡片組或是針孔準值器進行低中高Q值分析應用，另須結合不同中子偵測器，例如低 Q 值分析選用 MCP 偵測器，中高 Q 值分析選用 ^{3}He 雙偵測器系統。

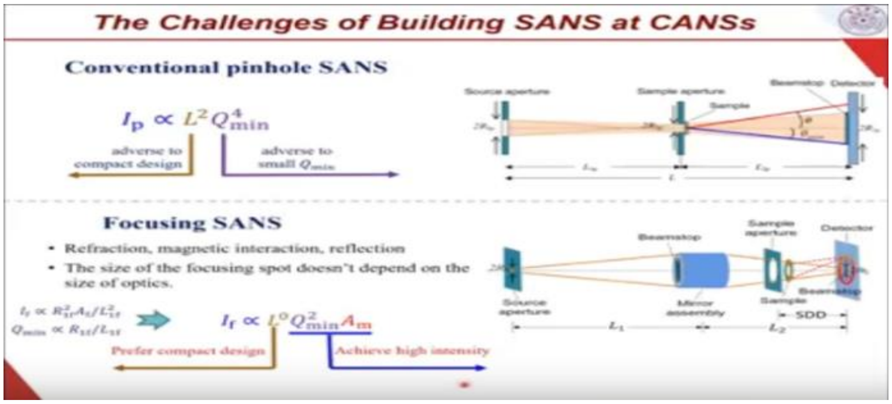
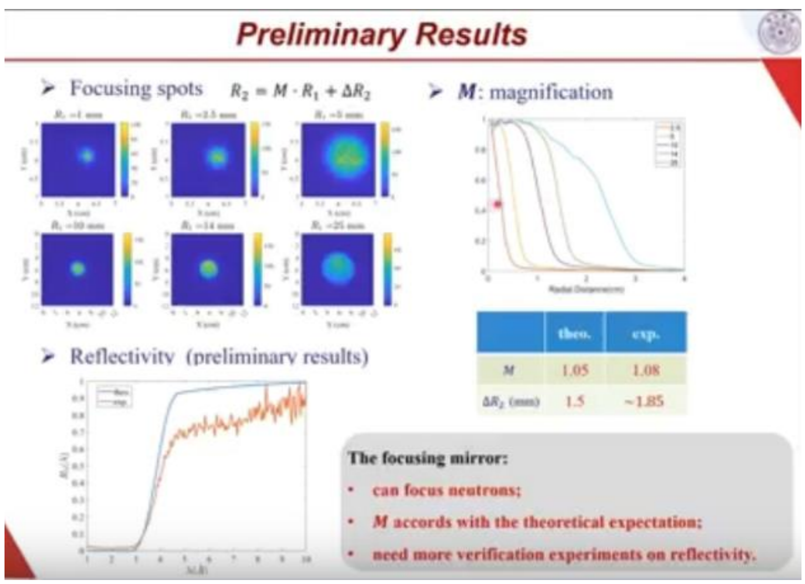


圖 4 傳統針孔準值小角中子散射系統與聚焦小角中子散射系統比較

傳統設計的小角度散射系統訊號強度與距離平方成反比，而聚焦型小角中子散射與距離成正比且具有較高訊號強度。目前已完成聚焦裝置製造工程與展示初步實測數據。



	theo.	exp.
M	1.05	1.08
ΔR_2 (mm)	1.5	~1.85

圖 5 聚焦裝置初步於中子束實測數據

目前結果與理論設計結果一致，可順利聚焦中子束。後續需要有更多的反射率驗證實驗。報告最後提出預計在西元 2025 年完成此小角度中子散射研究裝置建置。

二、法國 TORINO 大學報告: 中子光束準直器(collimator)設計與測試

中子準直器是中子光束進行分析工作時重要的調控因素之一，若中子光束準直性不佳是無法取得高品質的分析訊號。故在中子光學研究中，針對光束的準直性是決定品質的關鍵因素，也是相當光路中昂貴的部件之一。本研究是希望藉由新的設計以達到較小尺寸與較低成本的準直器，見圖 6。目前經過一定的調校，可得清楚的中子照射照片，可清楚辨識 5x5 網格的樣品。亦有分別進行加裝準直器與未加裝準直器的影像解析度比較，見圖 7，加裝後的影像解析度最小可達 42.5 微米，未加裝準值器之影像解析度約莫 100 多微米。未來將發展第三代準直系統，期望能達成 L/D 比值為 240 準直器，預計可應用於中子電腦斷層(neutrion tomography)影像分析，見圖 8。

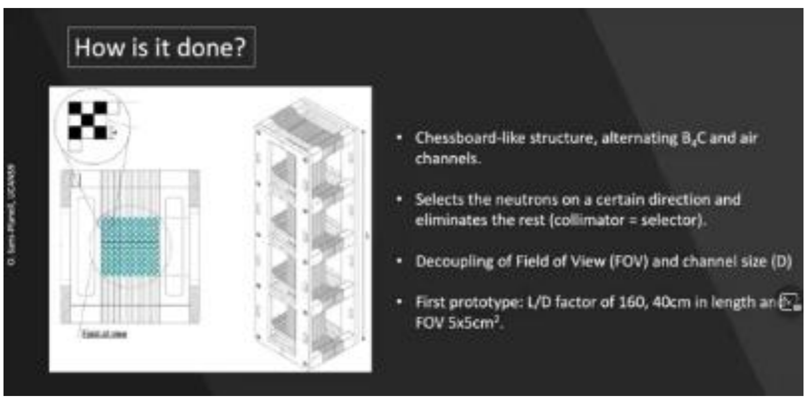


圖 6 Torino 大學設計特殊 L/D 比值準直器設計圖（左）與實際成品（右）

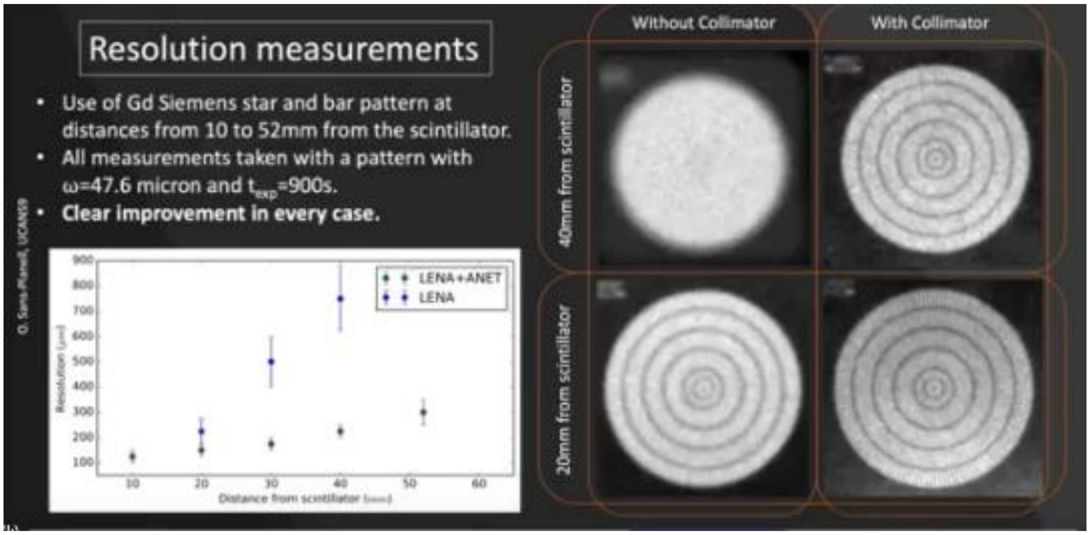


圖 7 加裝準直器與未加裝準直器的影像解析度比較

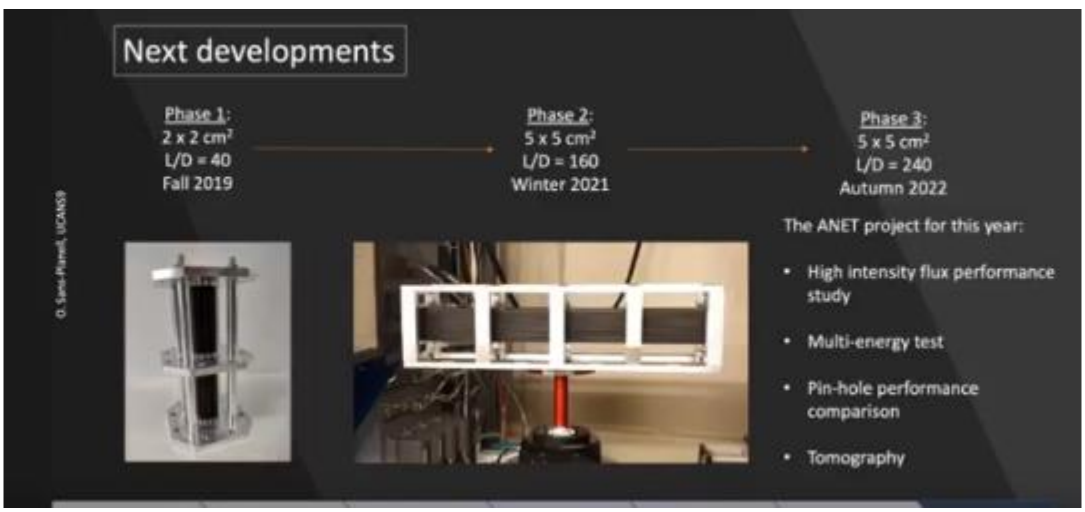


圖 8 Torino 大學準直器發展路徑圖

三、德國 Julich 研究所報告:可調中子光導設計應用於高中子通量加速型中子源於小樣品分析

德國 Julich 研究所針對未來將建置高亮度中子研究設備進行中子光導設計規劃，希望實現可調中子光導，以進行小樣品的分析。以繞射分析技術而言，X 光樣品只需要數微米即可進行繞射分析工作，但是中子應穿透性佳需要公分級以上的樣品，越大樣品意即製作成本越高。鑑於此，Julich 研究所設計新型中子波導名為 Selene，期望能達成縮小分析樣品的目的。

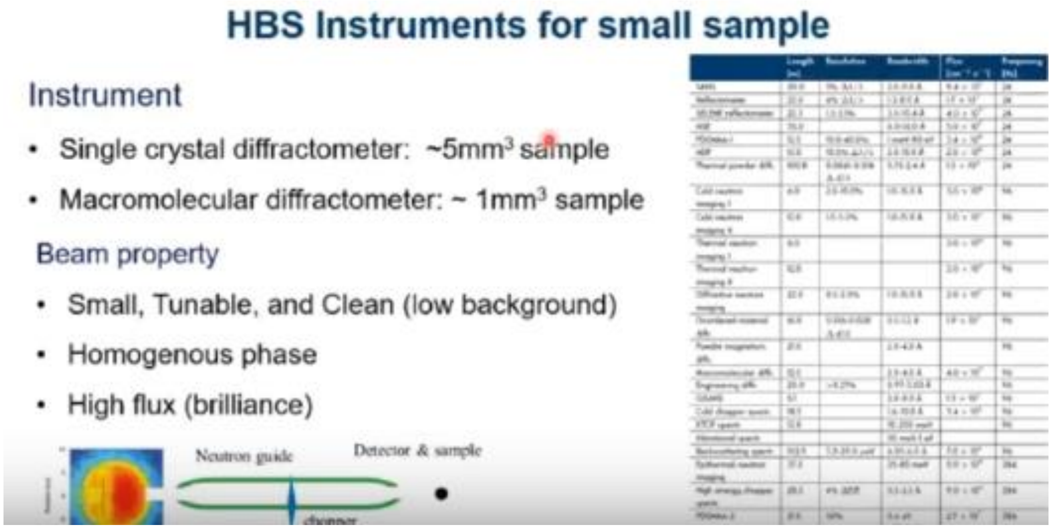
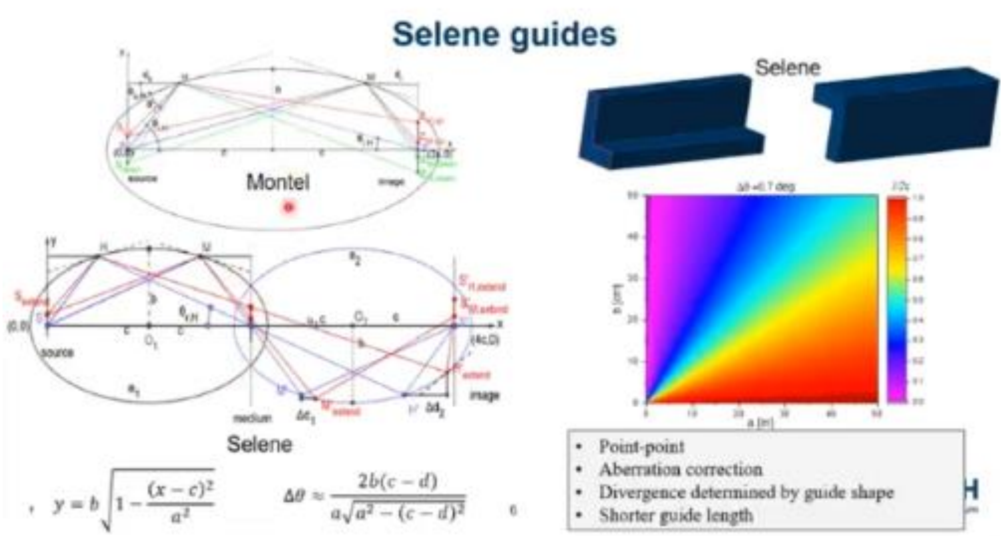


圖 10 Julich HBS 實驗站分析樣品目標

目標可針對約為 5 立方釐米的單晶樣品進行中子繞射分析工作，多晶樣品則目標為 1 立方釐米。期望藉由可調控低背景 Selene 中子波導與高通量單一波長中子束達成。



$$y = b\sqrt{1 - \frac{(x-c)^2}{a^2}} \qquad \Delta\theta \approx \frac{2b(c-d)}{a\sqrt{a^2-(c-d)^2}}$$

