行政院所屬各機關因公出國人員出國報告書

（出國類別：考察）

參訪日本國立癌症中心醫院暨出席第三十五屆質子治療研討會公差報告

服務機關：行政院原子能委員會

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目　　錄

摘　要

質子治療為放射醫學界之最新發展方向，其中質子治療加速器為原子能法所列管之可發生游離輻射設備，為了解有關質子治療相關科技之最新發展，及質子治療設施相關輻射安全管制措施，前往位於東京近郊的（亞洲第一個使用質子治療病人的醫院）日本國立癌症中心（National Cancer Center Hospital East）參訪，並參加於日本筑波大學舉辦的第三十五屆質子治療研討會（Proton Therapy Cooperative Group,PTCOG），參訪質子醫學研究中心（PROTON MEDICAL RESEARCH CENTER），了解國際上此項技術發展之最新情況。因國內已有醫療院所表示有意願引進此新科技，設置質子治療設施；因此我國更應多蒐集相關輻防資訊，除確保輻射安全外亦應注意輻射醫療之品質。

壹、 目的

一、 醫用質子治療機

質子治療是近幾年來廣受放射線醫學界注目的醫療技術，全世界目前從事質子治療的設施已超過 10 所以上，計畫中及興建中的設施也超過 10 所，目前已有數萬人接受過治療，且治療成效斐然。目前國內並無質子加速器，因此也沒有質子治療機。但國內有些醫院對引進此新技術有很大的興趣，而且鑑於質子治療機在癌症之治療上，有其特殊之醫療效果，因此預期我國也很快會擁有質子治療設備。

質子治療機的作用機制，是利用同步輻射加速器（syncrotron）或迴旋加速器（cycltron），將氫之質子加速到 250MeV 的能量（有些更高能量的加速器可以將碳離子加速到 320 MeV 的能量），然後再利用磁場等設備使質子轉變方向，引導至治療室來治療病人。由於質子治療機所使用之能量很高（能量使用範圍為 100~250MeV），且其能量釋放集中於特定深度，例如 250MeV 的質子射線在人體內最大能量深度為 33.5 ㎝（即 Bragg Peak 特性），在腫瘤治療時可以使劑量集中於病灶，並可減低周圍組織的劑

量。達到完全殺死癌細胞、減少正常組織受到輻射傷害的目的。可以說是未來利用放射線治療癌症的新利器。

由於質子治療建設經費龐大（約需新台幣 30 億元）且其能量很高，在輻射防護上除需要完善的屏蔽外，操作人員的訓練、醫學物理師的配合、輻射醫療品質的確保，都是需要注意的課題。

二、 質子治療的歷史

質子治療最先應用於癌症臨床上，是始於 1954 年。當時美國加州的 Lawrence Berkeley National Laboratory 研究所，將由物理研究用的加速器得到之質子射線，照射腦下垂體以緩和乳癌患者之症狀。1970 年初哈佛大學開發新的技術，將質子治療用於大範圍腫瘤，開啟了質子治療新的研究。

日本於 1983 年開始於筑波大學進行深部臟器的癌症質子治療，在肝臟腫瘤方面有良好的治療結果。由於近年來加速器製造技術的更新、治療計畫的電腦化、影像診斷技術的進步、以及世界各地質子治療設施成功的治療結

果，1995 年日本國立癌症中心開始建造質子治療設施，並於 1998 年開始臨床使用。

迄 1997 年止全世界已有 16 所質子治療設施，預計在 2010 年前，即可達到 30 所。

貳、行程

90 年 11 月 11 日------ 行程（台北-東京）

11 月 12 日------ 參觀日本國立癌症中心(東京）

11 月 13 日------ 研討會報到

11 月 14 日------ 出席研討會

11 月 15 日------ 出席研討會

11 月 16 日------ 出席研討會

11 月 17 日------ 返程（東京-台北）

參、參訪日本國立癌症中心

日本國立癌症中心共有兩個醫院，一個位於東京築地、擁有三十年歷史的國立癌症中心中央醫院，另一個位於千葉縣的柏市。本次參觀的即是位於千葉縣柏市，設有

質子治療設備的國立癌症中心東醫院。

日本國立癌症中心東醫院是由國立柏醫院、國立療養所松戶醫院合併而成，於 1992 年成立於千葉縣的柏市、共有 425 床。入院患者主要是肺癌、肝膽脾等消化器癌症為主，其他的癌症例如乳癌、血癌、骨癌等癌症病患，醫院也導入各種新的治療方式。醫院另一個特色是非常重視癌症患者的生活品質（Quality of life），是日本國立醫院中第一座設立安寧病房的醫院。此醫院所設置的質子治療設備是日本第一座、全世界第二座設置於醫院的質子治療設備。質子治療設備設置於醫院一樓，總共設有三間質子治療室。其中兩間是日本國內第一座設有可旋轉旋轉臂（gantry）的治療室，可以從各個不同的角度做全身的照射，克服了以往固定式治療設備的缺點。

二樓設有質子治療時必需之 bolus collimator（其功用是劑量校正，使腫瘤各部位都接受相同劑量）製作的電腦化設備，三樓則裝有診斷必須的電腦斷層攝影機、核磁共振儀等先進的機器。可說是一個設備完善且完全電腦化的醫院。

設置質子治療的樓層是採取負壓設計，在各治療室

中都裝有中子及加馬射線的監測器，進入治療室時需先打開設於治療室外的聯鎖裝置控制鎖，並將鑰匙拔下才能進入治療室操作儀器，在輻射安全設計上非常完備。

可旋轉旋轉臂（gantry）的治療室在設計上，比起固定式的可說是困難許多。帶動旋轉臂的轉輪重達 2 公噸，迴轉 gantry 的直徑 10 公尺、高 15 公尺，再加上使質子轉向的磁場設備，整個龐然大物約佔了三層樓高的空間（請參考附錄一的相片）。

此次參訪國立癌症中心東醫院時，拜訪了質子治療部門的主任荻野博士，他提供了一份院方平時對設備所做檢測項目的一覽表（附錄二）及當初向日本科學技術廳提出申請時的屏蔽計算資料（附錄三）供我們參考。據稱當初申請時，日本科學技術廳書面審查就花了將近一年的時間。

日本科學技術廳每三年稽查國立癌病中心東醫院一次，因稽查是以醫院為單位並不是以機器為單位，因此醫院並不會因為新添輻射設備，而增加醫院被稽查的頻度。科學技術廳來稽查時除了設備之外，密封、非密封物質都一併檢查，稽查時主要是審閱一些書面的記錄、檢查

聯鎖裝置之安全功能及偵測非管制區之輻射劑量 。

國立癌症中心東醫院的質子加速器，其輻射屏蔽的計算，是以實際治療病人的劑量以及人數來估算非管制區的劑量，其設計值是以每週250分次(fraction)，一年10000分次(fraction)計算。若以每人 25 分次(fraction)計算，則一年治療病人數是400人。

質子治療在眼部腫瘤、頭蓋底腫瘤、肝癌、前列腺癌、已證實有明顯的治療效果。今後，對於腦瘤、頭頸部腫瘤、肺癌、食道癌或腹部骨盆的腫瘤亦預期有明顯的治療效果。由於發展醫療專用的質子治療設施，成為世界各醫療先進國家必然的趨勢，因此日本國立癌症中心東醫院對於各種癌症的治療做成了臨床實施草案（protocol)，並且預定依序施行。

肆、質子治療合作組織研討會內容

此次在日本茨城縣筑波科學城、筑波大學學生會館，舉辦的第三十五屆質子治療合作組織研討會，共有約150人參加。除了 100 人左右是日本當地的學者專家之外，

從海外也有 50 多人來參加。包括俄羅斯、美國、德國、比利時、義大利、瑞典等國的專家學者與會。

整個研討會分成 3 天舉行，其討論的內容包括臨床醫學、保健物理、劑量評估、輻射生物效應、輻射醫療品質保証計畫、迴旋加速器設計等方面的議題。由各個不同的角度來討論質子治療應用上所遇到的問題；並且交換各不同治療機構的心得，包括利用質子治療癌症的成果，以及質子治療失敗的例子。在會議中特別簡介了日本最新的質子治療設施，位於兵庫縣的兵庫醫學中心。該中心之質子治療設施，除了使用氫離子之外，亦可使用碳離子來治療癌症病人，預計在 2002 年即可開始治療病人。

本次研討會共有 52 篇即席發表的論文以及另外 25 篇以 poster 形式發表的論文，共分成 7 個主題；研討會第一天晚上，還安排了日本有名的小提琴家天滿敦子的小提琴演奏，讓與會的成員在緊湊的討論會後，轉換不同的心情，繼續次一日的討論，以下是這次研討會發表論文的題目，詳細摘要如附錄四。

一、質子治療用於治療軀幹癌症方面的論文。

1. 質子治療在非小細胞肺癌上的臨床結果。

2. 質子治療在子宮頸癌的長程治療結果。

3. 質子治療在食道癌的治療結果。

4. 肝癌使用短期碳離子治療的結果。

5. 質子治療用於第二期肝癌的初步結果。

6. 筑波大學利用質子治療肝癌的結果。

7. 質子治療造成的身體障礙---PSI（Paul Scherrer Institute）的經驗分享。

二、加速器及射束光學方面的論文

1.PSI（Paul Scherrer Institute）對增進質子治療技術的長程計畫。

2.Respiration Synchronized Operation of Accelerator System in PMRC（Protron Medical Research Center）,Univ. of Tsukuba.

3.FFAG Accelerator for Protron Therapy.

4.Implementing a smooth-beam extraction control method in a synchrotron-based PBTS for active and

gated beam treatments.

5.Beam optics for a scanned proton beam at Loma Linda.

三、 臨床研究方面的論文

1.電腦斷掃描儀以及核磁共振儀影像用於診斷早期肝臟輻射傷害。

2.利用加強對比都普勒超音波儀器（Contrast enhanced Power Doppler Ultrasonography)評估質子治療過之肝癌。.

3.非小細胞肺癌利用碳離子治療後肺毒性之分析。

4.Targeting accuracy of respiration-gated protron beam irradiation for hepatocellular carcinoma.

5.骨及軟組織肉瘤的 Dose Volume Histogram 分析。

6.哈佛迴旋加速器治療葡萄膜黑色素瘤的長程結果。

四、 質子射束的輻射生物效應方面的論文

1.質子治療的輻射生物效應值（RBE）

2.質子的輻射生物效應值（RBE）--舊問題新觀點

3.日本三所高能量質子設施的輻射生物效應。

gated beam treatments.

5.Beam optics for a scanned proton beam at Loma Linda.

三、臨床研究方面的論文

1.電腦斷掃描儀以及核磁共振儀影像用於診斷早期肝臟輻射傷害。

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3.日本三所高能量質子設施的輻射生物效應。

4.質子醫學研究中心體外實驗的質子 RBE 值（相對於 Cs-137 加馬射線）初期報告。

5.兵庫醫學中心氫質子以及碳離子臨床前的生物評估。

6.我對質子治療的期待

由腫瘤外科醫師的觀點

由神經外科醫師的觀點

由小兒科醫師的觀點

五、 射束準備以及其他方面的論文

1.質子治療利用多層能量濾片的治療計畫系統。

2.Use of a miniature ripple filter for filetring ripple found in the distal of SOBP.

3.Membrane Type Liquid Variable Compensator.

4.Performances of a Test Model of a Compact Parallel Beam Scanner for Proton Therapy.

5.Proposal of a Cylinder Type Liqrid Varible Compensator.

6.New Patient Positioner for Proton Beam Therapy.

六、 劑量計算及劑量學方面的論文

1.Range Measurement System of Patient Body using Positron Camera in Heavy Ion Therapy.