圖 11 Selene 中子波導設計與模擬分析

比較未使用 Selene 中子波導的繞射儀，其總長度可達 20 公尺，而使用 Selene 中子波導則可縮短至 4 米，且中子通量可達到 ~10^7 n/s 單位之值。

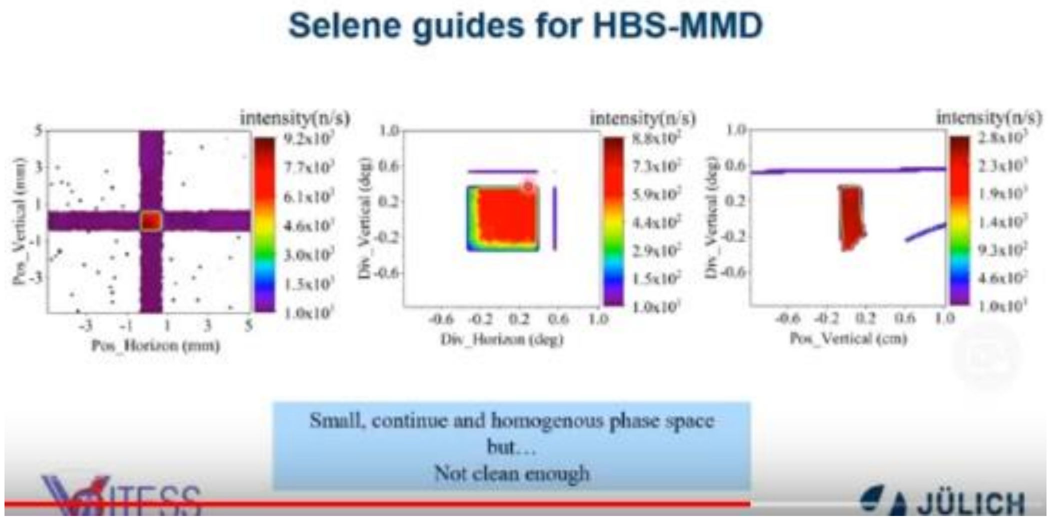


圖 12 Selene 中子波導模擬分析結果

四、日本 AIST 報告: 中子平板偵測器 IGZO-TFT 於加速型中子源影像分析

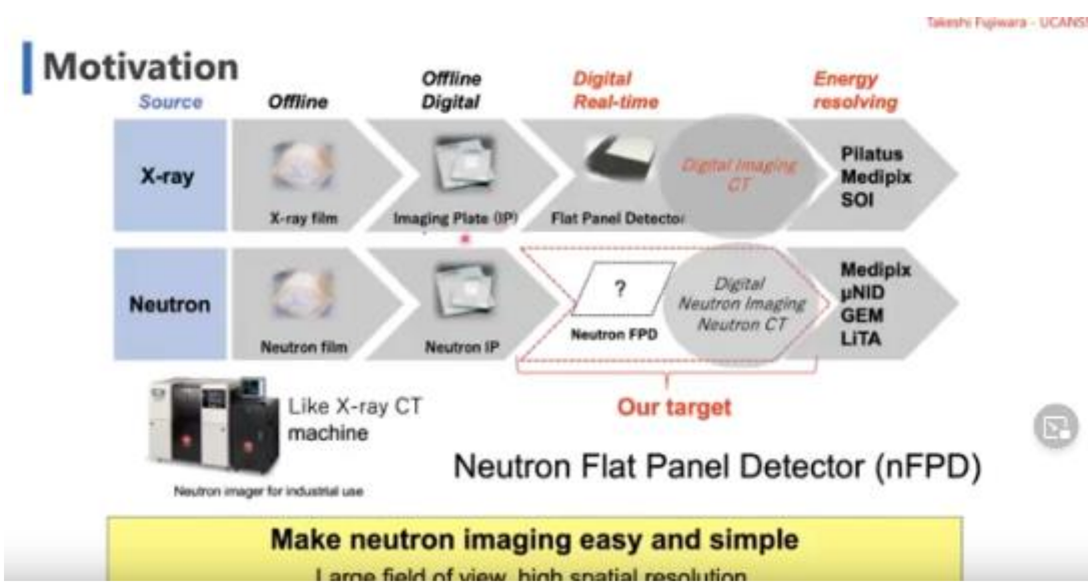


圖 13 中子影像分析與 X 光影像分析比較

本報告針對缺少中子電腦斷層掃描技術的平板式中子偵測器，運用與 X 光影像分析相似的方式進行中子影像分析開發設計。利用 IGZO 半導體材料（含有銦鎵鋅氧化物）為偵測訊號，其為高阻值電晶體可達 180 秒的訊號收集時間。如同一容器具有較小的漏洞，可儲存水的時間較長。Igzo 的 band gap 為 3.2eV，矽為 1.1eV。

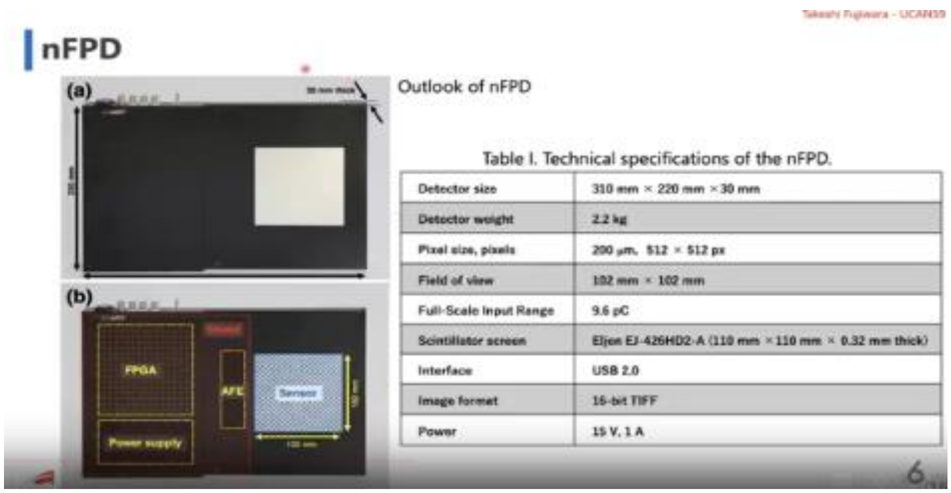


Table I. Technical specifications of the nFPD.

Detector size	310 mm × 220 mm × 30 mm
Detector weight	2.2 kg
Pixel size, pixels	200 μm, 512 × 512 px
Field of view	102 mm × 102 mm
Full-Scale Input Range	9.6 pC
Scintillator screen	Eljen EJ-426HD2-A (110 mm × 110 mm × 0.32 mm thick)
Interface	USB 2.0
Image format	16-bit TIFF
Power	15 V, 1 A

圖 13 中子平板式偵測器設計規格

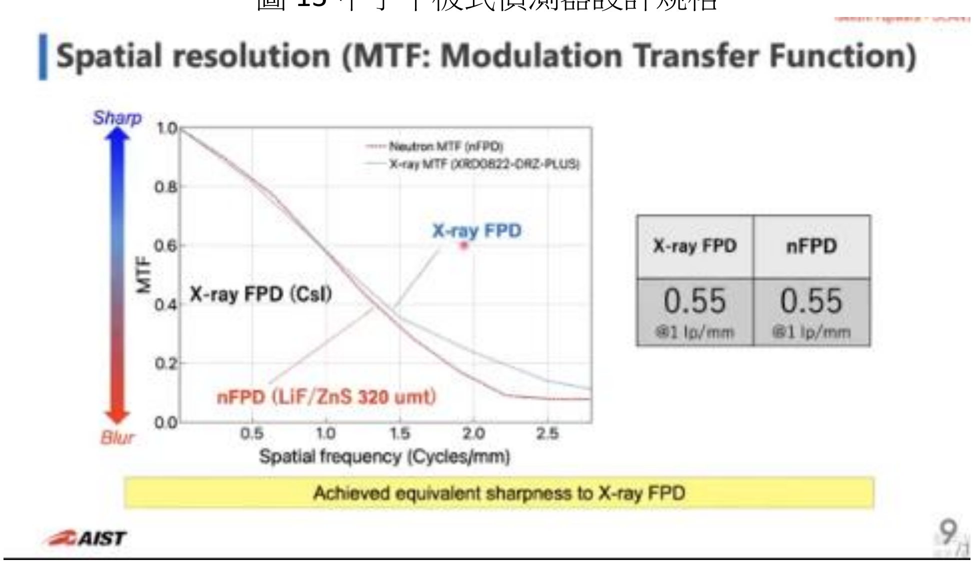


圖 14 中子平板式偵測器設與 X 光平板式偵測器空間解析度比較

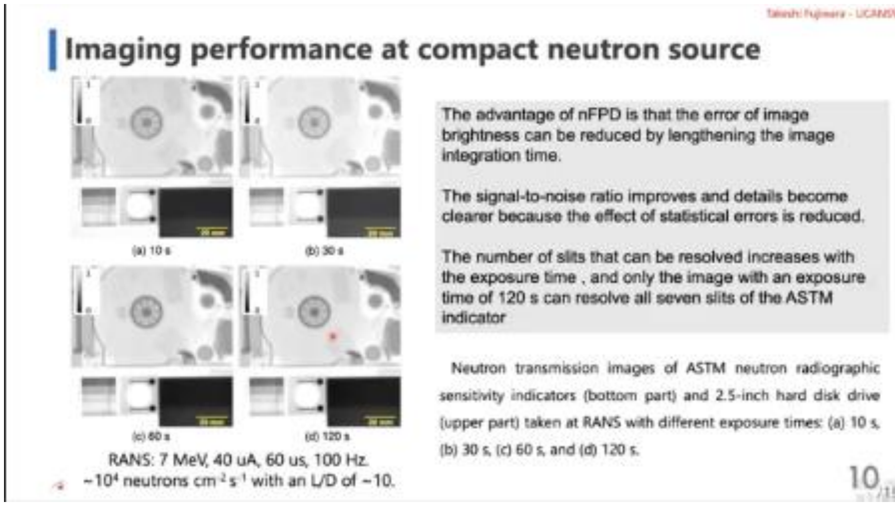


圖 15 電腦硬碟中子影像分析結果

AIST 成功開發具有好操作，高解析與高 FOV 值，能更快速進行電腦斷層分析潛力的中子影像偵測器。

(二) 中子其他應用技術

一、中國西安交通大學報告：以磁控濺鍍法在鋰靶材上鍍鈦塗層

這篇 Depositing a Titanium Coating on the Lithium Neutron Production Target by Magnetron Sputtering Technology 論文是由中國西安交通大學能源與動力工程學院核科學與技術系的人員進行簡報。此論文是以在鋰靶材上鍍著一層薄的鈦(Ti)塗層。這樣的鋰靶可以避免化合物的形成和鋰的蒸發(圖 16)。這種塗層要盡可能地不減少中子的產生率。該論文使用物理氣相沉積中的磁控濺鍍作為薄膜製程的方法，因該方法具有速度快、附著力好、膜厚容易控制、成膜性能好的優點。此外，它的低沉積溫度確保鋰將在塗層過程中不會熔化。在鋰樣品上，分別沉積了相同厚度的鋁、鉻和鈦塗層，因為它們具有良好的熱穩定性和優異的耐蝕性(圖 17)。塗層厚度為 200 奈米。此論文觀察包覆和裸露鋰樣品在空氣中的顏色變化過程，並進行比較，定性推斷鋰的化學狀態。實驗結果發現，通過磁控濺射技術在鋰靶材上沉積塗層是可行的。這種塗層可有效防止鋰劣化與空氣反應形成化合物。圖 18 顯示，有鈦塗層的鋰靶，可以經過九個小時的質子撞擊，而沒有顯著的劣化；相較於

沒有塗層的鋰靶，很快就形成氫氧化鋰(LiOH)。鉻作為塗層，其研究結果類似於鈦塗層；對於鋁，本研究中沒有發現鋁的繞射峰，需要進一步的研究(圖 19)。本論文的結論是，薄的塗層鋰靶比裸的鋰靶更便於儲存和運輸，可直接在空中的加速器束線上安裝和更換，無需在真空或超低溫環境與低濕度環境中進行(圖 20)。

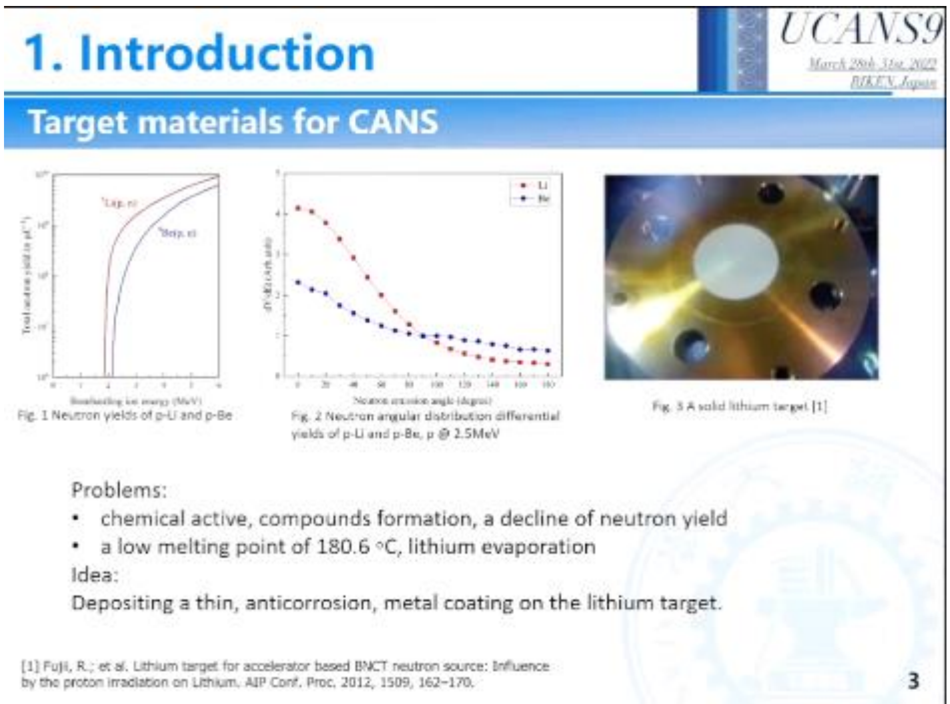
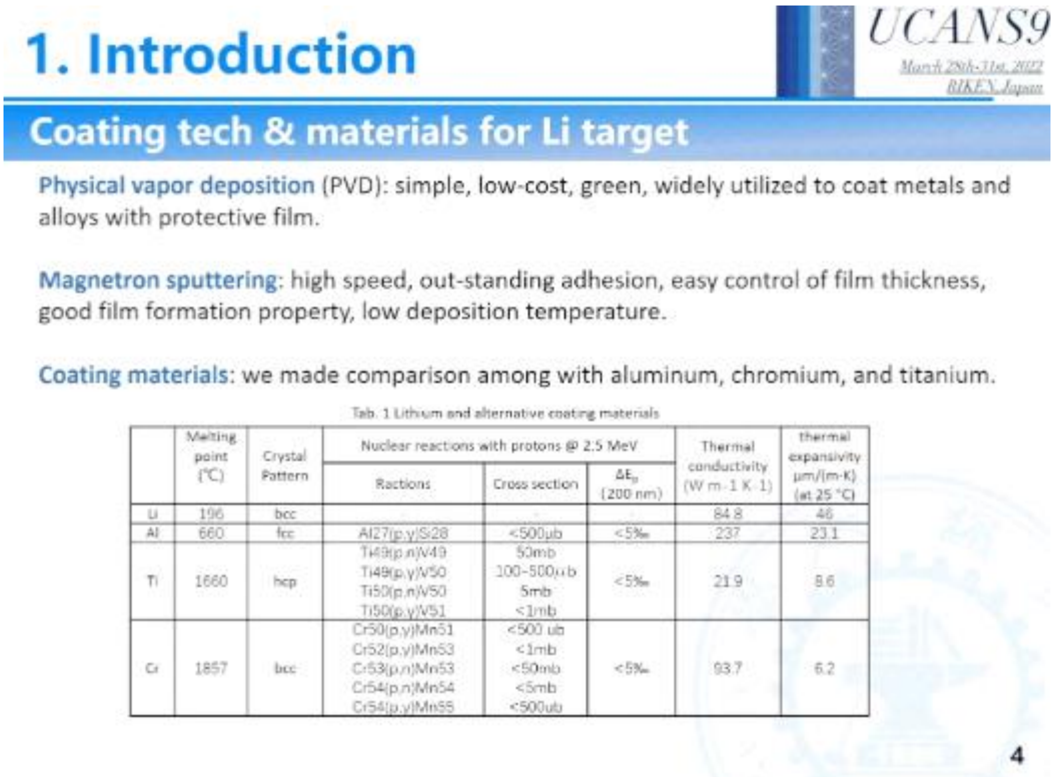


圖16 鋰靶作為中子源會出現的問題以及可能解決的方案



1. Introduction

UCANS9
March 28th-31st, 2022
RIKEN, Japan

Coating tech & materials for Li target

Physical vapor deposition (PVD): simple, low-cost, green, widely utilized to coat metals and alloys with protective film.

Magnetron sputtering: high speed, out-standing adhesion, easy control of film thickness, good film formation property, low deposition temperature.

Coating materials: we made comparison among with aluminum, chromium, and titanium.

Tab. 1 Lithium and alternative coating materials

	Melting point (℃)	Crystal Pattern	Nuclear reactions with protons @ 2.5 MeV			Thermal conductivity (W m-1 K-1)	thermal expansivity µm/(m·K) (at 25 °C)
			Ractions	Cross section	ΔE_p (200 nm)		
Li	196	bcc	-	-	-	84.8	46
Al	660	fcc	Al27(p,γ)Si28	<500µb	<5‰	237	23.1
Ti	1660	hcp	Ti49(p,n)V49 Ti49(p,γ)V50 Ti50(p,n)V50 Ti50(p,γ)V51	50mb 100~500µb 5mb <1mb	<5‰	21.9	8.6
Cr	1857	bcc	Cr50(p,γ)Mn51 Cr52(p,γ)Mn53 Cr53(p,n)Mn53 Cr54(p,n)Mn54 Cr54(p,γ)Mn55	<500 ub <1mb <50mb <5mb <500ub	<5‰	93.7	6.2

4

圖17 不同薄膜材料性質比較表，薄膜材料使用三種:鉻、鈦與鋁

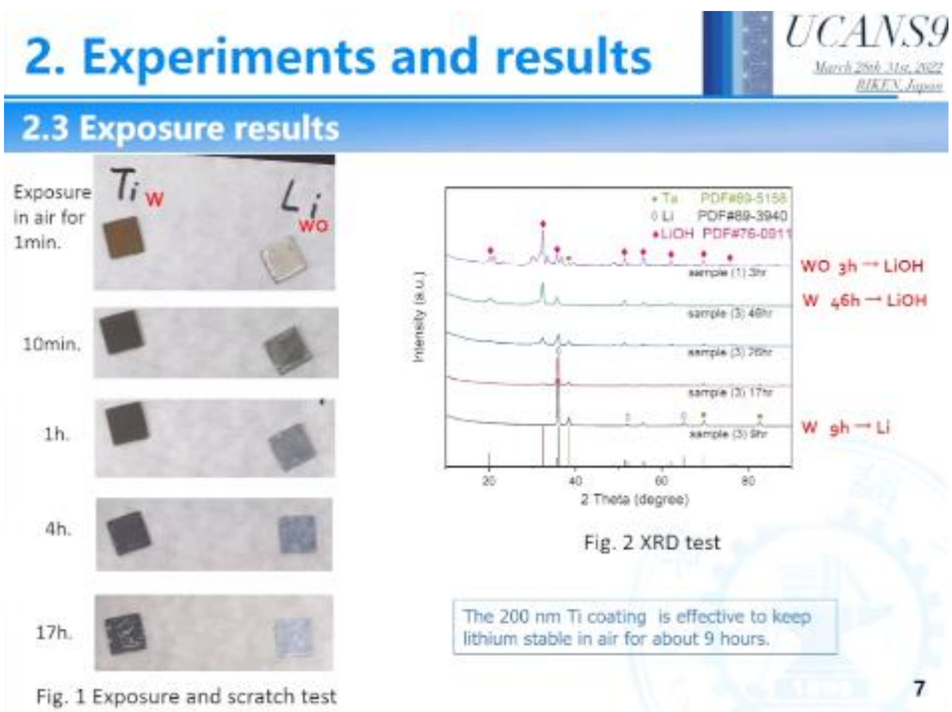


圖18 質子打在鈦塗層上面後的表面形貌與繞射分析結果

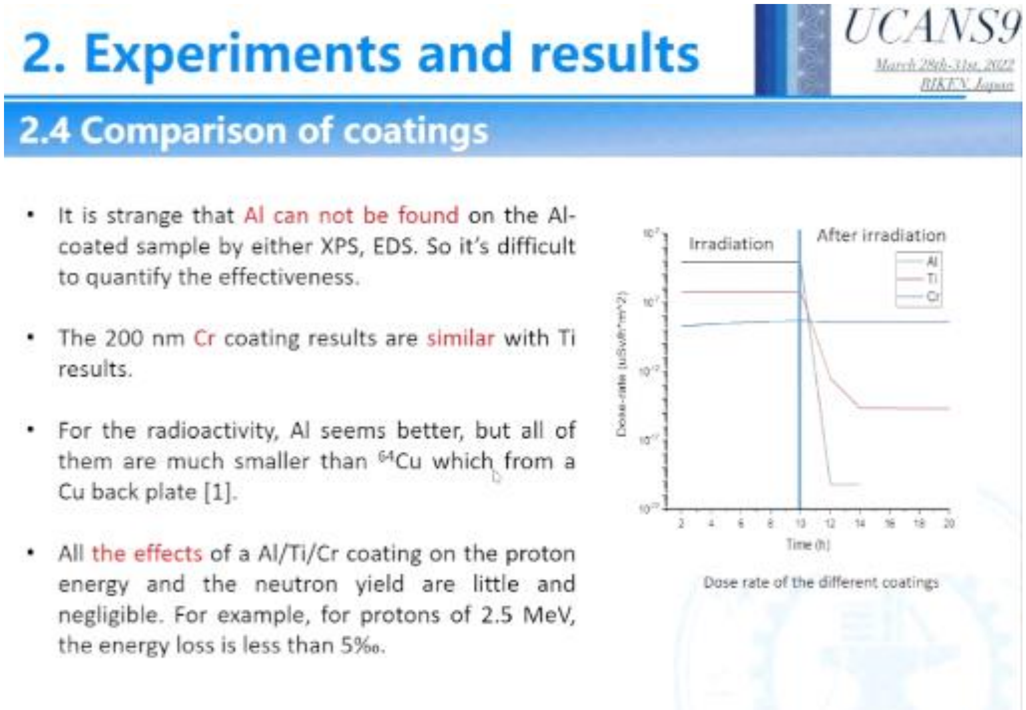


圖19 針對不同塗層的結果與討論

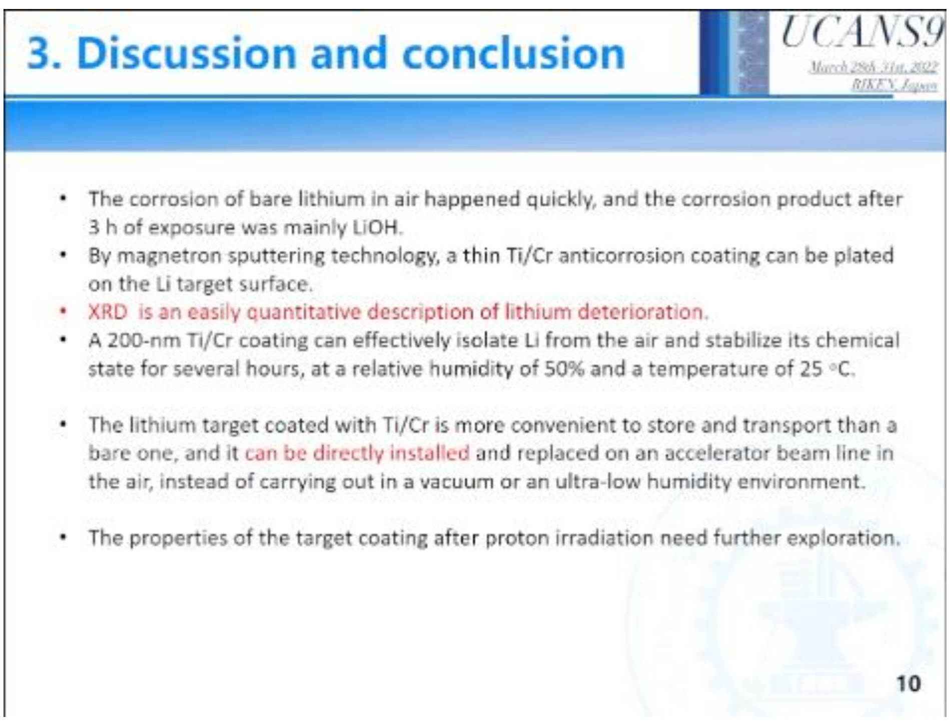


圖20 本篇論文的討論與結論

二、日本RIKEN理化研究所報告: 研發RANS-μ鹽度計進行水泥結構體的非破壞性現場檢測方法

這篇 Development of neutron salt-meter RANS-μ for non-destructive inspection of concrete structure at on-site use 演講是由日本 RIKEN 理化研究所的研究人員進行。最近，人們需要無需預處理的非破壞性方法來檢測大體積的結構物件，例如混凝土結構和工業廢物。尤其，由於世界上有橋樑結構因氯化物侵蝕而發生坍塌和許多嚴重破壞，因此需要對混凝土結構中氯離子濃度進行現場非破壞測量，圖 21 為從表面到鋼筋的深度剖面的混凝土結構。傳統的方法有許多可以獲取相關資訊，但有其限制，如圖 22。於是該單位便開始研發可攜式中子鹽分計，他們稱之為 RANS-μ 鹽度計(圖 23) 。該鹽度計結合 ^{252}Cf 中子源與和快速伽馬中子活化分析(prompt gamma neutron activation analysis, PGNAA)。實際案例：因氯化物侵蝕而損壞的拆除橋樑，進行鹽份收集，進行結果比較。他們的結果顯示，利用 RANS-μ 鹽度計測量斷裂橋面上的鹽份，是與傳統方式(如：鑽粉分析)的數值是相吻合的。目前的成果與未來的發展如圖 24 所顯示。