2.A simple pencil beam dose calculation module for daily treatment planning.

3 .The pixel ionization chamber：a detector for beam monitor and dosimetry.

4. Proton dose calculation in heterogeneous media：Pencil beam scaling versus Monte Carlo.

5.Implementation of an Pencil Beam Algorithm for Proton Treatment Using Different Kernels.

七、 品質保證計畫：協定、練習、未來展望方面的論文

1.品質保證用於質子治療。

2.日本粒子治療設施的 QA 協定。

3. PSI 所實行的品質保證。

4.PMRC 所實行的品質保證。

5.NPTC 的品質保證程序。

6.NCC 的劑量監視器校正程序。

7.NAC 的質子治療品質保證計畫。

8.GSI 的重粒子品質保證。

9.應用

10.PSI 質子使用者的網路：病人的轉診及資料分享。

另外還有 25 篇 poster 論文發表，主要是針對設施的系統設計、未來新設備、加速器設計、劑量評估等方面的論文。

伍、結論

1. 由於質子治療具有能量釋放集中於特定深度，在腫瘤治療時可以使劑量集中於病灶，並可減低周圍組織劑量的特性，因此是近年來放射線治療癌症的新利器。全世界目前從事質子治療的設施已超過 10 所以上，計畫中及興建中的設施也超過 10 所，在 2010 年前，預計可達 30 所以上。目前已有數萬人接受過治療，而且成效斐然。隨著科技的進步，將來或有可能取代直線加速器成為主要的放射線治療設備。因此，對此設備的輻射醫療品質的確保，及其輻射

安全的確立，將會是個重要的課題。

2. 使用此高能量的質子治療設備，需有很強的治療團隊，而且團隊合作格外重要。除了醫生之外，物理師、輻射生物專家都要一起參與。否則除了達不到應有的治療效果外，更可能造成重大之輻射傷害。

3. 為了確保輻射醫療品質及輻射安全，人才的確保將會是需要考量的問題。反觀今日國內的情況，清華大學輻射生物科系已走入歷史、醫學物理師制度也尚未建立完成，將來我國若引入質子醫療設備，我們可以買到最好的硬體設備、及一切軟體設備，但是如果沒有好的人才、適當的培訓，即使有最好的設備，也未必有良好的治療效果。為了確保質子治療設備之輻射醫療品質及輻射安全，應該更積極致力於人才的培訓。

陸、建議

1. 由於質子治療在癌症治療上有其不可取代的功效，

且世界上先進國家如美國、英國、德國等國，都已設置質子治療設備。因此將來國內醫學中心若考量引進質子治療設備及技術，政府應予大力協助，以提昇國內醫療水準。

2. 由於興建質子治療設備，需耗費新台幣數十億元，是很大的投資。且其產生之能量可達250MeV，雖然在治療室內，由於質子與物質作用的特性，輻射劑量很低，但產生質子之同步加速器或迴旋加速器，其周圍之輻射防護及屏蔽卻不可疏忽。因此在引進之初，一定要有完善的評估與嚴格的審查。

3. 為因應質子治療技術的未來趨勢，國內應該及早開始培養醫學物理師、輻射生物專業等方面的人才。並應早日確立醫學物理師的認證作業，以提昇國內輻射醫療品質。

4. 此次參加在日本筑波大學舉行的質子治療研討會，與會的成員除了醫師、醫學物理師、輻射生物研究人員以外，機器製造方面的專家（包括製造機器的廠商及大學機械系的教授）也參與論文的發表。結合了製造者、使用者、管理者各方面不同的意見，

從各種不同的角度來共同探討質子治療。國內也應多舉辦產、官、學結合的研討會，相信在新技術的推廣上定有助益。

5. 日本對於放射性物質及可發生游離輻射設備之稽查，係以醫院為單位，因此增設質子治療設備，並不會改變醫院被稽查的時間（若醫院只含有一般高能可發生游離輻射設備時為5年稽查一次，若醫院有包含非密封放射性物質之使用時，則為3年稽查一次)。平時則由醫院的輻射防護人員自行管理。我國稽查係以機器為單位，因此配合輻防法的修訂，將來亦可參考以醫院為單位，以有效達到整體稽查的效果。