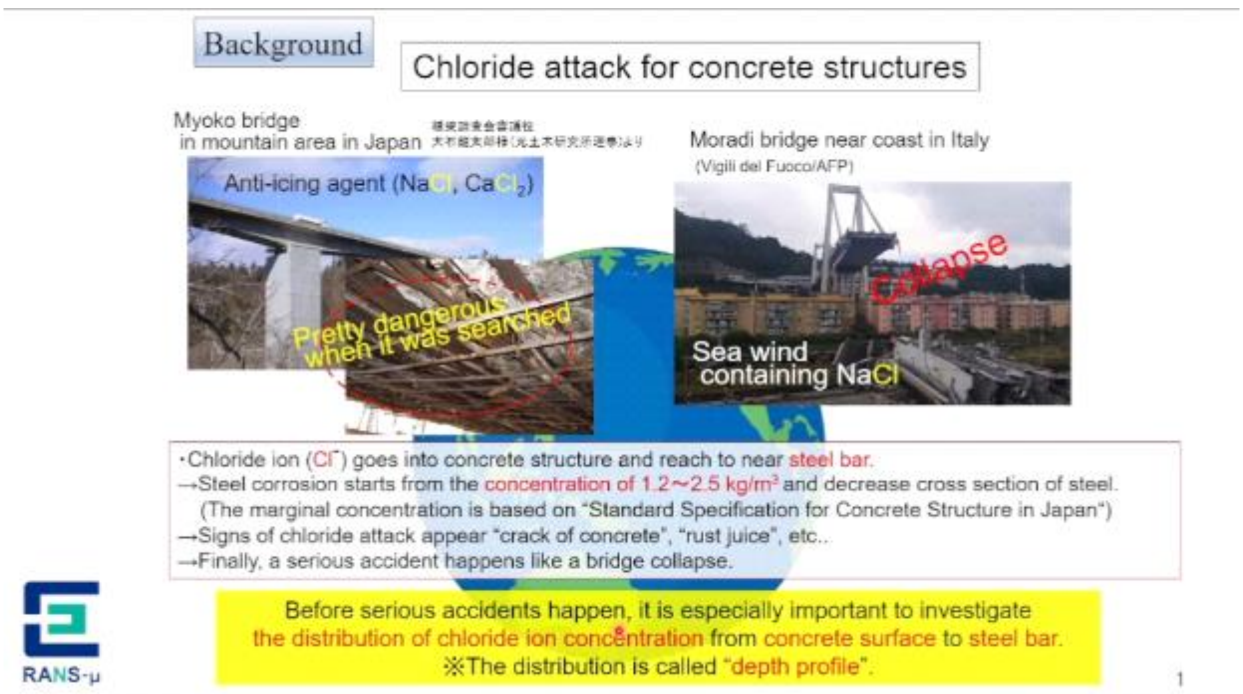


圖21 大型結構件受到外面氯鹽的影響而產生潛在的破壞

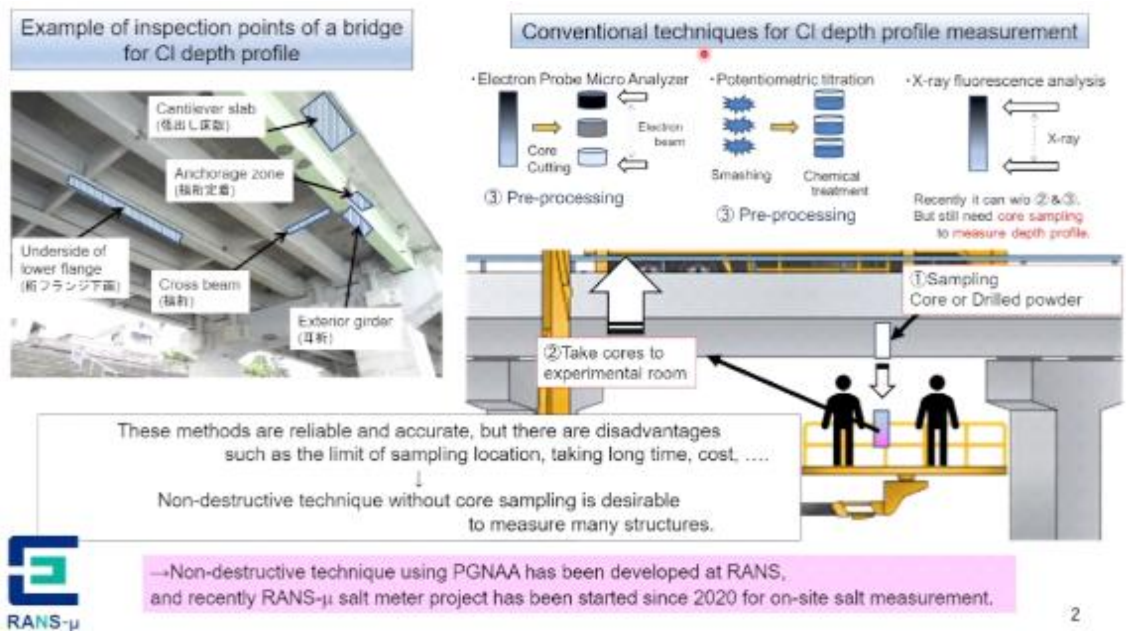


圖22 說明過去樣品取樣的方式，以及其優缺點。

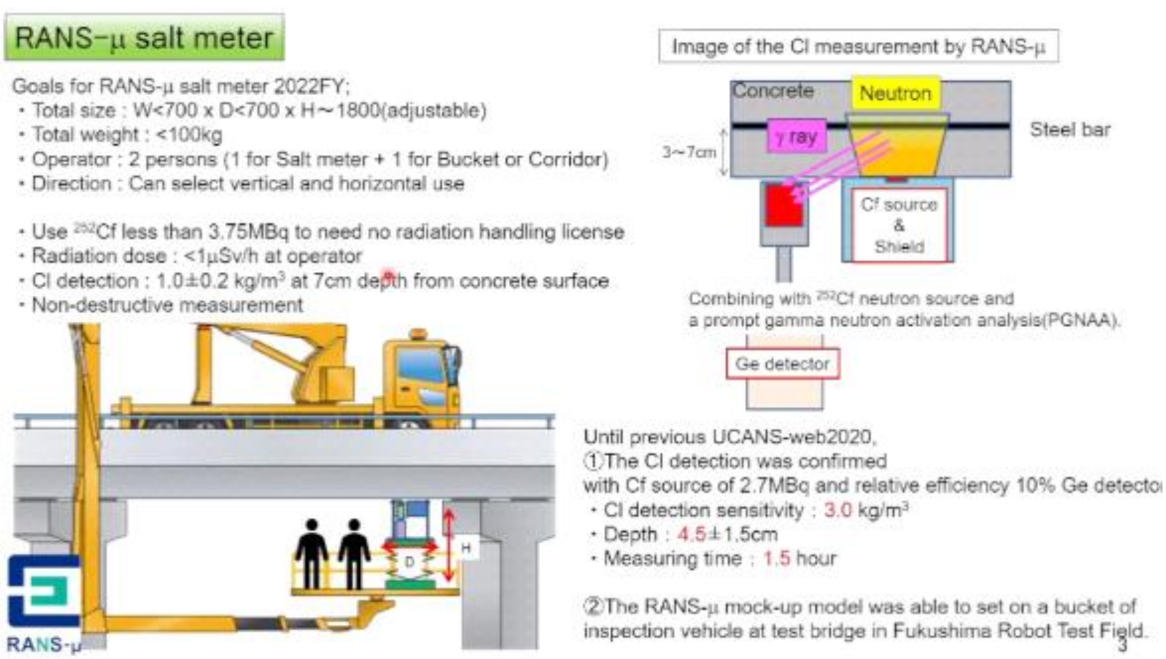


圖23 RANS-μ 鹽度計之示意圖

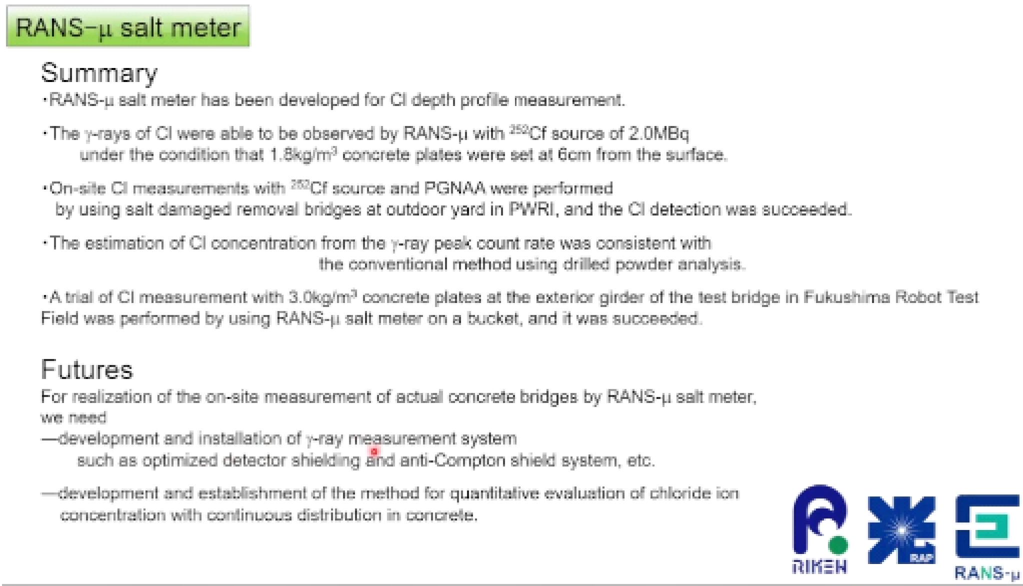


圖24 本篇報告的重點摘要

三、日本順天堂大學: 宇宙射線的中子照射對食物之影響

這篇是由日本順天堂大學 (Juntendo University)的健康科學院的研究人員進行 Effects of neutron radiation as cosmic radiation on food resources 演講。開頭提到，人類太空探索的主要挑戰之一是宇宙輻射的影響。近年來，在月球和火星等深空任務，由初級宇宙射線與屏蔽牆相互作用產生的中子輻射等次級輻射的影響是顯著的。輻射，尤其是中子輻射，對食物資源的影響迄今尚未得到深入研究，儘管在體內攝取食物很重要。在這項研究中探討從生化角度分析了中子輻射對食物的影響。具體來說，作者使用 RIKEN 加速器驅動的緊湊型中子源 (RANS) 用高達 5 MeV 的快中子輻照小塊肉，並對蛋白質和脂質的硝化和氧化進行了生化分析。獲得的結果如下：在小中子劑量下，蛋白質的硝化和脂質的氧化與中子劑量成比例增加。然而，隨著中子注量的增加，硝化被抑制並在 0.1Gy 和 1Gy 之間達到飽和。

實驗說明如下：此次，作者製作了一個樣品載台，以便可以用沒有緩速劑的鈹靶附近的具有高能中子（約為 1MeV）照射食物樣品（圖 25 Fig.1），這對應於深外太空航天器內部的宇宙輻射。中子束是控制在 0.01 Gy 到 3 Gy 的範圍內照射，對應於質子束電流 5.7 μA 與照射 30 秒至 34.4

μ A 與 1,270 秒。 通過調整質子電流和輻照時間，輻射達到對數刻度的劑量。 同時，中子數量由銦的活化進行評估。核反應 $^{115}In(n,n')^{115m}In$ 的生化分析結果如圖 25 Fig.2 所示：Fig.2 左圖顯示了用考馬斯亮藍 (Coomassie brilliant blue (CBB) stain) 染色可視覺化的 SDS-PAGE 分離的蛋白質。在中子輻照下沒有觀察到蛋白質電泳(electrophoresis)圖譜的差異。 右圖顯示了使用對蛋白質中硝化色氨酸殘基特異的小鼠抗體進行蛋白質印跡 (Western Blotting, WB) 的結果。在低於 100 公斤分子量 (kDa) 的蛋白質條帶中，隨著輻射劑量的增加，蛋白質的硝化作用很小。 對於 100 kDa 以上的條帶，硝化作用似乎增加了。圖 25 Fig.3 顯示了使用 Image J 影像軟體對 WB 中約 110 kDa 的條帶進行半定量。 隨著輻射劑量增加到 1 Gy，觀察到這種硝化作用的增加。說明攝入經高能輻射照射的食物的生物毒性超出了本研究的範圍。這項研究將定位為太空食物攝入影響的一個過程，未來將考慮各種發展。

Fig.1 Sample folder made by aluminum

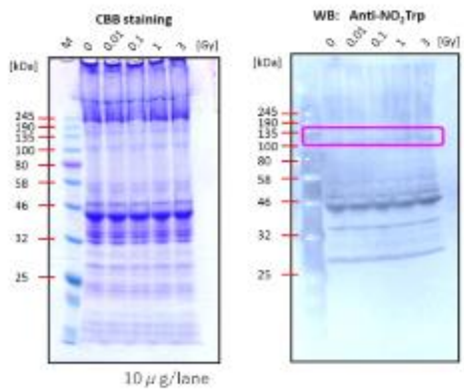


Fig.2 Electrophoresis CBB staining (left) and WB with anti-nitrotryptophan antibody (right)

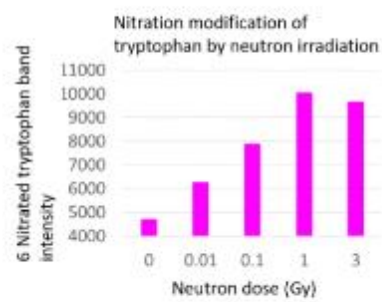


Fig.3 Nitration of tryptophan by neutron irradiation

圖 25 中子輻射對於食物中各項數據展示

四、大阪醫藥大學報告: 利用加速器超熱中子源進行硼中子捕捉治療

大阪醫藥大學研究團隊利用加速器超熱中子源針對癌症治療進行硼中子捕捉 (BNCT) (Accelerator based epithermal nertron source for clinic boron neutron capture therapy) 報告，本治療技術為全球首個經國家認可的癌症中子醫療技術，日本大阪醫

藥大學可謂是全球第一。首先介紹硼中子捕捉治療技術，將含有 ^{10}B 藥物注射到腫瘤處，再經由超熱中子照射後，轉變為 alpha 粒子與 ^{7}Li，進而殺死癌細胞。大阪醫藥大學從西元 2008 起開展硼中子捕捉藥物開發工作，2012 年展開 BNCT 腦瘤治療研究，2016 年進行腦癌與頭頸癌症臨床治療研究，2018 年成立 Kansai　BNCT 醫學中心，2020 年取得日本政府同意進行醫療行為執照與健保給付。

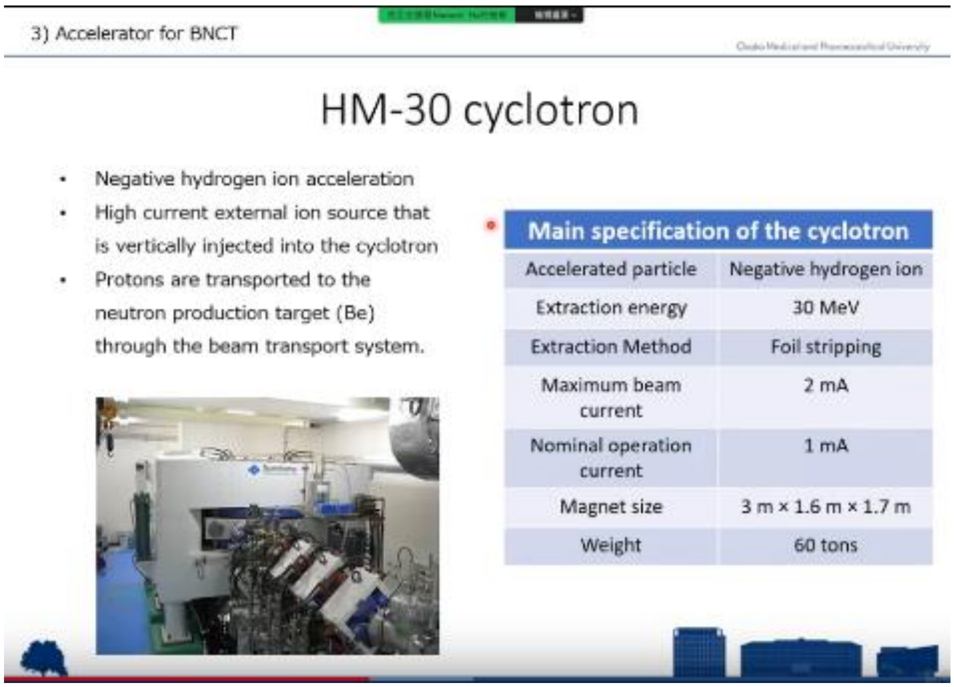


圖 26　BNCT 治療用 30MeV 迴旋加速器

大阪醫藥大學團隊使用 30MeV 迴旋加速器與 Be 靶產生超熱中子進行腦瘤與頭頸癌治療，見圖 26。10-40KeV 的中子是最適用於 BNCT 目的，穿透深度約為 4 ~ 10 公分，且不易造成表皮傷害。中子束需要有緩衝及塑型裝置以利調節適當能量的中子精準照射到腫瘤處，基中 Pd 和 Fe 為緩衝器，Al 和 CaF_2 為中子塑型用途，見圖 27。大阪醫藥大學經過多年的設計改良，已有許多成功案例，進而通過日本厚生省執照申請，成為全球第一張可進行治療 BNCT 中子加速器系統，進而造福相關的癌症病患。報告中並提出診斷流程，BNCT 定位醫療流程，相當詳細地介紹並且加以實例

說明，也告知在日本進行治療約一個療程為 1000 美元的費用（健保給付後），其實並沒有想像中的昂貴。或許在相關技術推進與主管單位認知進步，在不久將來，台灣也能有第一套 BNCT 治療設備與醫療院所。

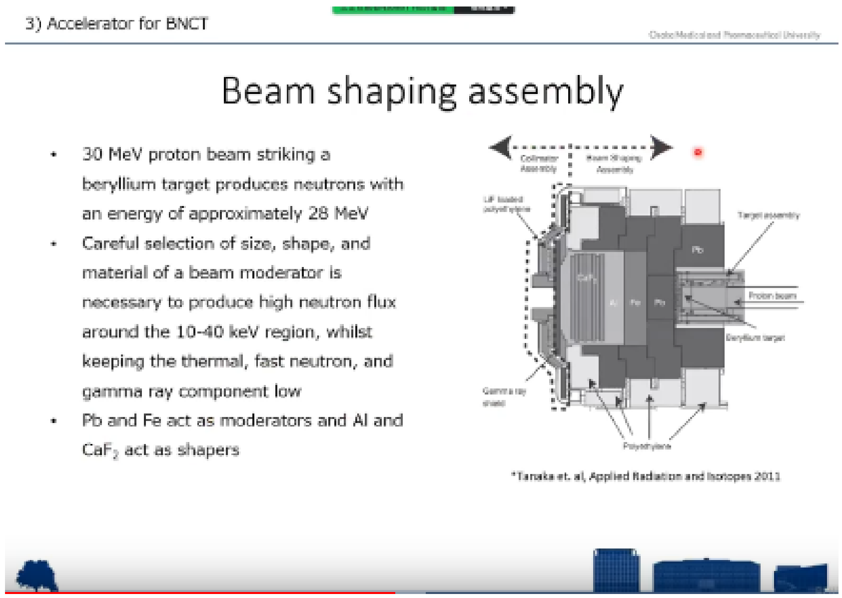


圖 27　BNCT 治療用中子塑型裝置

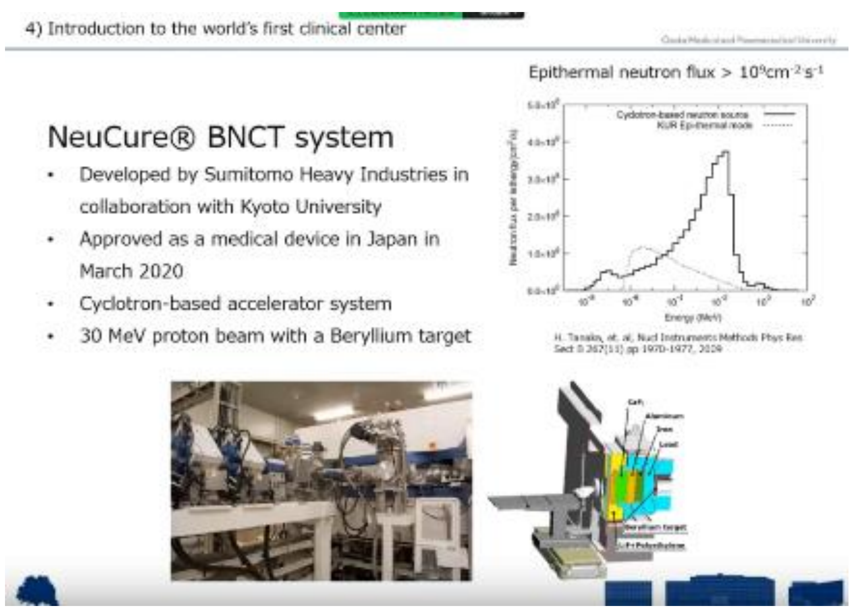


圖 28　世界第一套可治療用 BNCT 系統加速器實機與病床設計圖

四、 建議事項

(一) 因應本所未來將建置 70MeV 加速器，但因國內機構對中子研究相對稀少，中子人才培育相對不易，建議積極投入年輕人員，深耕中子技術發展，以提升本所未來競爭力。

(二) 期望持續參與此類 UCANS 國際研討會議，有利對本所未來的中子技術發展擴展視野，協助聚焦，在投入有限資源時更有效率地取得最佳效益及貢獻。

五、 附錄:

附錄一: **UCANS9 國際研討會每日議程及演講議題**

UCANS9 Timetable 1st day (Monday, March 28th, 2022)
https://zoom.us/j/2336507610

	Japan JST (UTC+9)	Europe CET (UCT+1)	America EDT (UCT-4)		Title	Speaker	Affiliation
	17:00 17:20	9:00 9:20	4:00 4:20	Opening session			
K-1	17:20 17:50	9:20 9:50	4:20 4:50	Keynote lecture1	Towards a Network of Accelerator-based Facilities in Europe	Thomas Brückel	JCNS
	17:50 18:00	9:50 10:00	4:50 5:00	Break (10min)			
I-1	18:00 18:20	10:00 10:20	5:00 5:20	Session A *CANS projects and facility development 1* (Chair: *TBD*)	*(INVITED)* RIKEN Accelerator-driven compact neutron systems, RANS project and their capabilities	Yoshie OTAKE	RIKEN
O-1	18:20 18:35	10:20 10:35	5:20 5:35		Introduction of Particle Accelerator Facility at Sun Yat-sen University	Liang LU	Sun Yat-sen University
O-2	18:35 18:50	10:35 10:50	5:35 5:50		HIGH FLUX NEUTRON SOURCE FOR VARIOUS APPLICATIONS	Marina Bikchurina	Budker Institute of Nuclear Physics
I-2	18:50 19:10	10:50 11:10	5:50 6:10		*(INVITED)* Overview of the current status and research at Hokkaido University neutron source facility, HUNS	Takashi Kamiyama	Hokkaido University
O-3	19:10 19:25	11:10 11:25	6:10 6:25		Status of the neutron source development for fusion reactor engineering development in Korea	Dong Won LEE	Korea Atomic Energy Research Institute (KAERI)

O-4	19:25 19:40	11:25 11:40	6:25 6:40		Simulation and Design of an IPHI-based neutron source, first steps toward SONATE	MOM Borana	IRFU, CEA, Université Paris-Saclay
	19:40 20:00	11:40 12:00	6:40 7:00	Break (20min)			
I-3	20:00 20:20	12:00 12:20	7:00 7:20	Session B *Target development 1* (Chair: *TBD*)	(*INVITED*) A flexible target station for Hi-CANS	Paul Zakalek	Jülich Centre for Neutron Science (JCNS-HBS), Forschungszentrum Jülich
O-5	20:20 20:35	12:20 12:35	7:20 7:35		Genetic Algorithm-Based Optimization of a Target for the Production of Atmospheric-Like Neutrons via 100 MeV Proton Beam	Soobin Lim	Seoul National University
O-6	20:35 20:50	12:35 12:50	7:35 7:50		Depositing a thin coating on the lithium neutron production target by magnetron sputtering technology	Zhaopeng Qiao	Xian Jiaotong University
O-7	20:50 21:05	12:50 13:05	7:50 8:05		A comparative study of target and moderator for Prototype Canadian Compact Neutron Source (PC-CANS) by using MCNP and FLUKA	Sana Tabbassum	School of Health Sciences, Purdue University
	21:05 21:20	13:05 13:20	8:05 8:20	Break (15min)			
I-4	21:20 21:40	13:20 13:40	8:20 8:40	Session C *Instrumentation and measurement 1* (Chair: *TBD*)	(*INVITED*) Recent progress on the grazing-incidence focusing small-angle neutron scattering (gif-SANS) instrument at CPHS	Weihang Hong	Tsinghua University
O-8	21:40 21:55	13:40 13:55	8:40 8:55		Design and test of a compact neutron collimator	Oriol Sans-Planell	Università degli Studi di Torino, INFN (Sezione di Torino)
O-9	21:55 22:10	13:55 14:10	8:55 9:10		Coupling HICANS with SELENE guides for tunable beam at small samples	Zhanwen Ma	Lanzhou University; Jülich Centre for Neutron Science, Forschungszentrum Jülich
O-10	22:10 22:25	14:10 14:25	9:10 9:25		Sample synchronized Neutron Stroboscope at RANS	Atsushi Taketani	RIKEN
O-11	22:25 22:40	14:25 14:40	9:25 9:40		Imaging Performance of Neutron Flat-Panel-Detector using IGZO-TFT at Compact Neutron Source	Takeshi Fujiwara	AIST
O-12	22:40 22:55	14:40 14:55	9:40 9:55		Can the electro-disintegration reaction be used for the ultra-high energy resolution analysis for fast neutrons?	Yuqi Yang	Tsinghua University
O-13	22:55 23:10	14:55 15:10	9:55 10:10		Development of neutron salt-meter RANS-μ for non-destructive inspection of concrete structure at on-site use	Yasuo Wakabayashi	RIKEN

UCANS9 Timetable 2nd day (Tuesday, March 29th, 2022)

(*Oral*) https://zoom.us/j/2336507610 (*Poster*) https://zoom.us/j/95143724792

	Japan JST (UTC+9)	Europe CET (UCT+1)	America EDT (UCT-4)		Title	Speaker	Affiliation
I-5	17:00 17:20	9:00 9:20	4:00 4:20	Session D *CANS Application* (Chair: *TBD*)	(*INVITED*) System-level soft error testing technology using CANS	Hidenori Iwashita	NTT
O-14	17:20 17:35	9:20 9:35	4:20 4:35		Current development status of iBNCT001, the demonstration device of a linac-based neutron source for BNCT	Hiroaki Kumada	University of Tsukuba
O-15	17:35 17:50	9:35 9:50	4:35 4:50		A Preliminary Neutron Imaging Study of Moisture Transport in Cement-Based Materials on PKUNIFTY (A Compact Accelerator Based Neutron Imaging Facility at Peking University)	Dongyang Wang	Peking University
O-16	17:50 18:05	9:50 10:05	4:50 5:05		Collaborative advances in bulk texture measurement techniques based on the JAEA large neutron sources and the RIKEN compact neutron source	Pingguang Xu	Japan Atomic Energy Agency
O-17	18:05 18:20	10:05 10:20	5:05 5:20		Effects of neutron radiation as cosmic radiation on food resources	Machiko Hatsuda	Faculty of Health Science, Juntendo Universtiy
O-18	18:20 18:35	10:20 10:35	5:20 5:35		The neutron activation analysis of mineral ores by an electron linear accelerator-based photoneutron source	Tongyuan Cui	Department of Engineering Physics, Tsinghua University
	18:35 18:55	10:35 10:55	5:35 5:55	Break (20min)			
K-2	18:55 19:25	10:55 11:25	5:55 6:25	Keynote lecture2	Accelerator based epithermal neutron source for clinical boron neutron capture therapy	Naonori Hu	Kansai BNCT Medical Center, Kyoto University Institute for Integrated Radiation and Nuclear Science