柒、附錄

（一）參訪國立癌病中心東醫院及參加研討會相片。

（二）國立癌病中心東醫院平時院方設備自行檢測一覽表。

（三）國立癌病中心東醫院質子治療設備

申請許可時，送日本科學技術廳之部分資料。

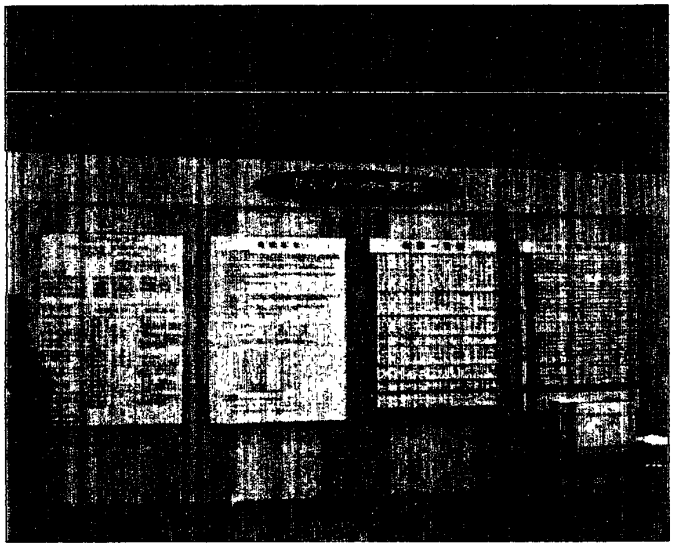
（四）第三十五屆質子治療研討會議程。

附錄一、參訪國立癌病中心東醫院及參加研討會相片。

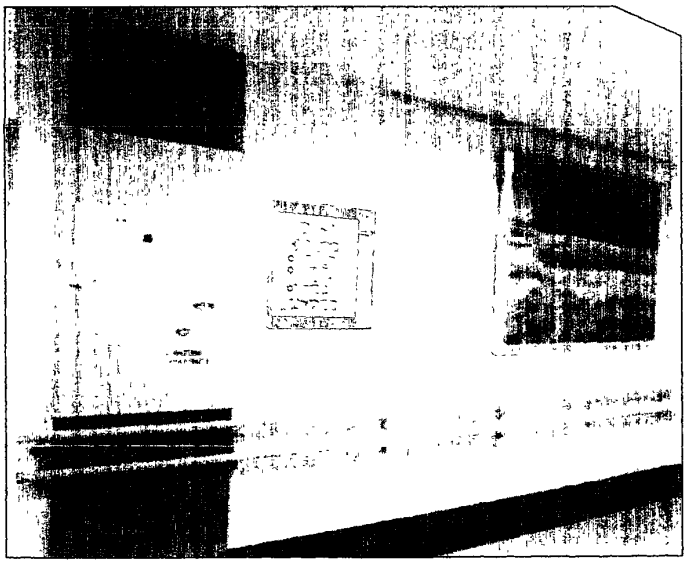
附錄一

國立癌症中心東醫院外觀

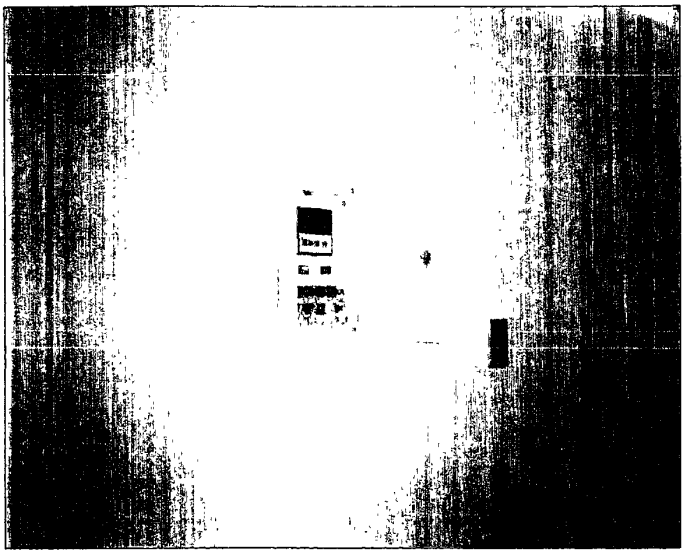
院內組織一覽表



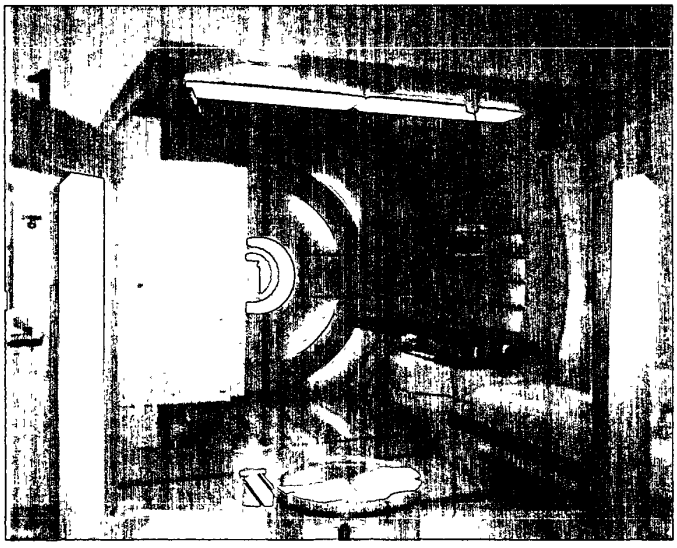
通往質子治療設施的走道



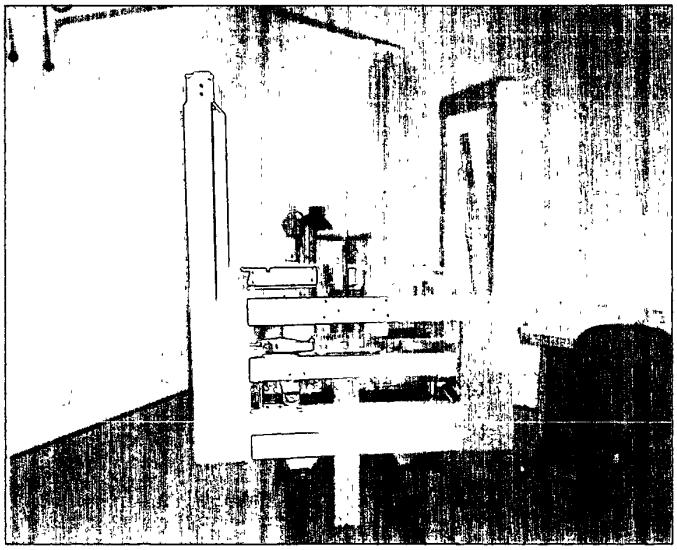
質子治療室外之聯鎖裝置控制鎖，進入前需將鑰匙拔下才可啟動儀器



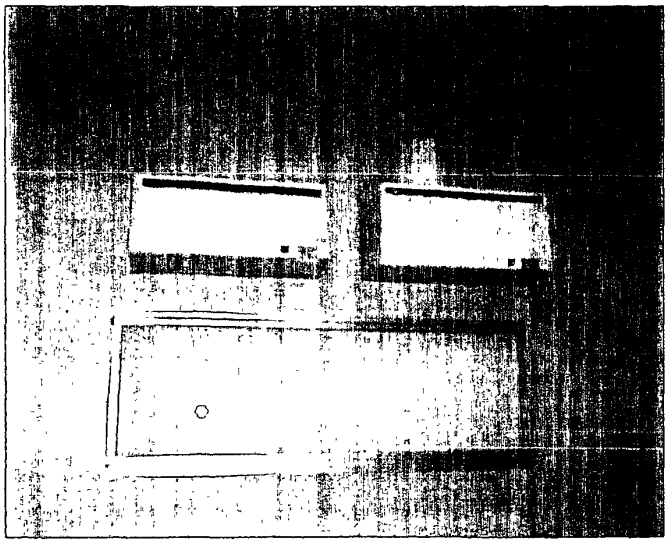
可旋轉式質子治療機



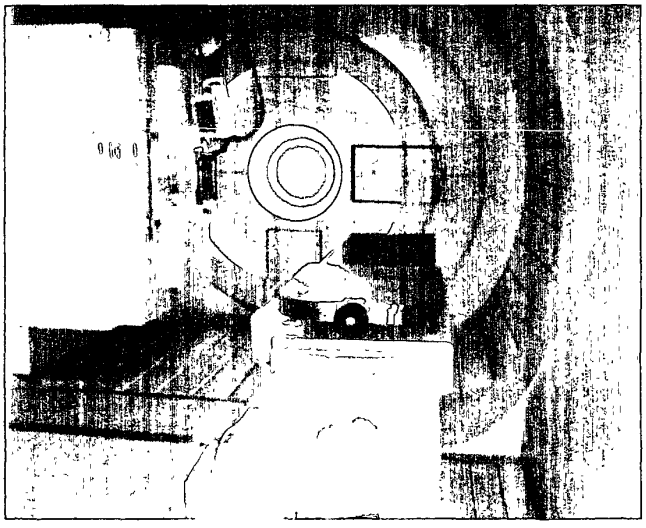
劑量校正用假體



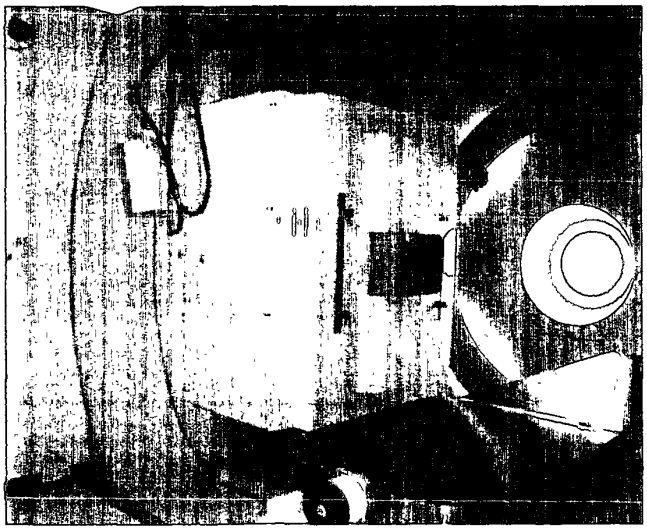
治療室內之中子及
加馬線監測器



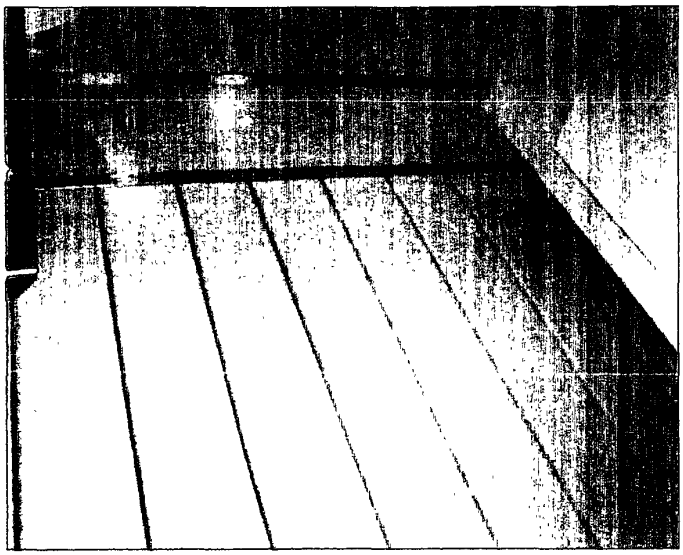
可旋轉式質子治療機
機頭及table



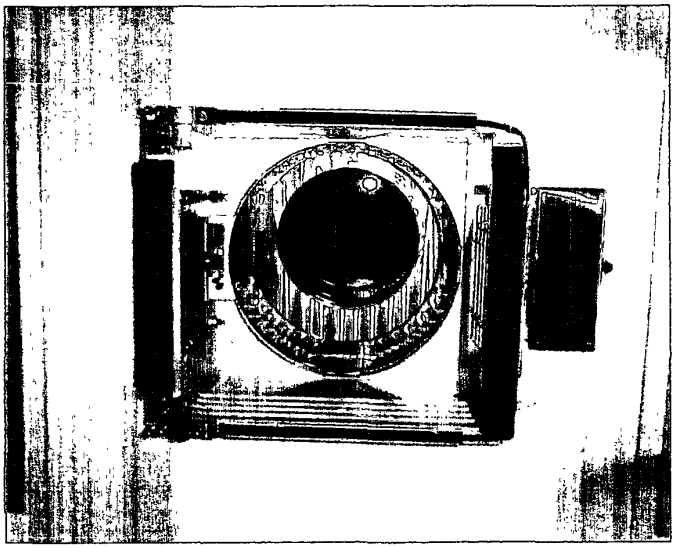
可旋轉式質子治療機
機頭及table



帶動旋轉臂的旋轉帶

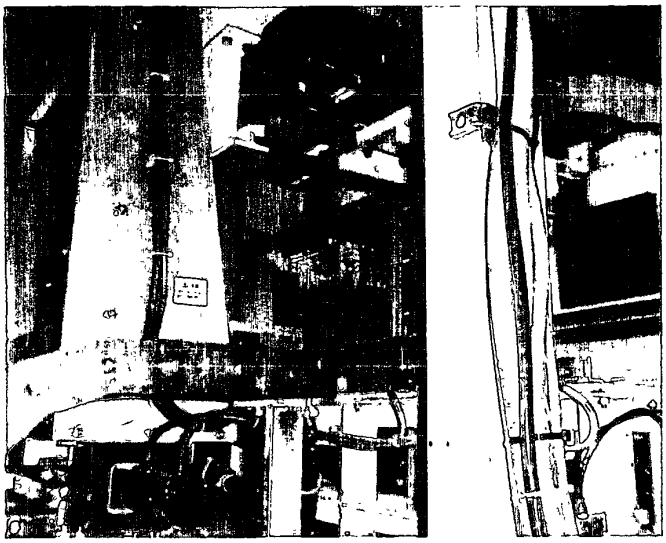


質子治療機準直儀

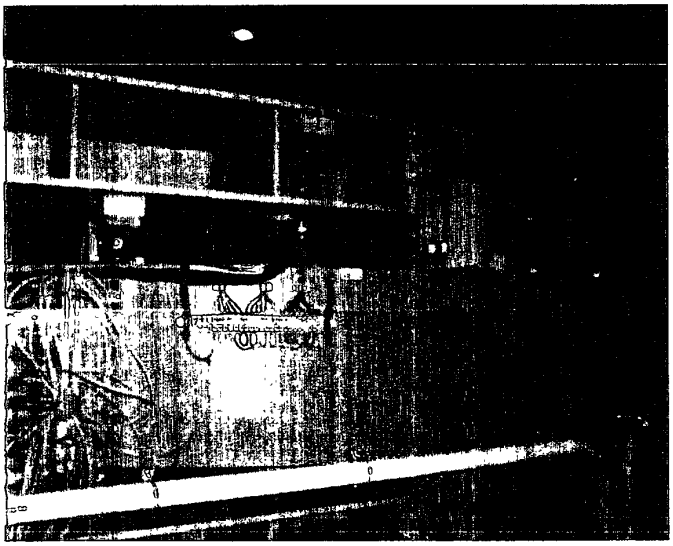


固定式質子治療機

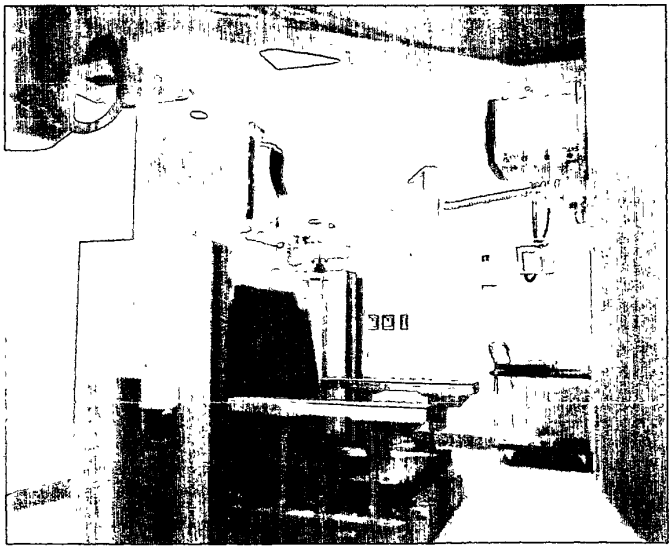
可旋轉式質子治療機
旋轉臂內部構造