I-6	19:25 19:45	11:25 11:45	6:25 6:45	Session E *Instrumentation and measurement 2* (Chair: *TBD*)	(*INVITED*) Neutron scattering and radiography at the IPHI – Neutron facility	Frédéric Ott	Laboratoire Léon Brillouin, CEA, CNRS, Univ. Paris-Saclay
O-19	19:45 20:00	11:45 12:00	6:45 7:00		The realization of neutron and X-ray bimodal imaging driven by a single electron linear accelerator	Yangyi Yu	Tsinghua University
O-20	20:00 20:15	12:00 12:15	7:00 7:15		Instrument suite for DARIA compact neutron source	Konstantin Pavlov	SPbSU
I-7	20:15 20:35	12:15 12:35	7:15 7:35		(*INVITED*) Small-angle Neutron Scattering Available in Tokyo Area. Time-of-Flight Instrument ib-SAS at Compact Spallation Neutron Source RANS.	Satoshi Koizumi	Ibaraki Univ
O-21	20:35 20:50	12:35 12:50	7:35 7:50		Development of the Instrument Suite of the HBS	Klaus Lieutenant	Forschungszentrum Juelich
O-22	20:50 21:05	12:50 13:05	7:50 8:05		The Detection of Neutron Spectrum Ranging from 0.1 MeV to 100MeV with a CLYC Scintillator	Weixin Zhou	Department of Engineering Physics, Tsinghua University
	21:05 21:20	13:05 13:20	8:05 8:20	Break (15min)			
	21:20 22:50	13:20 14:50	8:20 9:50	Poster session 1 *CANS facility developments, Moderator developments, Target developments*			
P-1					RIKEN accelerator-driven transportable neutron source prototype RANS-II	Tomohiro Kobayashi	RIKEN

P-2	High brilliance neutron source optimized for very high pulsed magnetic field experiments	Mina Akhyani	EPFL
P-3	Operation of RANS	Atsushi Taketani	RIKEN
P-4	Conceptual Shielding Design of a Transportable Accelerator-driven Neutron Source	Quanxu Jiang	School of Nuclear Science and Technology, Xi'an Jiaotong University
P-5	Experimental verifications for a multi-objective shielding design method on RANS	Baolong Ma	Xi'an Jiaotong University
P-6	Improvement of mesitylene cold moderator at KUANS	Seiji Tasaki	Kyoto University
P-7	Influence of the location and shape of the para-hydrogen in the TMR on the brightness of the source for CNS DARIA	Nikita Kovalenko	NRC "Kurchatov Institute" - PNPI
P-8	Development of Tantalum-based target system for the production of atmospheric-like neutrons driven by the 100-MeV proton accelerator at KOMAC	Nam-Woo KANG	Korea Atomic Energy Research Institute
P-9	A design for the BNCT target system with the compact neutron source	Shaozhang Qi	Department of Engineering Physics, Tsinghua University
P-10	Monte Carlo simulation design of BNCT beam shaping assembly for accelerator-based neutron source	Dominik Dziura	University of Windsor
P-11	Model calculation on angular distributions of neutron for the proton induced reaction on the 7Li	Jiaqi Hu	Xi'an Jiaotong university
P-12	Thermal simulation study of different beam spot for a rotating lithium target	Yaocheng Hu	Department of Nuclear Science and Technology, School of Energy and Power Engineering, Xi'an Jiaotong University
P-13	Research of target with micro-channel structure for transportable accelerator-driven neutron source	Xiaobo Li	Xi'an Jiaotong University
P-14	Water Corrosion of Tungsten Target for Accelerator-driven Neutron Source	Yupeng Xie	School of Nuclear Science and Technology, Xi'an Jiaotong University
P-15	Optimization numerical simulation of the target for DARIA CNS.	Aleksei I. Klimov	Saint Petersburg State University

UCANS9 Timetable 3rd day (Wednesday, March 30th, 2022)

(*Oral*) https://zoom.us/j/2336507610 (*Poster*) https://zoom.us/j/94961414390

	Japan JST (UTC+9)	Europe CET (UCT+1)	America EDT (UCT-4)		Title	Speaker	Affiliation
I-8	17:00 17:20	9:00 9:20	4:00 4:20	Session F *Target development 2* (Chair: *TBD*)	(*INVITED*) Tests of a 30 kW Beryllium target at IPHI	Jerome SCHWINDLING	CEA/IRFU, Univ. Paris-Saclay
O-23	17:20 17:35	9:20 9:35	4:20 4:35		Optimization of a target with microchannel cooling using advanced simulation technologies	Qi Ding	Jülich Centre for Neutron Science JCNS-HBS, Forschungszentrum Jülich GmbH
O-24	17:35 17:50	9:35 9:50	4:35 4:50		Verification process of the system design of an accelerator-based thermal neutron source at SARAF through Monte-Carlo simulations	Tsviki Y. Hirsh	Soreq NRC
O-25	17:50 18:05	9:50 10:05	4:50 5:05		Decay heat in ISIS spallation neutron target: FLUKA simulations and measurements	Lina Quintieri	ISIS, STFC, Rutherford Appleton Laboratory
O-26	18:05 18:20	10:05 10:20	5:05 5:20		When and why you change your Neutron Target?	Toshikazu Kurihara	KEK/Univ. of Tsukuba
O-27	18:20 18:35	10:20 10:35	5:20 5:35		Multilayer beryllium target design for DARIA compact neutron source	Anton R. Moroz	Saint Petersburg State University, Petersburg Nuclear Physics Institute named by B.P. Konstantinov of NRC "Kurchatov Institute"
O-28	18:35 18:50	10:35 10:50	5:35 5:50		HBS High Power Density Neutron Target - Design and Experimental Tests	Johannes Baggemann	JCNS-HBS, Forschungszentrum Jülich
	18:50 19:10	10:50 11:10	5:50 6:10	Break (20min)			

K-3	19:10 19:40	11:10 11:40	6:10 6:40	Keynote lecture3	How to survive for next two decades? ~ In the case of SANS in Hokkaido University Neutron Source ~	Masato Ohnuma	Hokkaido University
I-9	19:40 20:00	11:40 12:00	6:40 7:00	Session G *CANS projects and facility development 2* (Chair: *TBD*)	(*INVITED*) IAEA activities concerning CANS	Ian Swainson	IAEA
O-29	20:00 20:15	12:00 12:15	7:00 7:15		Neutron performance and its future prospect of the compact electron accelerator-driven neutron facility AISTANS	Koichi Kino	AIST, ISMA
O-30	20:15 20:30	12:15 12:30	7:15 7:30		The Jülich HBS Project for accelerator based neutron sources	Thomas Gutberlet	Forschungszentrum Jülich
O-31	20:30 20:50	12:30 12:50	7:30 7:45		Development status of Compact Accelerator-driven Neutron Sources in XJTU	Sheng Wang	School of Nuclear Science and Technology, Xian Jiaotong University
I-10	20:50 21:05	12:50 13:05	7:45 8:05		(*INVITED*) Brining a CANS to Canada: Project Overview	Drew Marquardt	University of Windsor
O-32	21:05 21:20	13:05 13:20	8:05 8:20		Status of Cyclotron Neutron Sources Development in Taiwan	Shiaw-Huei Chen	Institute of Nuclear Energy Research, Atomic Energy Council
O-33	21:20 21:35	13:20 13:35	8:20 8:35		Development of the Pelletron-based Neutron Source at the Nuclear Applications Laboratory, Lund University	R.J.W. Frost	Division of Nuclear Physics, Department of Physics, Lund University
	21:35 21:50	13:35 13:50	8:35 8:50	Break (15min)			

21:50 23:20	13:50 15:20	8:50 10:20	Poster session 2 *CANS applications, Accelerator developments, Instrumentation developments*			
P-16				Fabrication and RF test of the 500 MHz-RFQ linear accelerator for transportable neutron source RANS-Ⅲ	Shota Ikeda	RIKEN
P-17				Development of the accelerator system for a transportable compact neutron source in XJTU	Haipeng Li	Xi'an Jiaotong University
P-18				Development of proton injector of RFQ for transportable neutron source in XJTU	Hao Luo	Xi'an Jiaotong University
P-19				Development of a low threshold fast neutron detector using plastic scintillator with MPPC	T. Hashiguchi	riken
P-20				Development of pulse width identification type PSD system	Setsuo Sato	High Energy Accelerator Research Organization
P-21				THE POWDER DIFFRACTOMETER MONOPOLY AT THE COMPACT NEUTRON SOURCE DARIA	Anastasiia Pavlova	Saint Petersburg State University
P-22				Towards a GI SANS Instrument for the PC CANS: Target-Moderator Optimization and Instrumentation Design with MCNP & VITESS	Dalini D. Maharaj	University of Windsor
P-23				Thermal neutron CT image reconstruction based on the exact solution of the discrete Radon transformation	Takaoki Takanashi	RIKEN
P-24				Neutron detection devices based on InGaP solar cell with boron converter	Yasuki Okuno	KINKEN Tohoku Univ
P-25				Automatic measurement system of neutron dose at RANS experimental hall	Tsubasa Yamano	Rikkyo University
P-26				Evaluation of thin water thickness on a steel plate at RANS	Atsuhi Taketani	RIKEN
P-27				Estimation of double-differential cross-sections of Be-9(p,xn) reaction for new nuclear data library, JENDL-5	Satoshi Kunieda	JAEA
P-28				Measurement of Internal Stress in Metal using Neutron Diffraction	Ryo Kurihara	Nihon University
P-29				Novel methodological study for neutron diffraction stress measurement using compact accelerator-driven neutron source RANS	Chihiro Iwamoto	RIKEN
P-30				Neutron Scattering Imaging for Defects in Anchorage of Bridge Cable	Kunihiro Fujita	RIKEN

UCANS9 Timetable 4th day (Thursday, March 31st, 2022)

https://zoom.us/j/2336507610

	Japan JST (UTC+9)	Europe CET (UCT+1)	America EDT (UCT-4)		Title	Speaker	Affiliation
O-34	17:00 17:15	9:00 9:15	4:00 4:15	Session H *Accelerator developments* (Chair: *TBD*)	Influence of proton beam loss on dose rate distribution in RANS experimental hall	Mingfei Yan	RIKEN
O-35	17:15 17:30	9:15 9:30	4:15 4:30		Advances in the ESS-BILBAO injector	Ibon Bustinduy	ESS-Bilbao
O-36	17:30 17:45	9:30 9:45	4:30 4:45		Design Considerations for a Proton Linac for a Compact Accelerator Based Neutron Source	Mina Abbaslou	TRIUMF
O-37	17:45 18:00	9:45 10:00	4:45 5:00		A design for the high yield neutron source driven by an electron linear accelerator	Yuxuan Lai	Tsinghua University
	18:00 18:15	10:00 10:15	5:00 5:15	Break (15min)			
I-11	18:15 18:35	10:15 10:35	5:15 5:35		(*INVITED*) Improvements in thermal neutron scattering data sampling in PHITS	Jose Ignacio Marquez Damian	Spallation Physics Group, European Spallation Source
O-38	18:35 18:50	10:35 10:50	5:35 5:50		Optimization of moderator materials based on genetic algorithm for A-BNCT	Yulin Ge	Sino-French Institute of Nuclear Engineering and Technology, Sun Yat-sen University
O-39	18:50 19:05	10:50 11:05	5:50 6:05		Experience of exploitation of cold neutron moderators on pelletized mesitylene and possibility of using it in compact neutron sourse DARIA	Mukhin Konstantin	Joint Institute for Nuclear Research, St. Petersburg University
I-12	19:05 19:25	11:05 11:25	6:05 6:25	Session I *Moderator development and Monte Carlo method* (Chair: *TBD*)	(*INVITED*) Neutron Scattering Kernels for Methane I & II and Ethane III	Rolando Granada	Centro Atómico Bariloche, CNEA
O-40	19:25 19:40	11:25 11:40	6:25 6:40		Cold moderators for the High Brilliance Neutron Source	Alexander Schwab	JCNS-2, FZJ
O-41	19:40 19:55	11:40 11:55	6:40 6:55		Monte Carlo simulation of a mesitylene based cold moderator system for accelerator-driven compact neutron sources	Jingjing Li	Jülich Centre for Neutron Science JCNS-HBS, Forschungszentrum Jülich GmbH
O-42	19:55 20:10	11:55 12:10	6:55 7:10		Experimental validation of cold neutron source performance with mesitylene moderator installed at RANS	Y. Ikeda	RIKEN
O-43	20:10 20:25	12:10 12:25	7:10 7:25		Optimized thermal moderators for Compact Accelerator-driven Neutron Sources	U. Rücker	JCNS-HBS, Forschungszentrum Jülich
	20:25 20:45	12:25 12:45	7:25 7:45	Closing			

附錄二、投稿 UCANS9 國際研討會的口頭論文摘要及簡報

Status of Cyclotron Neutron Sources Development in Taiwan

Shiaw-Huei Chen, How-Ming Lee, Sheng-Long Jeng, Hsiao-Ming Tung, Tun-Yuan Yung, Chien-Hsiang Chen, Weng-Sheng Kuo, Ting-Shien Duh, and Shiou-Shiow Farn.

Institute of Nuclear Energy Research, Atomic Energy Council, Taiwan, R.O.C.

This paper briefly descripts the current status of the development of neutron sources by using cyclotron accelerator in Taiwan. At present, Taiwan has only one old neutron research reactor, Tsing Hua Open-pool Reactor (THOR), located at Tsing Hua National University in Hsinchu. THOR has been operated for nearly sixty years, currently has been used for researches such as BNCT and neutron radiography etc. Another neutron instrument station SIKA (Spin-polarized Inelastic. K-space Analyzer) supported by Taiwan is located in ANSTO, Australia. SIKA has been obtained commission to providing services since year 2015, and this has encouraged Taiwan's scientists to turn their research interests in the neutron field which also lead to the increases on demand for more neutron instruments on various experiments.

At Institute of Nuclear Energy Research (INER), we had a neutron Test Research Reactor (TRR) which was shut-down in 1988 and now in decommission process, a replacement pilot project TRRII had been conducted for several years but was subsequently canceled in 2002.

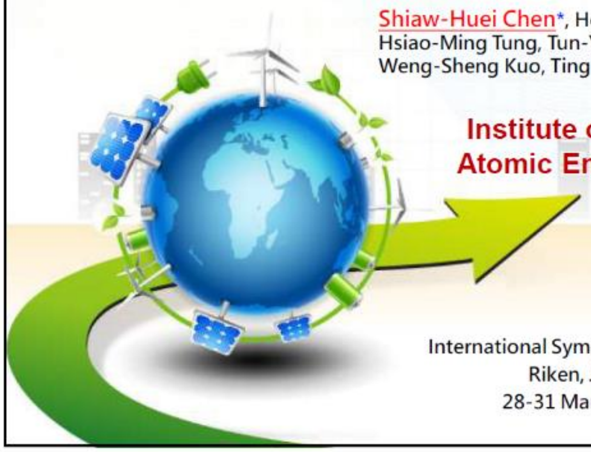
An alternative way for neutron scientists in Taiwan to have a new neutron source is through proton beam from cyclotrons. INER has a 28-years-old 30MeV cyclotron which has been served as a nuclear isotope production facility for medical applications. In 2020 a small scale neutron source project by utilizing one proton beam lines of cyclotron was initiated. The goals of this project are to establish facilities to study the neutron irradiation effect on semiconductor devices and for the neutron radiography.

But due to the outbreak of pandemic Covid-19 in 2020, one urgent consequence was the sudden shortage of the supply of imported isotope medicine. INER's 30MeV cyclotron came to the rescue and was run at full capacity to meet the nuclear medicine needs. In late 2020, due to strategic consideration of secure and prevention on the domestic supply chain of nuclear medicine, a new 70MeV/1mA cyclotron 4-year construction plan was proposed and approved the Taiwan government. With the specs of high power proton beam in this new cyclotron project, thus makes a high emittance neutron source possible, a neutron research laboratory is also proposed. The neutron stations in this project will include the thermal neutron diffraction and fast neutron radiation facilities.

Status of Cyclotron Neutron Sources Development in Taiwan

Shiaw-Huei Chen*, How-Ming Lee, Sheng-Long Jeng, Hsiao-Ming Tung, Tun-Yuan Yung, Chien-Hsiang Chen, Weng-Sheng Kuo, Ting-Shien Duh, and Shiou-Shiow Farn.

Institute of Nuclear Energy Research, Atomic Energy Council, Taiwan, R.O.C.



International Symposium UCANS9
Riken, Japan
28-31 March 2022

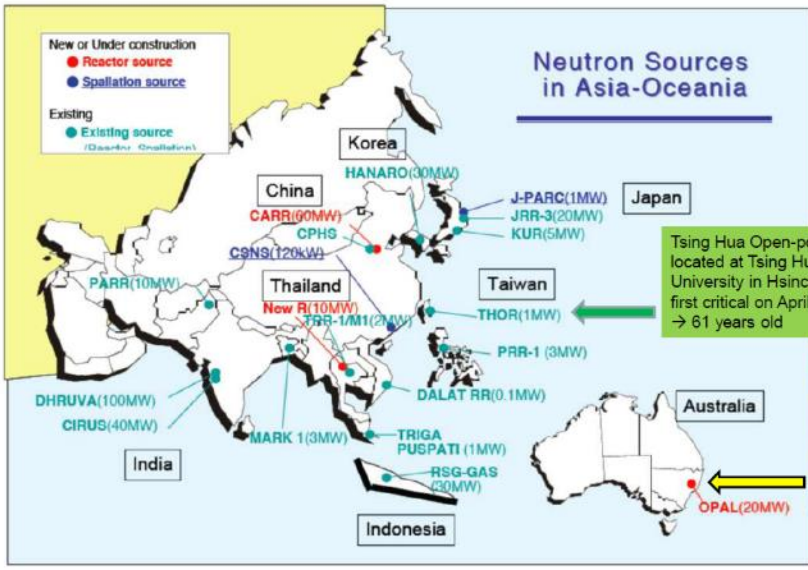
核能研究所

OUTLINE

1. Current Neutron Source in Taiwan
2. Development of 30 MeV Cyclotron Neutron Source
3. Planning for the 70 MeV Cyclotron Neutron Source
4. Conclusions

1

Current Neutron Source in Taiwan



Tsing Hua Open-pool Reactor (THOR) located at Tsing Hua National University in Hsinchu. It reached its first critical on April 13, **1961**.
→ 61 years old

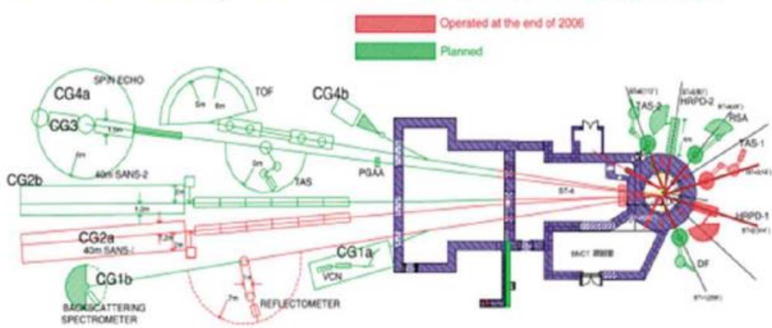
Taiwan supported SIKA (Spin-polarized Inelastic. K-space Analyzer) neutron instrument station in OPAL ANSTO. Providing services **since 2015**.

Submission to the ICSU Foresight exercise from AONSA, the Asia-Oceania Neutron Scattering Association, http://j-parc.jp/MatLife/en/AONSA/files/AONSA_ICSU_submission_FINAL%2024-1-10.pdf

2

Past Neutron Source Program TRRII

At Institute of Nuclear Energy Research (INER), we had a Test Research Reactor (TRR) which was shut-down in 1988 and in decommission process now, a replacement pilot project named as TRRII had been conducted for several years but was subsequently canceled in 2002.

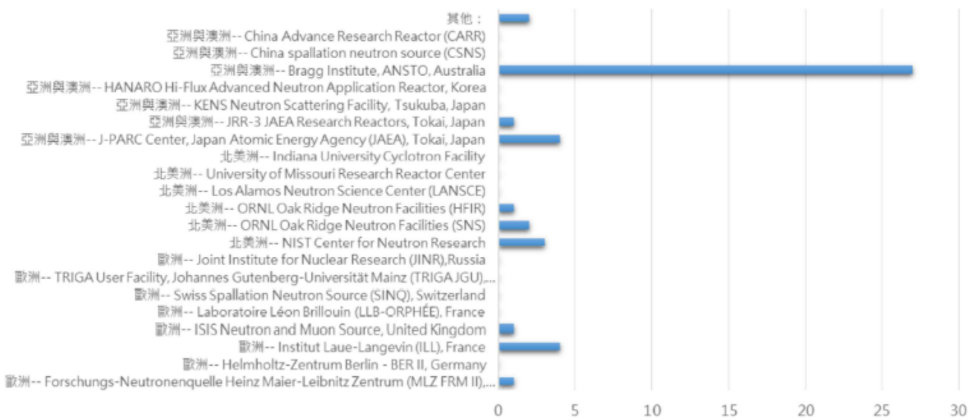


Schematic Drawing of the TRRII (1998 -2002)

3

Neutron Users in Taiwan

Last year (2021) INER performed a survey to investigate the neutron facilities and scientific needs of neutron users in Taiwan.



Statistic of neutron facilities Taiwan neutron users had applied and performed experiments.

4

OUTLINE

1. Current Neutron Source in Taiwan
2. Development of 30 MeV Cyclotron Neutron Source
3. Planning for the 70 MeV Cyclotron Neutron Source
4. Conclusions

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2. Development of 30 MeV Cyclotron Neutron Source

- **Goal**: Neutron sources and applications development
- **Neutron source**: Be Target from INER's 30 MeV Cyclotron proton beam
- **Neutron applications**:
  1. Thermal neutron radiography
  2. Fast neutron radiation damage on electronic devices
- **Project period**: 2021 ~ 2023 (4 years)

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TR30 Cyclotron at INER

- TR30 : TRIUMF (TRI-University Meson Facility, Canada's National Laboratory for Particle and Nuclear Physics) · EBCO (now ACSI), operating since year 1993 。
- Services : 1. medical isotope production facility; 2. proton beam irradiation services; 3. industrial and research studies

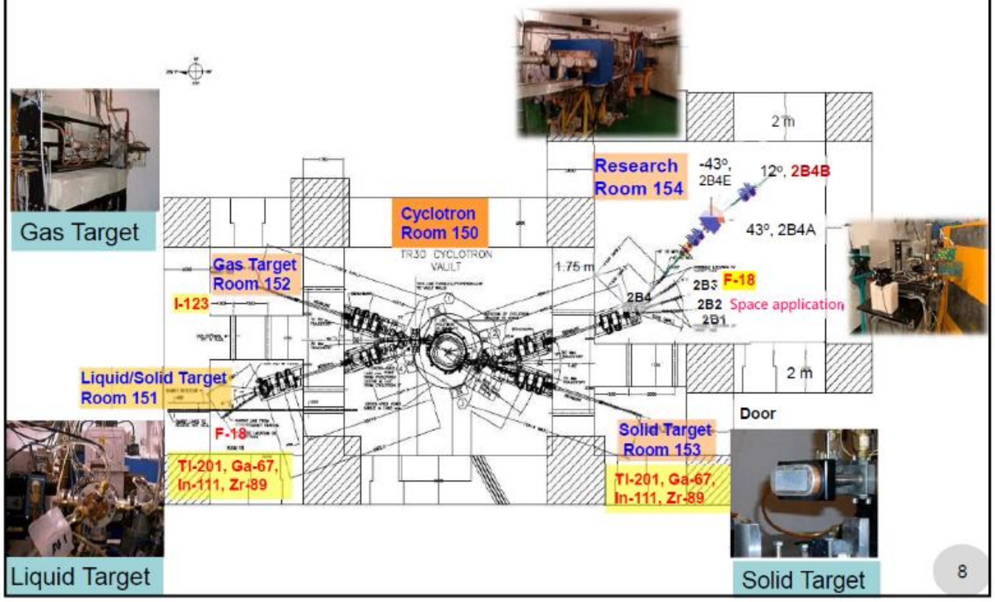
TR30 Cyclotron

Particle	H^-
Beam Energy (MeV)	15~30
Beam Extracted (μA)	200 → 500
RF	
Dee Voltage (kV)	50
Frequency (MHz)	73.129
Harmonics	4
Amplifier power(kW)	40 → 100
Ion source	H^- cusp type
output current(mA)	5 → 10
Beam focus system*	SQQ → EBSQQ* + Pulser
Beam efficiency	10% → 33% (at 0.3 mA)
Vacuum(torr)	$< 5 \times 10^{-7}$
Magnet	4-sector radial ridge
Beam number	4
Beam O/P port number	9 → 13
Solid Target Station	
Target current(μA)	200

- S: Solenoid, Q:Quadruple, B: Buncher, E:Einzel lens.

7

Layout of TR30 Cyclotron Building

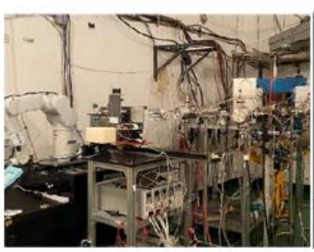


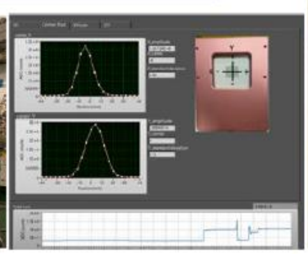
8

Proton Beam Irradiation Services

Proton Beam Specs:

- Beam Energy：15 – 30 MeV
- Beam Current： 0.1 nA – 100 μA
- External Irradiation in air：
  FOV：3 cm^2 (1cm radius circle), fixed sample
  15*15 cm^2, movable sample
- External Irradiation in vacuum ：
  FOV：3 cm^2, fixed sample





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Neutron Beam Irradiation Services (Planning)

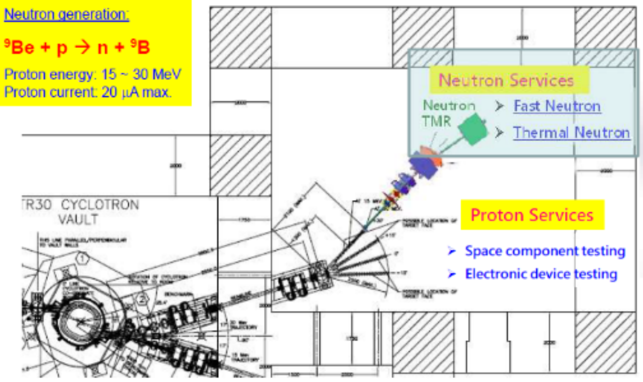
small scale neutron source using cyclotron (2022-2023)

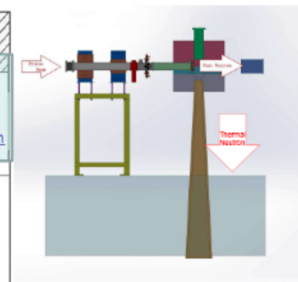
- Fast Neutron ≥ 10^6 n/(cm^2·s)、0° exit、neutron irradiation on electronic devices
- Thermal neutron ≥ 10^5 n/(cm^2·s)、90° down to basement、neutron radiography

Neutron generation:

$^9Be + p \rightarrow n + {}^9B$

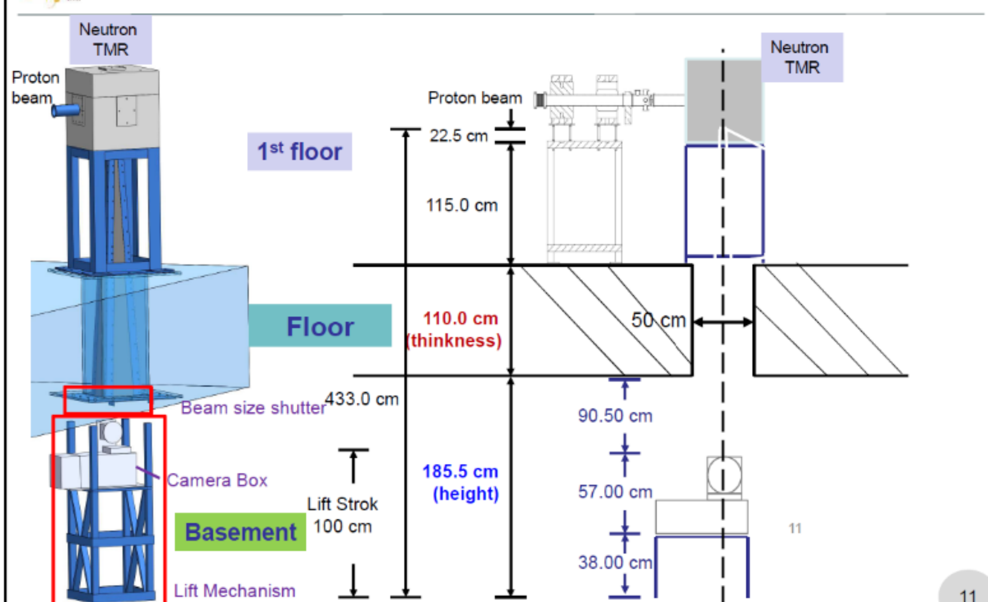
Proton energy: 15 ~ 30 MeV
Proton current: 20 μA max.