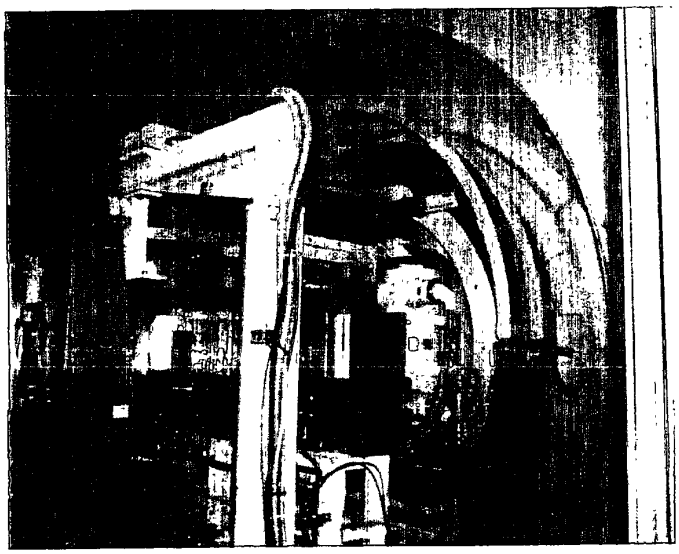
可旋轉式質子治療機
旋轉臂內部磁場構造



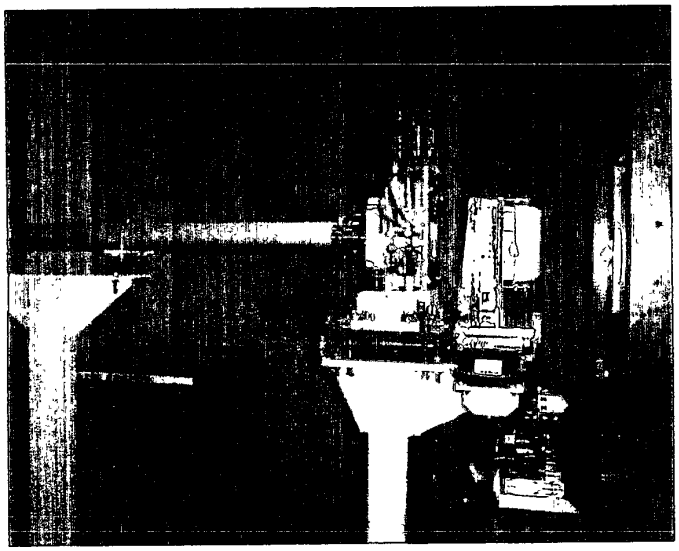
固定式質子治療機



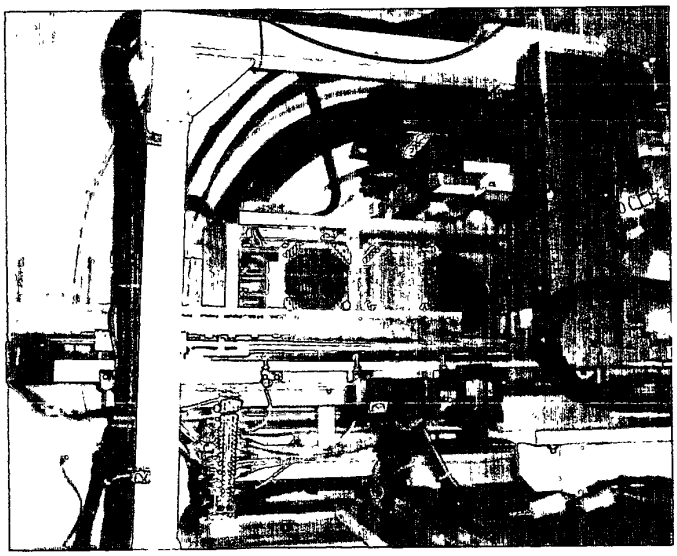
固定式質子治療機
內部構造



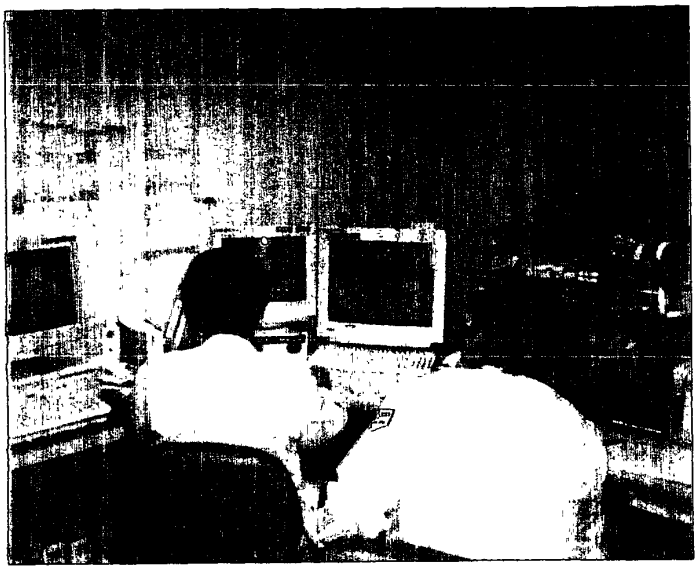
固定式質子治療機
射線濾片及散射片



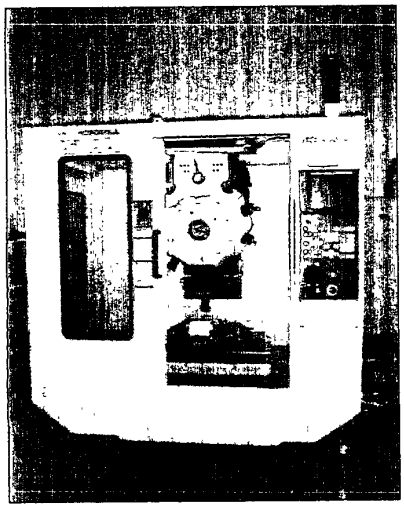
固定式質子治療機
射線濾片及散射片



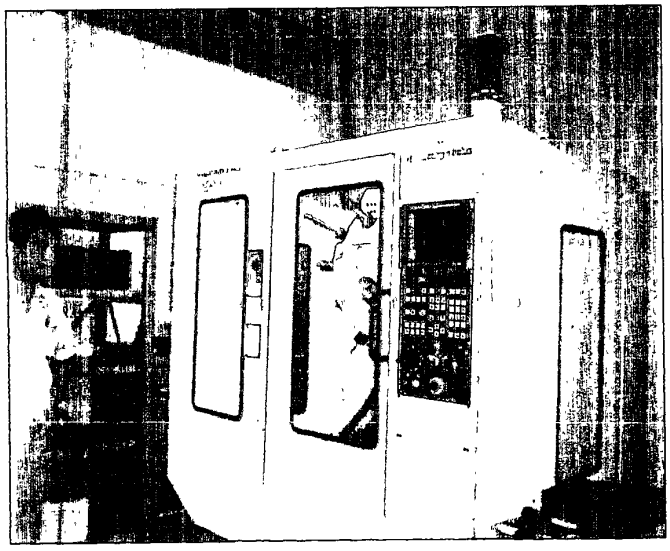
迴旋加速器控制室



製作Bolus之設備

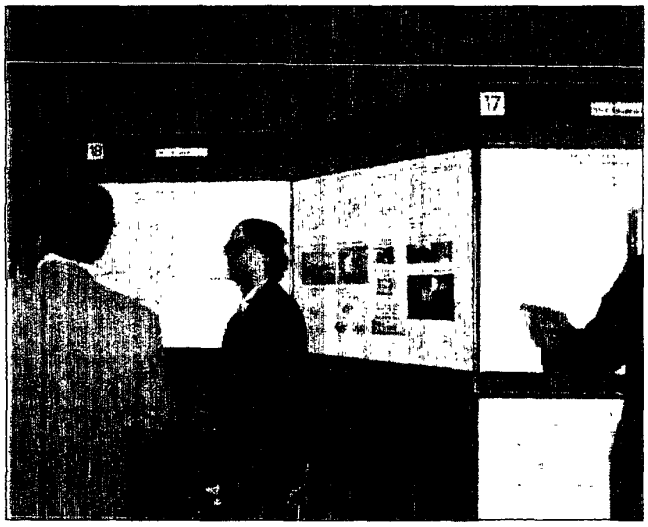


製作Bolus之設備

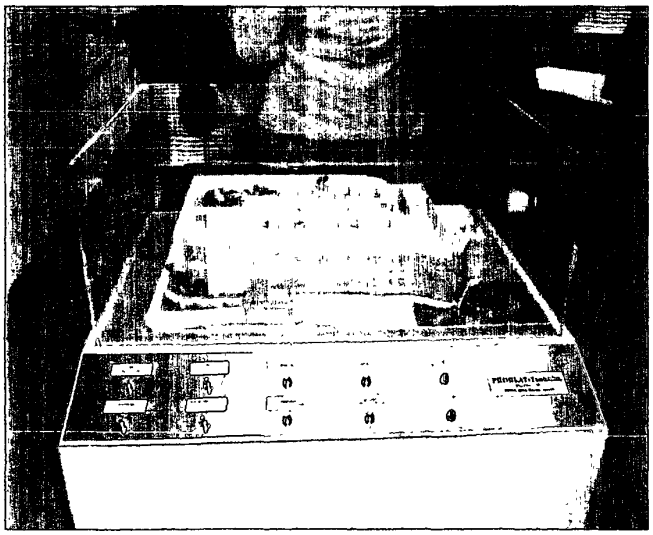


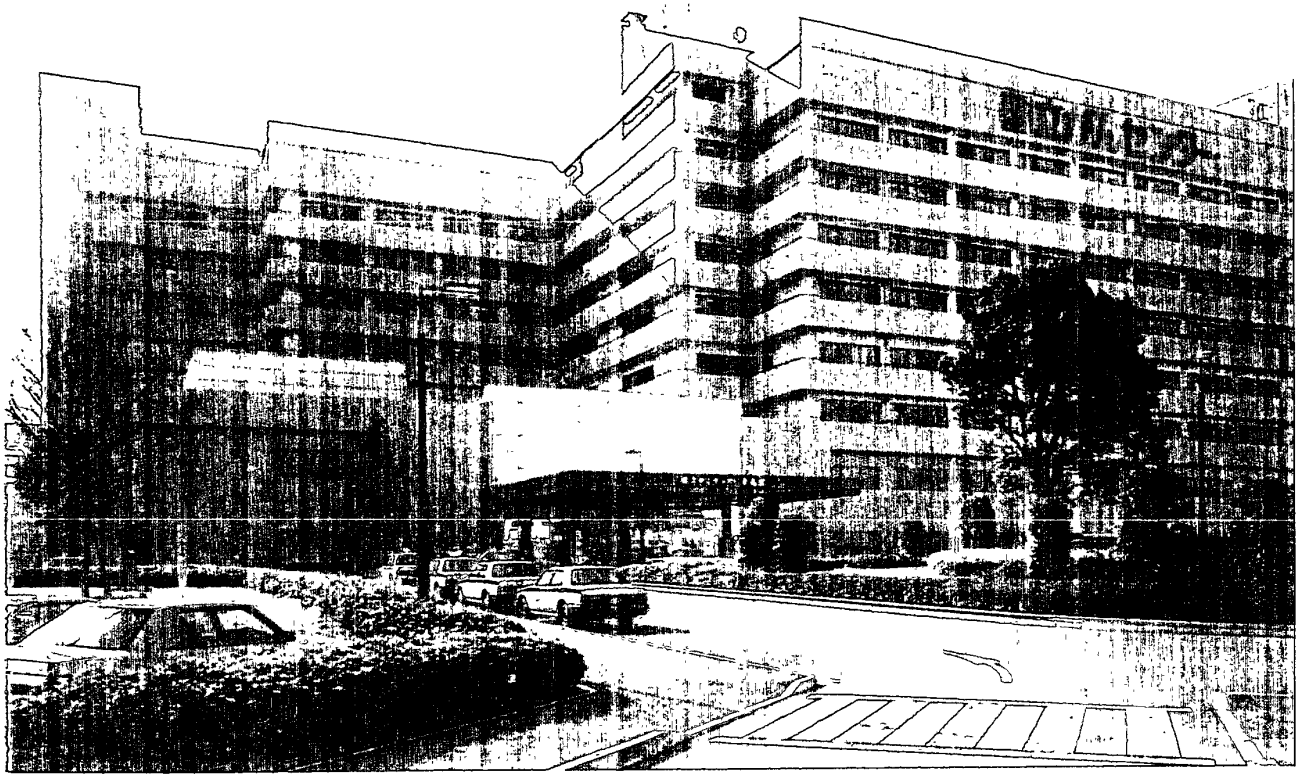
研討會Poster 展示

研討會Poster 展示



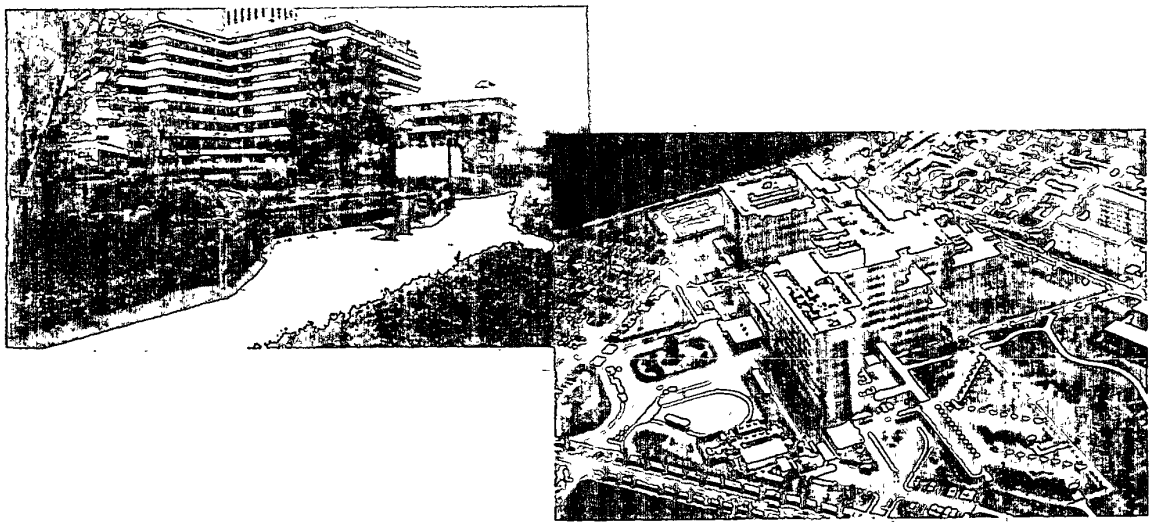
研討會展示迴旋加速器
及質子治療機模型





国立がんセンター東病院

NATIONAL CANCER CENTER HOSPITAL EAST



国立がんセンター東病院の目的

国立がんセンター東病院は、国立病院、療養所再編成の一環として、国立柏病院、国立療養所松戸病院が統合され、425床を持つがんに対する高度先駆的医療機関として、平成4年7月に新たに千葉県柏市に設立されました。国立がんセンターは、東京、築地に30年以上の歴史を持ち、多くの世界的な研究業績を生み出してきました。東病院の開設にともない、築地の病院は国立がんセンター中央病院と改称され、東病院は中央病院と機能分担をはかり、密接な連携を持ってがん患者の診療と研究にあたっております。

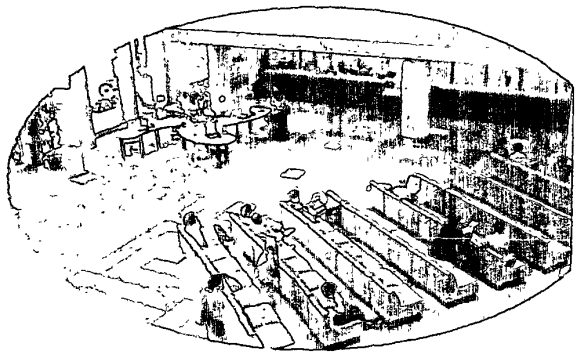
東病院では、外来は全てのがんに対応可能ですが、入院については特に肺がん、肝・胆・膵などの消化器がん、頭頸部がんなどを主体にし、また、乳がん、造血器腫瘍、骨・軟部腫瘍なども積極的に診療し、新しい診療技術の開発を行っています。進行がんに対しては、有効な薬物療法や集学的治療法を開発し、適切な臨床試験研究により標準的治療法を確立するために努力しております。

東病院の特徴の1つとして、患者の生き方の質（Quality of life, QOL）を重視し、機能温存療法などQOLに重点をおいた診療や研究を行うのみならず、がん患者の福利のために病院の診療環境を整えております。治療の限界については、それを乗り越える努力と共に、それを謙虚に認めるという姿勢も重要であります。そのため、がん終末期患者に対する“緩和ケア”病棟25床が国立病院としては初めて院内独立病棟型として設立され、全人的ケアをおこなっております。

東病院は、開院以来3年が経過し、フル稼動の状態にあります。目覚ましく進歩した分子腫瘍学、画像診断技術、情報化の新しい波を取り入れながら、平成6年4月に隣接して開所した研究所支所と密接に連携して研究を展開し、診療技術の向上をはかっています。国立がんセンターに新たに導入されたスーパーコンピューターを用いた人工知能技術や高次画像処理技術による診断治療の支援システムの開発が始まると共に、柏と築地の両キャンパスを光ファイバーで結ぶ事によってテレメデシンやテレビカンファレンスが可能となり、東病院と中央病院との距離の制約を克服して、機能分担による高度先進医療が効率よく実行できる時代を迎えました。この様な医学の新しい視点からがんの診療、研究をさらに充実・発展させ、患者さんに信頼されると共に、国民の期待に沿える病院を目指しております。

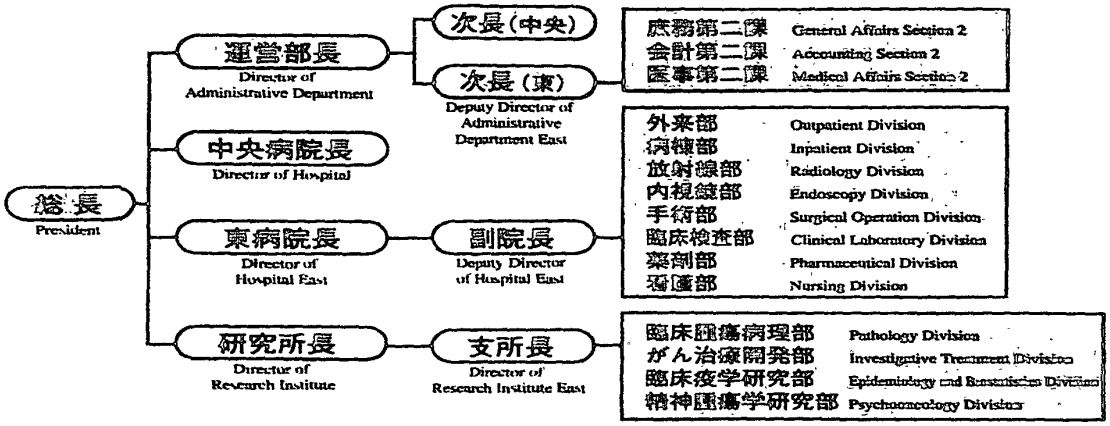
国立がんセンター(東)の歩み

昭和 60年 3月28日　国立病院・療養所再編成・合理化の基本指針
61年 1月 9日　国立病院・療養所再編成計画策定
62年11月27日　柏・松戸統合病院整備基本計画案の概要
63年 3月10日　国立第二がんセンター（仮称）基本計画
63年12月21日　国立第二がんセンター（仮称）本館着工
平成 3年 1月 1日　国立第二がんセンター（仮称）設立準備室設置
4年 6月 1日　研究所支所着工
4年 6月18日　健医発第739号により国立がんセンター東病院を発足
4年 6月25日　東病院本館竣工
4年 7月 1日　総長 末舛 恵一
4年 7月 1日　院長 阿部 薫 就任
4年 7月 1日　研究所支所長 児玉 哲郎 就任
4年 7月 1日　東病院診療開始
5年10月 1日　研究所支所長 江角 浩安 就任
6年 2月24日　研究所支所竣工
6年 4月 1日　総長 阿部 薫 就任
6年 4月 1日　院長 下山 正徳 就任
7年 4月 1日　院長 海老原 敏 就任

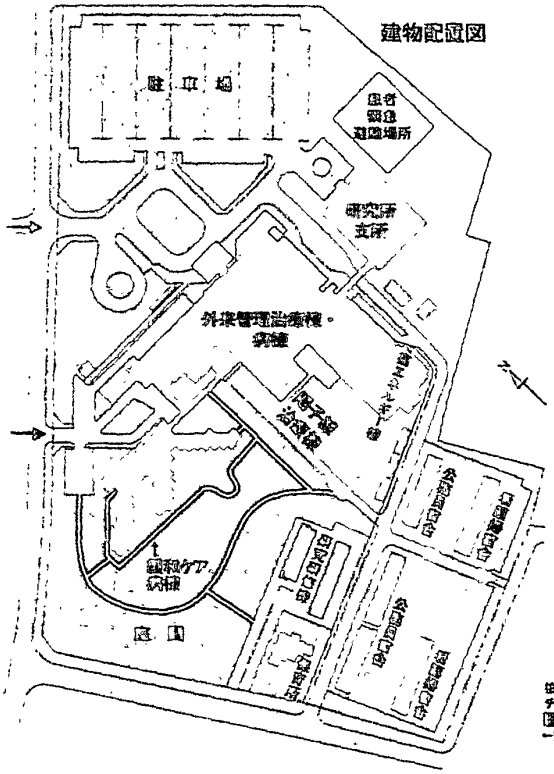


自然の採光を生かした、明るい印象性に富むエントランスホール

国立がんセンター(東)組織図

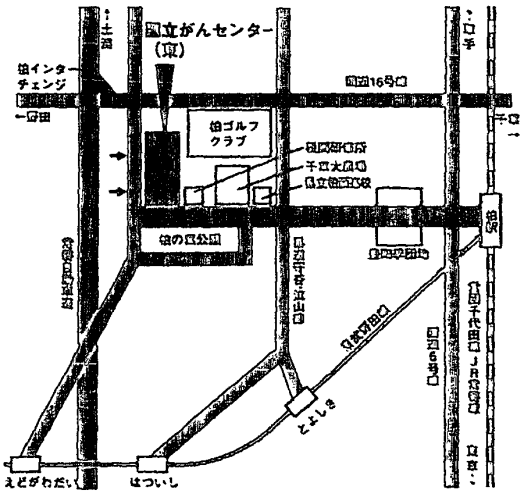


施設へのご案内



施設概要
病　床　数：一般病棟400床、緩和ケア病棟25床
診療科名：内科、小児科、精神科、消化器科、外科、
整形外科、脳神経外科、呼吸器科、呼吸器外科、
皮膚科、婦人科、眼科、耳鼻咽喉科、理学診療科、
放射線科、麻酔科、歯科

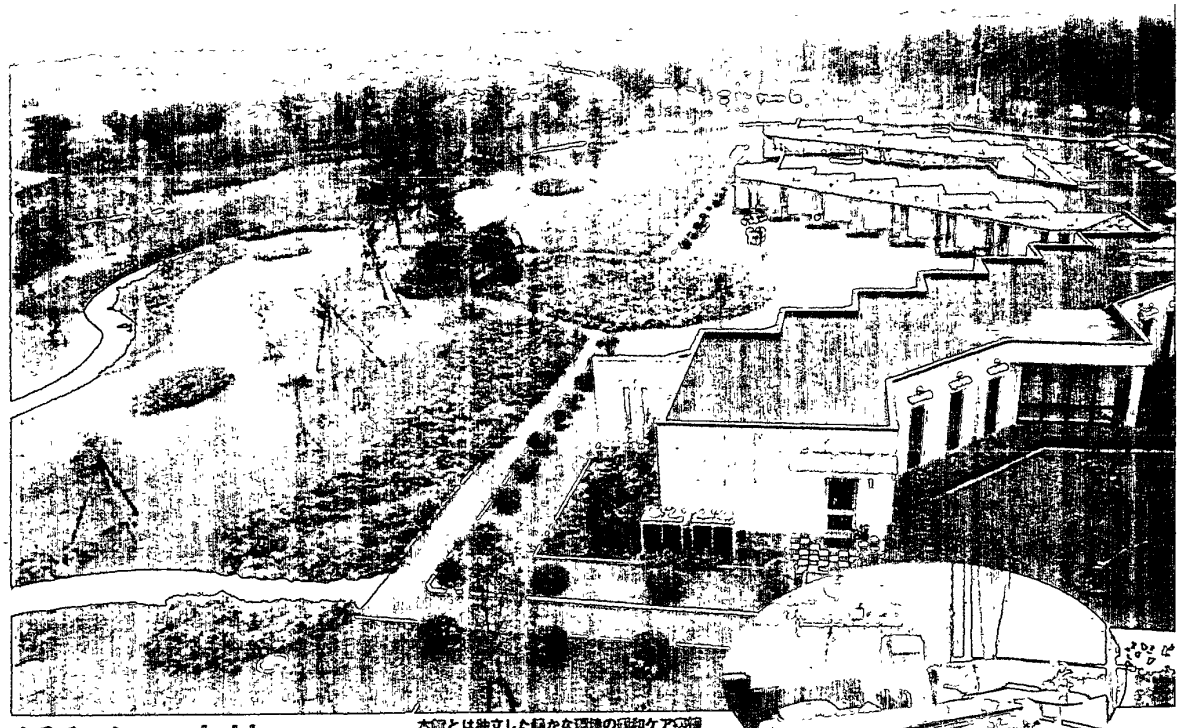
設備概要
敷地面積：79,929.14m²
建築面積：8,175.13m²
延べ面積：36,787.32m²
構造・階数：主体構造　鉄骨鉄筋コンクリート造
階数　本館　地下1階地上9階塔屋1階
緩和ケア病棟　地上1階
ダムウェーター：検査科　1台
搬送機：中型搬送設備　18ステーション
自走台車　12ステーション
駐車場：300台