Schematic drawing of Neutron Beam Irradiation setup

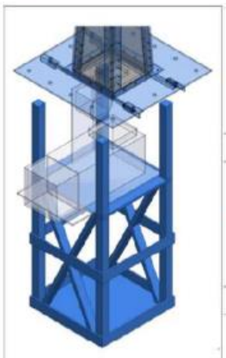
Set-up of the Neutron Imaging

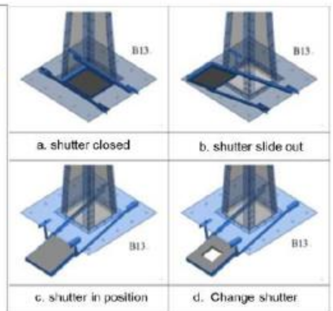


Set-up of the Neutron Imaging

Loading and Beam Shutter
- Material: 10%B-HDPE
- Beam Size : w/o, 10 x 10 cm^2, 15 x 15 cm^2, 25 x 25 cm^2
- Frame: Al 6061-T6

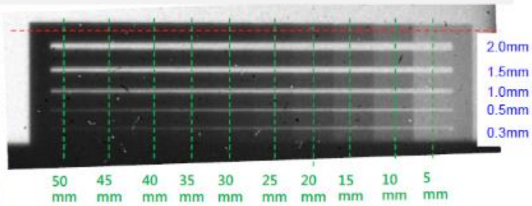
Camera Box
- Scintillator: $^6LiF:ZnS$
- Scintillator Size: 15 x 15 cm^2
- Camera: PCO Edge 5.5、SBIG ST3200

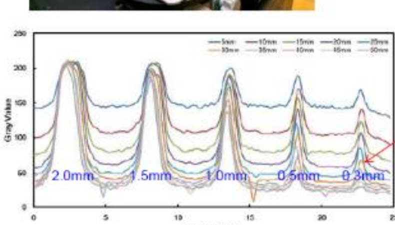


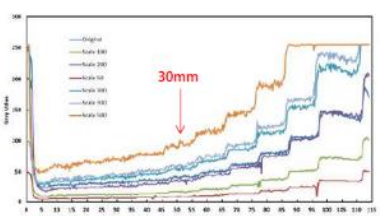


Testing of Neutron Camera Box

A steel sample was made with 10 steps in thickness from 0.5 cm to 5 cm, 5 horizontal slots with different width from 0.3 mm to 2.0 mm.







* Camera box test was performed at THOR reactor.

OUTLINE

1. Current Neutron Source in Taiwan
2. Development of 30 MeV Cyclotron Neutron Source
3. Planning for the 70 MeV Cyclotron Neutron Source
4. Conclusions

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Cyclotrons Available in Taiwan

	Hospitals	Year licensed	Brand	Model	Country	Proton Energy (MeV)	Deuteron Energy (MeV)	Current (μA)	Note
1	T. P. Hospital	1992	Scanditronix	MC17F	Sweden	17.0		80	
2	Y. Med.Univ. . Hospital	1999	CTI	RDS111		11.0		65	
3	S. G. Hospital	2001	GE	MINI Trace	USA	9.6		50	
4	General Army Hospital	2003	IBA	Cyclone 18/9	Belgium	18.0		300	
5	Bud. Hospital	2003	GE	PET Trace	USA	16.5	8.4	100	
6	E.Univ. Hospital	2005	GE	PET Trace	USA	16.5	8.4	100	
7	Run. Hospital	2005	Sumitomo	HM12S	Japan	12.0	6.0		
8	NTU Hospital	2005	GE	PET Trace	USA	16.5	8.4	100	PETtrace 800
9	Linkou Chang Gung Memorial Hospital	2007	Sumitomo	HM12S	Japan	12.0	6.0		
10	Linkou Chang Gung Memorial Hospital	2012	GE	PET Trace	USA	16.5	8.4	100	PETtrace 800
11	Linkou Chang Gung Memorial Hospital	2015	Sumitomo	Proton Therapy System	Japan	70 - 230		~ 300 nA	
12	INER	1993	Triumf	TR30/15	Canada	15 - 30	(15.0)	500	29 year old (2022)
13	INER (plan)	?(2027)	Best / IBA		Canada/Belgium	28* - 70		1000	* special request

Proton Energy Gap at 30 ~ 70 MeV will be filled by this project.

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Production of isotopes by TR-30 Cyclotron

Table of medical isotope provided by INER 30 MeV cyclotron

Isotope	Nuclear Reaction	Proton Energy	Production
^{18}F	$^{18}O(p,n)^{18}F$	17 MeV	1 Ci/batch
^{123}I	$^{124}Xe(p,2n)\ ^{123}I$	30 MeV	2~5 Ci/batch
^{201}Tl	$^{203}Tl(p,3n)\ ^{201}Tl$	**28 MeV**	5 Ci/batch
^{67}Ga	$^{68}Zn(p,2n)\ ^{67}Ga$	24 MeV	3 Ci/batch
^{111}In	$^{112}Cd(p,2n)\ ^{111}In$	22 MeV	4 Ci/batch
^{89}Zr	$^{89}Y(p,n)^{89}Zr$	15 MeV	Under test

It's becoming important during Co-Vid 19 period, when oversea supplies are unstable.
*$^{201}Tl\ t_{1/2}$ = 72.9 h.

This explains the demand for 28 MeV.

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Provider for 30 - 70 MeV Cyclotron

Best 70 P Cyclotron

35 - 70 MeV, 750 μA + 4 beamlines + 2 solid target systems

28 - 70 MeV (Discussed) 1000 μA (options)

IBA Cyclone 70 Proton

30 - 70 MeV, 750 μA + 4 beamlines + 2 solid target systems

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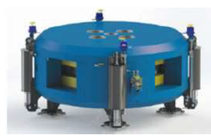
Planning for the 70 MeV Cyclotron

Nuclear Medicine Research Center

- Support current 30 MeV cyclotron isotope production line.
- Development of new nuclear isotope and nuclear medicine.
- Two solid target station and one gas target station are planned

Proton Laboratory :

- Patch up the missing 30~70 MeV proton energy gap in Taiwan
- Proton irradiation testing platform for space and electronic component
- New radiation-resistant material development



28~70 MeV, 1 mA

Neutron Laboratory :

- Neutron Target with 70MeV/1mA proton beam to achieve high neutron yield。
- Fast/thermal/cold neutron target station with possible six lines of neutron analytic instrument is planned.
- In current phase (2023-2026), thermal neutron diffraction and fast neutron science station will be built first.

Research lab.s for the 70 MeV cyclotron facilities.

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3. Planning for the 70 MeV Cyclotron Neutron Source

- **Goal: Multiple purpose research center**
  - (1) Nuclear Medicine Research Center
  - (2) Neutron Laboratory
  - (3) Proton Laboratory
- **Neutron Laboratory : (in current time - funding)**
  1. Thermal neutron diffraction
  2. Fast neutron test platform
- **Neutron source : Ta/Be Target from INER's 70 MeV Cyclotron proton beam**
- **Project period: 2023 ~ 2026 (4 years)**

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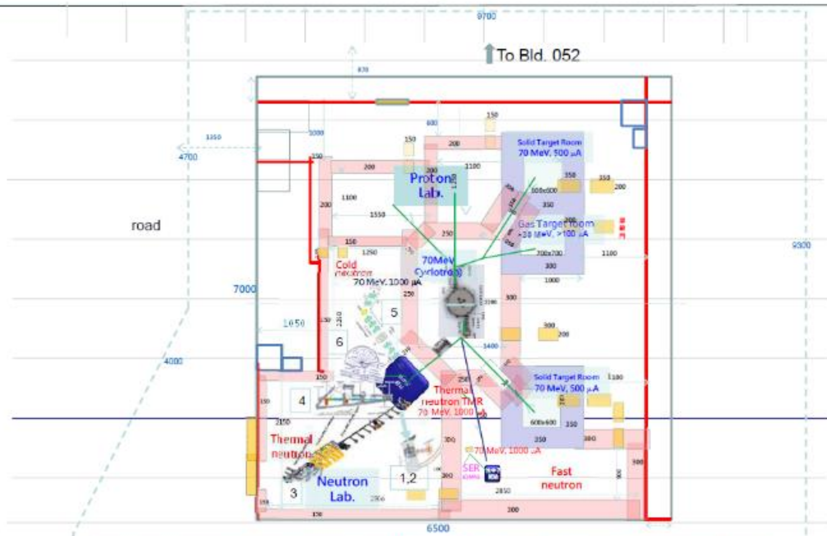
Floor Plan of 70 MeV Cyclotron Building (1st floor)



Note: In neutron lab. where the notations are 1. Neutron Diffraction、2. Neutron Stress、3. Neutron SANS、4. Neutron Radiography、5. Neutron Scattering、6. Neutron Back-scattering。

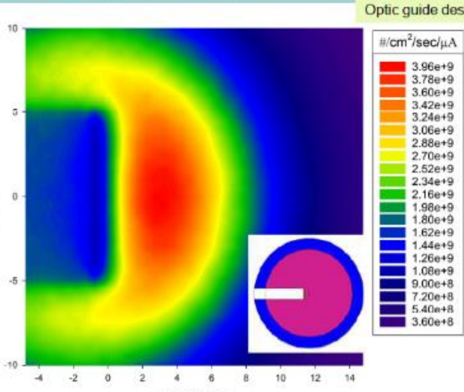
[unit: cm]

Thermal Neutron Diffraction Science Station

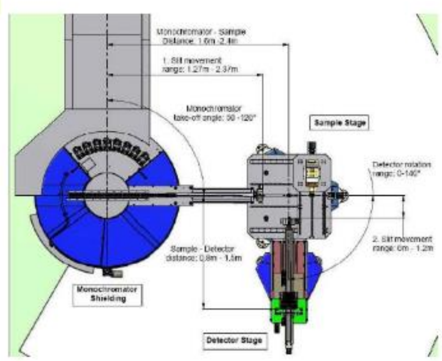
Thermal neutron source (Ta target) MCNP simulation

Optic guide design

Thermal neutron diffraction Instrument



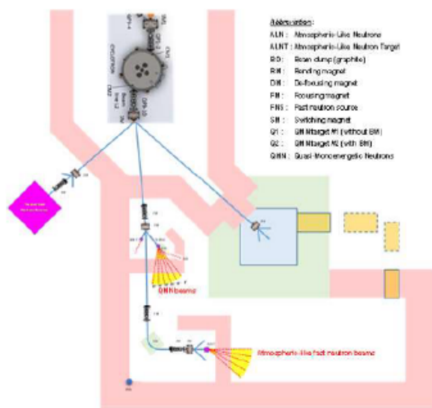
Thermal neutron flux distribution for 70 MeV/1mA proton beam.
(TMR are Ta/PE/Pb, Ta target area 10cm by 10cm, thermal neutron energy in 10meV ~ 500meV)



Proposed design of neutron **powder diffraction** instrument

(provided by Mirrotron Inc.)

Plan for fast neutron science station



Layout for the fast neutron test region

Quasi-monoenergetic neutron source (Be/Li target)

Quasi-Monoenergetic Neutron (QMN) Source (Beryllium target)

Neutron		Cyclotron		Target			
Peak energy	Yield estimated	Proton energy	Proton current	Materials	Thickness	Range projected	Thickness to Range
(MeV)	(n/s)	(MeV)	(uA)	--	(mm)	(mm)	--
68		70	100	Be	2.0	26.85	7.4%
58		60	100	Be	2.0	20.34	9.8%
48		50	100	Be	1.0	14.63	6.8%
38		40	100	Be	1.0	9.77	10.2%
28		30	100	Be	1.0	5.80	17.2%

Quasi-Monoenergetic Neutron (QMN) Source (Lithium target)

Neutron		Cyclotron		Target			
Peak energy	Yield estimated	Proton energy	Proton current	Materials	Thickness	Range projected	Thickness to Range
(MeV)	(n/s)	(MeV)	(uA)	--	(mm)	(mm)	--
68		70	100	Li	5.0	92.15	5.4%
58		60	100	Li	5.0	69.77	7.2%
48		50	100	Li	2.0	50.17	4.0%
38		40	100	Li	2.0	33.47	6.0%
28		30	100	Li	2.0	19.88	10.1%

Atmospheric-like neutron source (Be/W target)

C) Atmospheric-like Neutron Source

Neutron		Cyclotron		Target				
Energy range	Yield estimated	Proton energy	Proton current	Materials	Thickness	Range projected	Thickness to Range	Duty
(MeV)	(n/s)	(MeV)	(uA)	--	(mm)	(mm)	--	--
1-70		70	100	W	3.7	4.37	84.7%	80%
1-70				Be	22.8	26.85	84.9%	20%

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4. Conclusions

- Taiwan's THOR reactor had been operating for 61 years, to plan ahead, new projects of using cyclotron as neutron sources has been proposed and executed at INER since 2021.
- A small scale neutron source by using the existing 30 MeV cyclotron with Be target is presented, some preliminary results are shown.
- Planning for the new 70 MeV cyclotron with a dedicated neutron laboratory is described with space for future expansion of more neutron facilities.
- At this moment, INER don't have a cyclotron neutron source.
- Many conceptual designs and instrument construction are still in process . We hope to present more results in the future.

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End

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