(交通)
ＪＲ柏駅西口より東武バス25分　タクシー15分
・営団地下鉄千代田線 大手町から柏駅45分 西口下車
・営団地下鉄日比谷線 または千代田線・北千住でＪＲ常磐線乗換えＪＲ柏駅西口下車
・ＪＲ常磐線上野駅より柏駅30分
常磐自動車道柏インターから千葉方面に出て16号線を右折5分

所在地
〒277 千葉県柏市柏の葉 6-5-1
電話(代表) 0471-33-1111　診療予約電話 0471-33-1111
内線 2117

NATIONAL CANCER CENTER HOSPITAL EAST



本館とは独立した静かな環境の緩和ケア病棟

緩和ケア病棟

○国立病院として初めての本格的な緩和ケア病棟
○治癒や延命が困難ながん患者さんを対象にした疼痛などの症状緩和と精神的なケアを行う
○全個室にシャワー、トイレと整理ダンス、食器棚、冷蔵庫を装備
○コンサートやお花会を開いたり、患者さん・家族のための憩いの場になるサン・ルームの設置
○家族休憩室や家族が調理できる台所の設置
○健康保険「緩和ケア病棟入院料」の適用

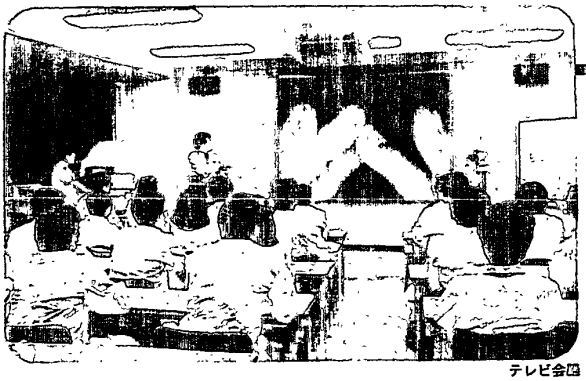
薬剤部門

○天井、壁面にヘパフィルター装備の散薬調剤コーナーを設けたクリーンな調剤室
○IVH(中心静脈栄養輸液)を調製するための無菌調製室
○入院患者さんへの薬歴管理と服薬指導

ボランティアによる移動図書サービス

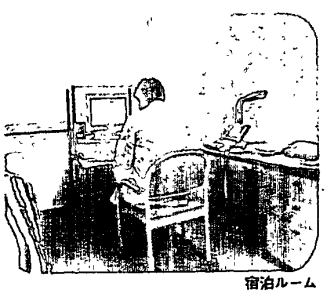
ボランティア活動

○ボランティアの温かい心のこもった活動にささえられる療養環境
○外来案内、移動図書、緩和ケア病棟、生け花、ギャラリー、新聞配達、イベント、花壇と多彩な活動内容
○きめの細かいサービスとピンクのエプロンが目印のボランティア



テレビ会議

研究・研修部門

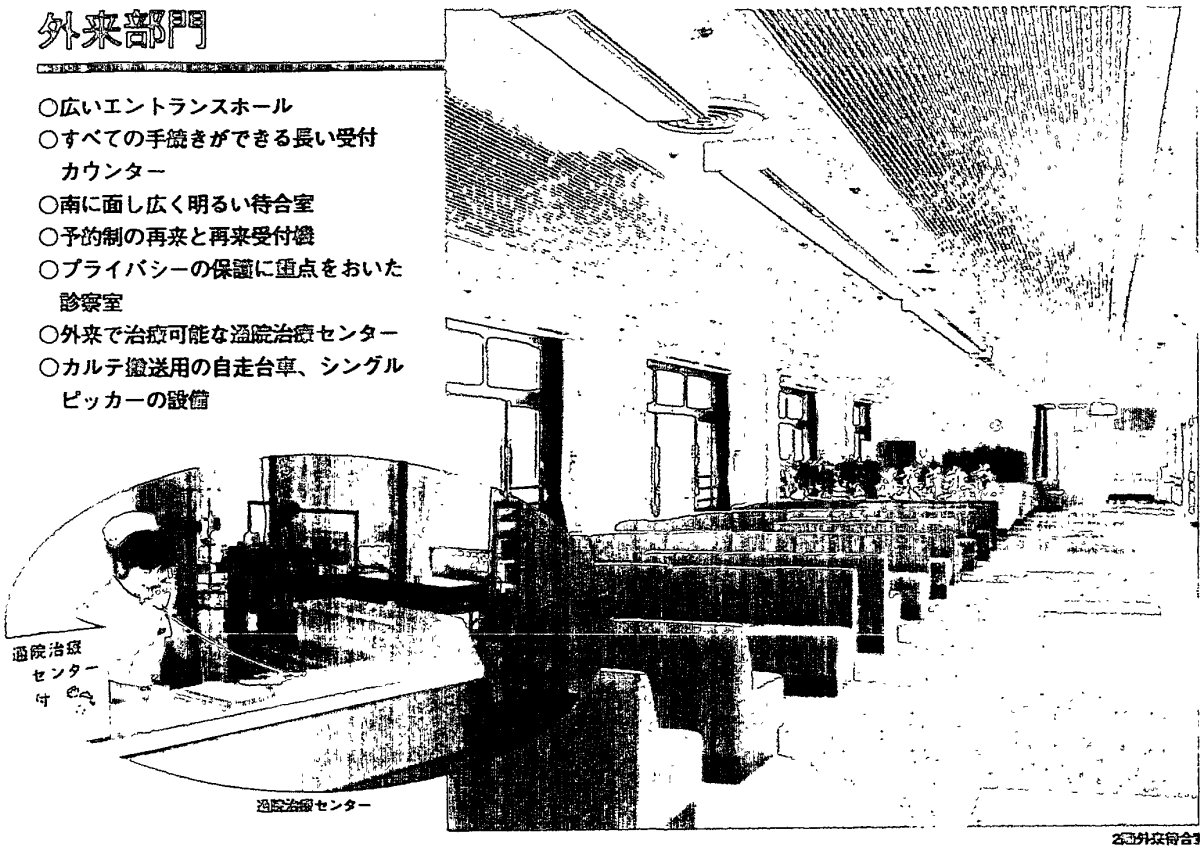


宿泊ルーム

○がんの診断、治療に携わる医師、看護婦、技師、薬剤師のための研修
○研修者の便宜のため宿泊施設を設備

外来部門

○広いエントランスホール
○すべての手続きができる長い受付カウンター
○南に面し広く明るい待合室
○予約制の再来と再来受付機
○プライバシーの保護に重点をおいた診察室
○外来で治療可能な通院治療センター
○カルテ搬送用の自走台車、シングルピッカーの設備

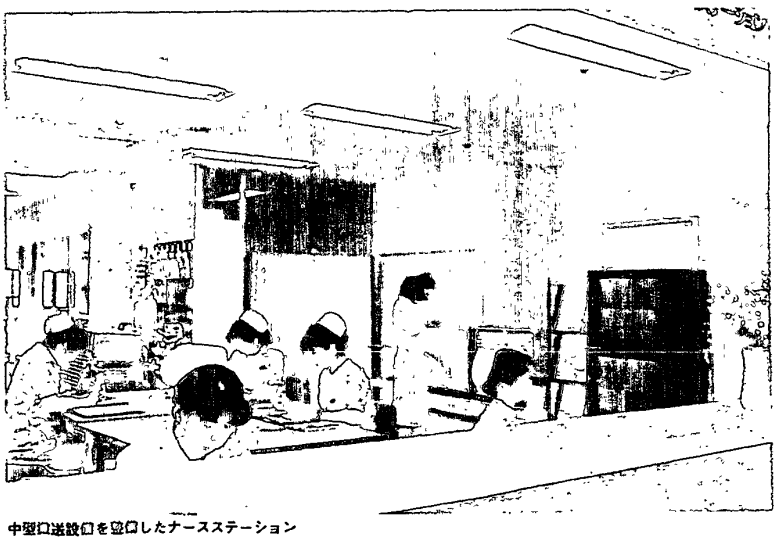


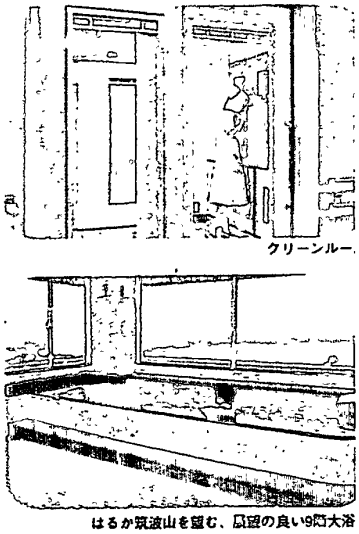
看護部門

○患者さんが受ける診療のすべてにかかわる看護部
○患者さんの思いにとどく看護
○あたたかな看護サービス

病棟部門

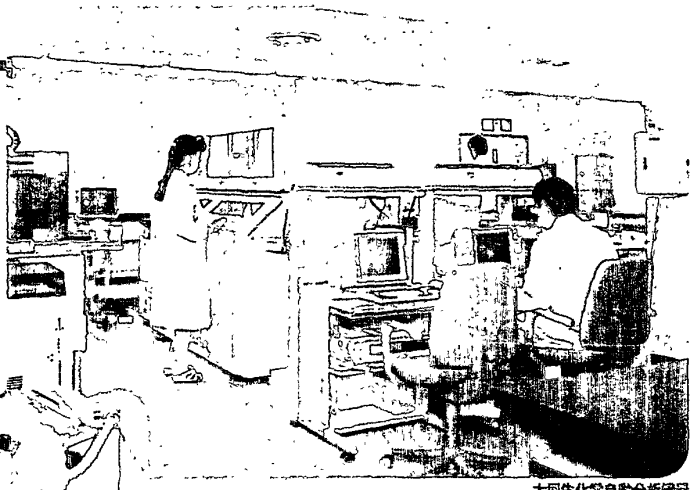
○大きな窓と高い天井、ゆったりしたスペースの明るい病室
○タイルカーペット使用による静かな療養環境
○中型搬送システムの設備
○骨髄移植専用のクリーンルーム（8階：8床）
○患者さん用の大浴場とくつろげる患者ラウンジ（9階）


中型搬送設備を設置したナースステーション

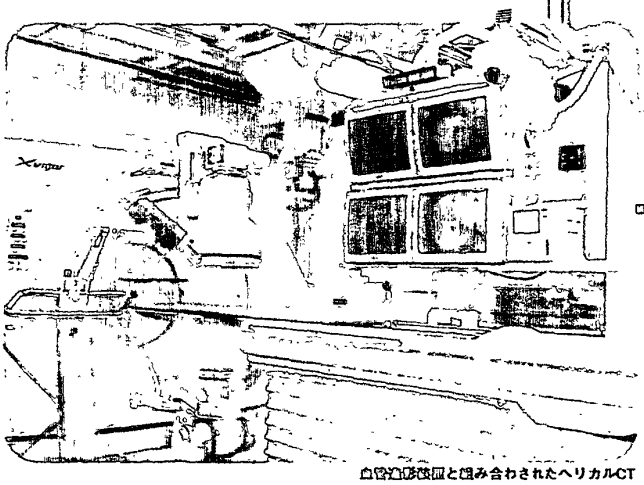


臨床検査部門

○壁のない広いスペースに配置された最新の
大型機器
○外来、通院治療センターに接した
血液検体検査室
○大型コンピュータと連動した迅速な検査と
精度管理
○がんの診療を支える病理検査



大型生化学自動分析機器



血管造影装置と組み合わされたヘリカルCT

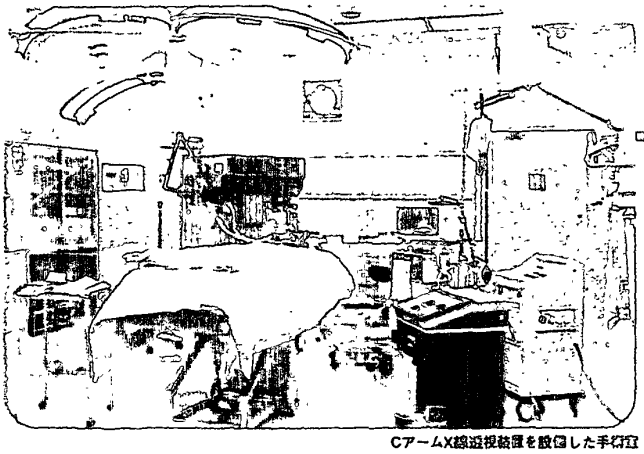
放射線部門

○充実した画像診断部門と放射線治療部門
○CT、MRIをはじめとする最新の診断機器と
CRシステムの採用
○マイクロトロンとコンピューターを駆使した
治療計画装置

内視鏡部門

○消化管（食道、胃、大腸）および胆膵内視鏡
検査
○喉頭および気管支内視鏡検査
○超音波内視鏡検査
○テレビ内視鏡を用いた検査と、得られた画像
の電子的処理による的確な診断
○レーザー照射、内視鏡的粘膜切除などによる
がんの治療

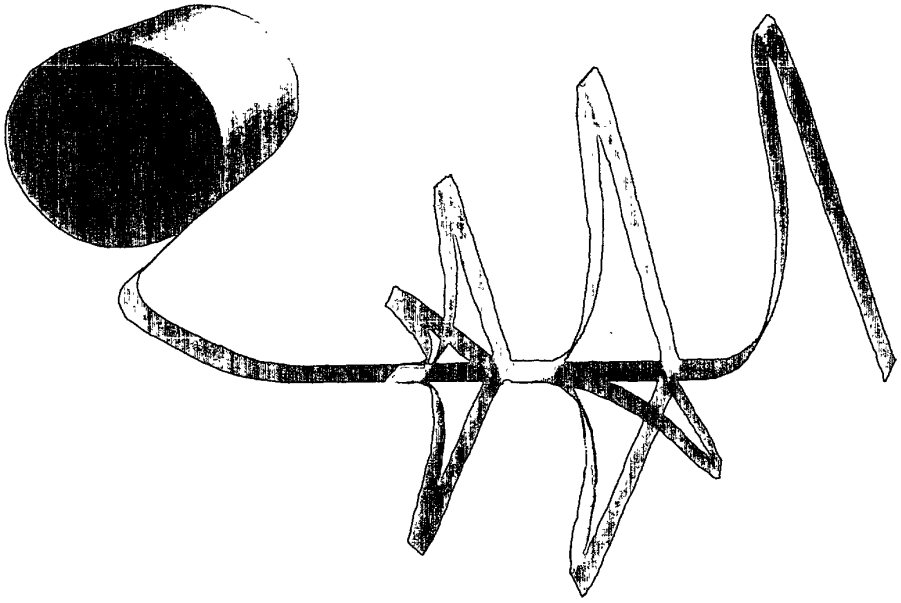
X線テレビ内視鏡検査室



Cアーム X線透視装置を設備した手術室

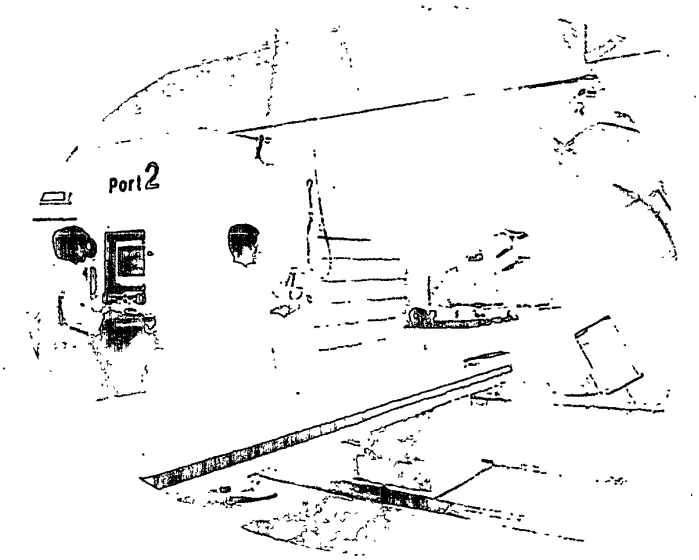
手術、ICU、中材部門

○垂直層流方式ヘパフィルター、圧差ダンパーを装備
し室内の環境保持に重点をおいた手術室
○Cアーム方式のX線透視装置と特殊手術台の組合せ
により可能な透視下の手術操作
○術中照射により難治がんに対応
○インケアボート（天井懸垂式各種モニター収納台）
を整備し、外科、内科患者に対応するgeneral ICU
○ダブルドアー、フロアローディング方式のオートク
レーブの採用による清潔環境の中央材料部



国立がんセンター
陽子線治療

―がん治療への新たなる挑戦―



国立がんセンター東病院

陽子線治療の歴史

陽子線が初めてがんの治療を目的に臨床医学に使用されたのは1954年のことでした。当時は進行乳癌患者の症状緩和の目的に、ローレンスバークレー研究所（米国、カリフォルニア）の物理研究用加速器から得られる細い陽子ビームによる脳下垂体への照射治療が行われました。1970年代のはじめに、ハーバード大学（米国、マサチューセッツ）でより大きな腫瘍に対する陽子線治療法が開発され、臨床応用の研究がさらに進められました。

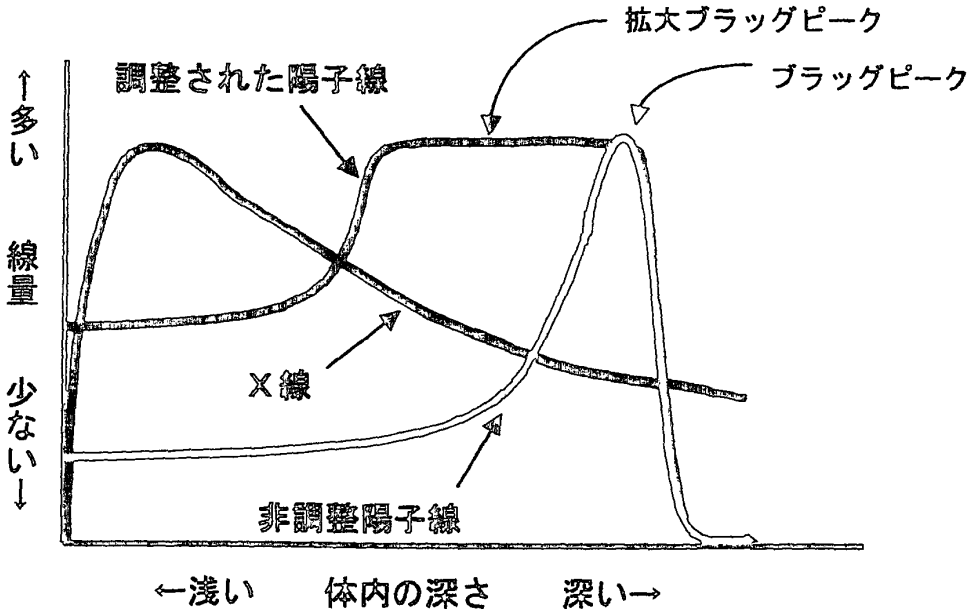
1983年には我が国でも深部臓器に発生したがんの治療を目的に筑波大学で陽子線治療が開始されました。この施設では高いエネルギーの陽子線を垂直方向から照射でき、肝臓がんの治療などに良好な成績をあげています。さらに病院内に医療専用の陽子加速器を設置して、種々のがん治療に陽子線による良質な放射線治療を提供する施設が近年増えています。

世界の陽子線治療施設から報告されてきた陽子線治療の有用性と加速器技術・治療計画コンピュータシステム・画像診断技術などにおける近年のめざましい進歩を背景に、1995年、国立がんセンターに新しい陽子線治療施設を導入することが決定され、計画から3年足らずの1998年から臨床使用が開始されました。

陽子線の特徴

陽子線のような電気をおびた重イオンは、停止する直前に大きな線量を組織に与える性質があります。入射陽子の速度を調節するなどして体内の任意の領域に、均一で集中性のよい線量の投与が行えます。

この結果、周囲の正常な部分には強い副作用を生じさせずにがんを治療できます。

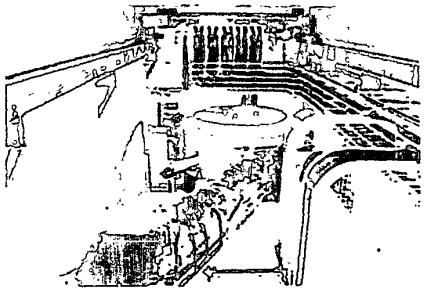


ブラッグピークとは？

通常の放射線治療で用いられているX線は体内に入るにしたがって放射線量が減少してゆきます。陽子線は表面近くではあまり線量を出さずに、ある深さで一気に放射線を放出してなくなってしまいます。これをブラッグピークと呼びます。がんの治療では病巣の大きさに合わせてこのピーク幅を拡げたり（拡大ブラッグピーク）、病巣の深さに合わせてピークの深さを調整することにより治療します。

施設の特徴

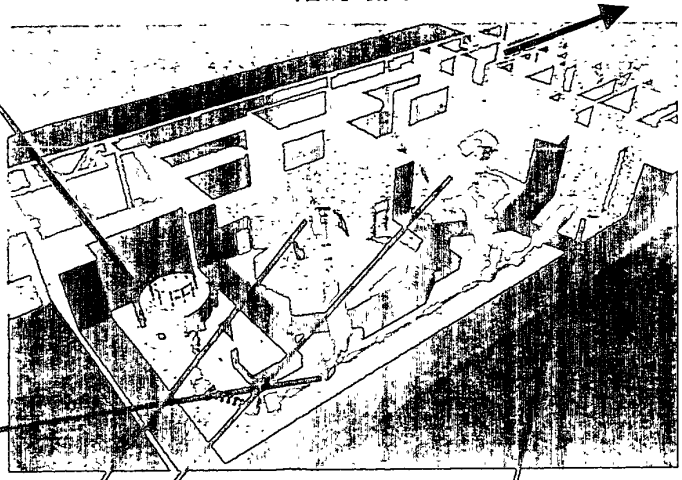
国立がんセンターの陽子線治療施設は、国内で最初の、世界でも2番目の病院内に設置された医療専用の施設です。既存の病院棟と直結していますので、入院・外来のどちらでもスムーズに治療が受けられます。1階には陽子線治療の主たる機器が設置されています。効率よく使用するために照射治療室は3室あり、そのうちふたつは国内初の回転ガントリー方式です。これは全身どの部位でも自由な方向からの照射が可能な装置で、従来の固定門方式の欠点を克服したものです。2階にはボーラス・コリメータと呼ばれる治療に必要な器具を製作するための工作機械が設置されています。がんの診断と治療効果判定に有用なポジトロンCTシステムの設置も計画されています。3階には診察室を中心にCT、MRIなどの画像診断機器と治療計画コンピュータシステムなどが設置されています。

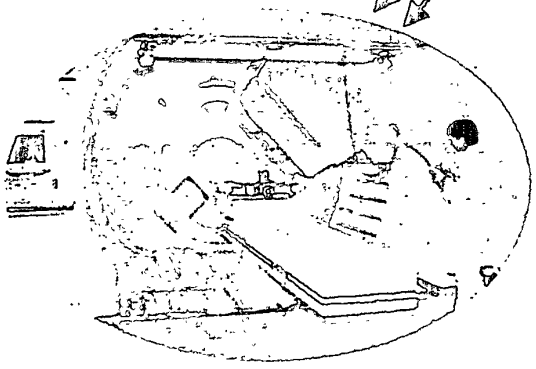


陽子加速器（サイクロトロン）

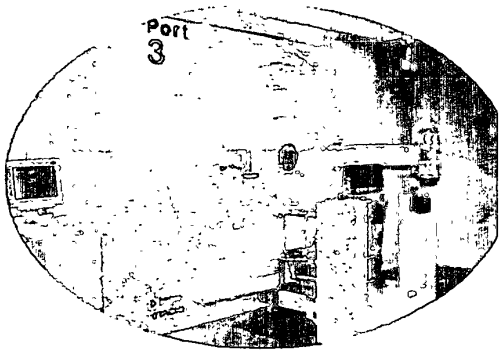
ビーム輸送部

1階鳥瞰図





ガントリー照射室

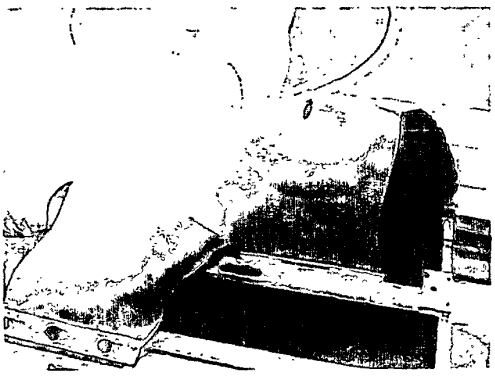


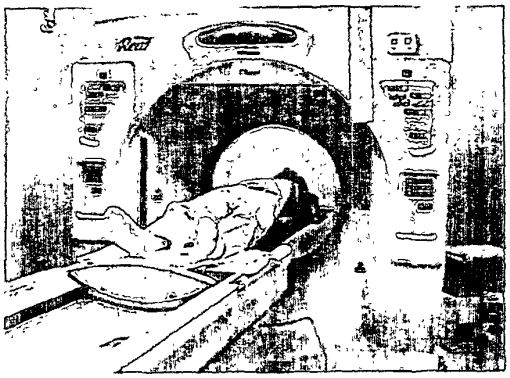
水平固定照射室

陽子線照射の実施まで

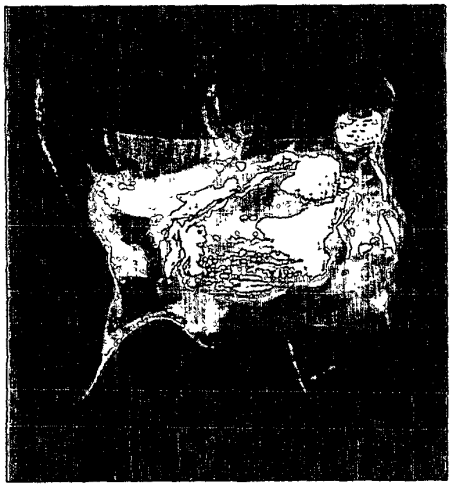
医師による診察ならびに必要な検査を受けていただきます。その後複数の医師等により陽子線治療の適応や方法について検討が行われます。

患者さん個別の固定用具を作成します。

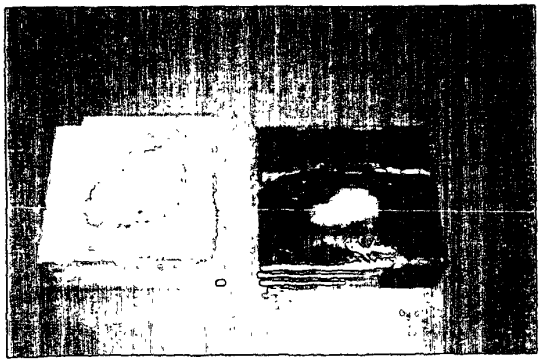




固定用具を装着した状態でCT検査を行います。



コンピュータを用いて陽子線治療の計画を立てます



患者さん個別のコリメータ（右）およびボーラス（左）と呼ばれる器具を作成します。

以上の準備が終わると陽子線治療が始まります。病巣を狙い撃ちする治療ですので、毎回正確な位置合わせを行います。

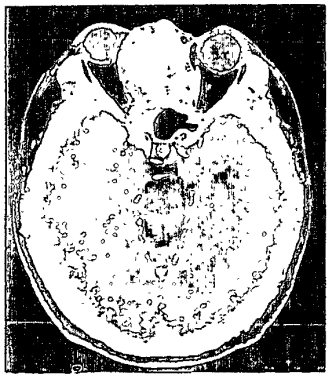
通常、陽子線治療は数回ないし数十回繰り返して行います。

陽子線治療の今後の展開

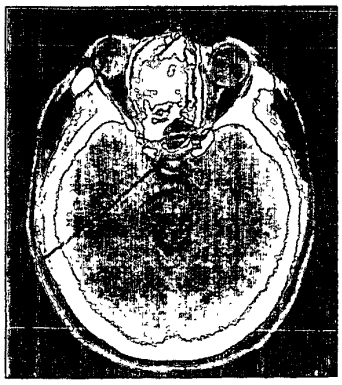
陽子線治療は眼腫瘍、頭蓋底腫瘍、肝臓がん、前立腺がんなどに対しては有効性が明らかとなっています。さらに脳腫瘍、頭頚部がん、肺がん、食道がん、あるいはさまざまな腹・骨盤部のがんや軟部腫瘍などに対しても有効性が期待されています。

医療専用装置を用いた陽子線治療のこれからの展開には、低侵襲的で効果的な放射線治療としてより多くの患者さんの治療が行える体制を整えるとともに、陽子線治療が真に適応となる疾患や病態ならびにその運用方法を臨床試験によって確定することが重要です。

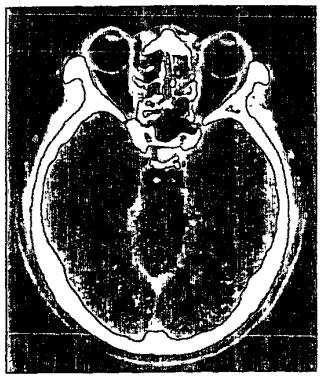
国立がんセンターではさまざまな疾患や病態に対する臨床試験実施計画書（プロトコール）を作成し、順次施行してゆく予定です。



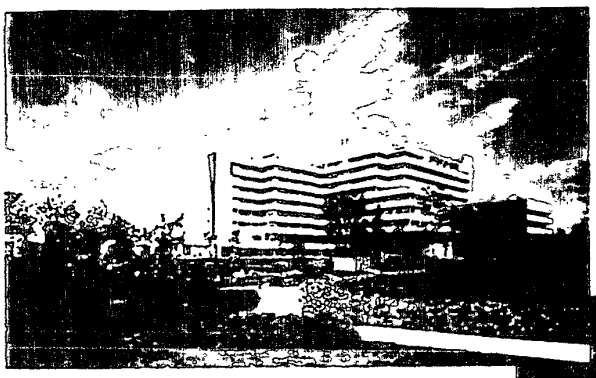
副鼻腔がんの陽子線治療前のCT画像



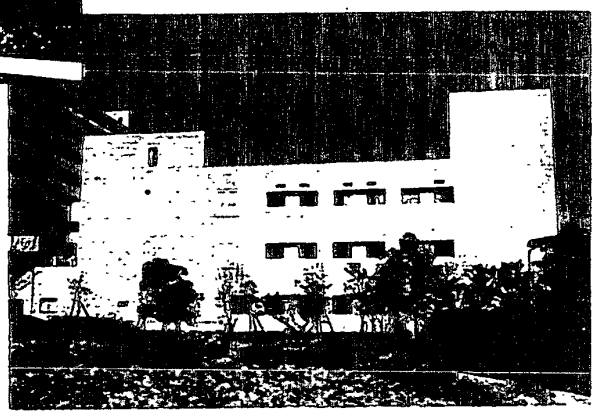
陽子線の線量分布図



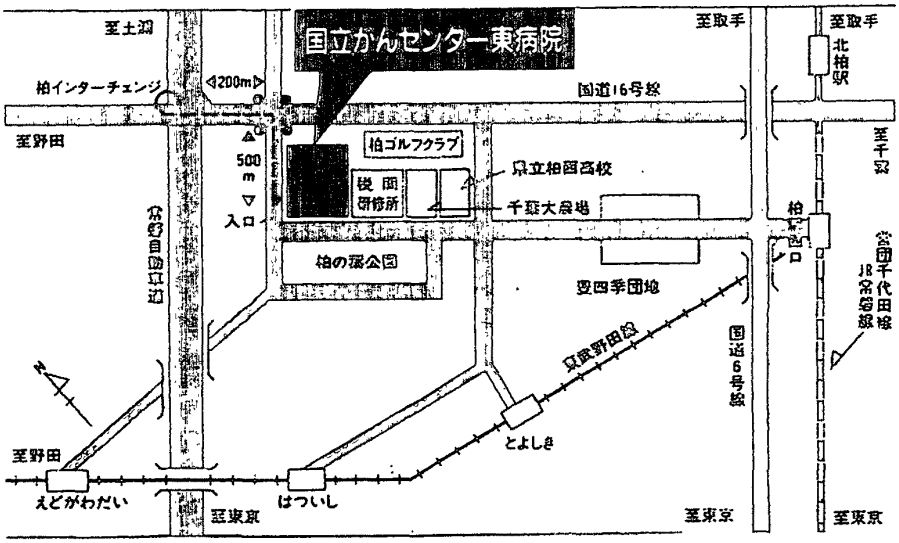
治療後CT画像
腫瘍は消失しています



国立がんセンター東病院



陽子線治療棟



交通機関

1. JR常磐線柏駅下車

   西口より東武バス国立がんセンター行き終点下車（約20分）

2. 常磐高速道柏インターより国道16号線柏方面最初の交差点右折約500m

所在地

〒277-8577　千葉県柏市柏の葉6-5-1

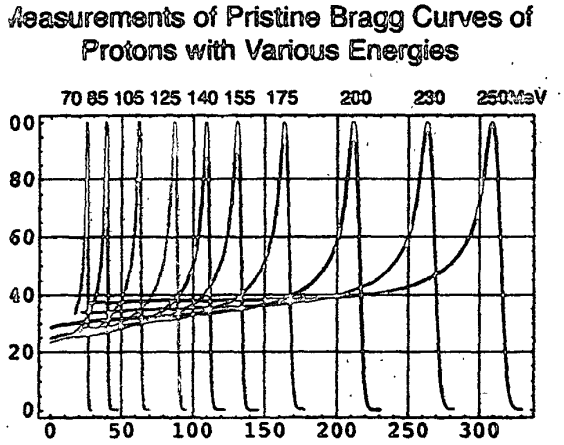
電話（代表）　0471-33-1111

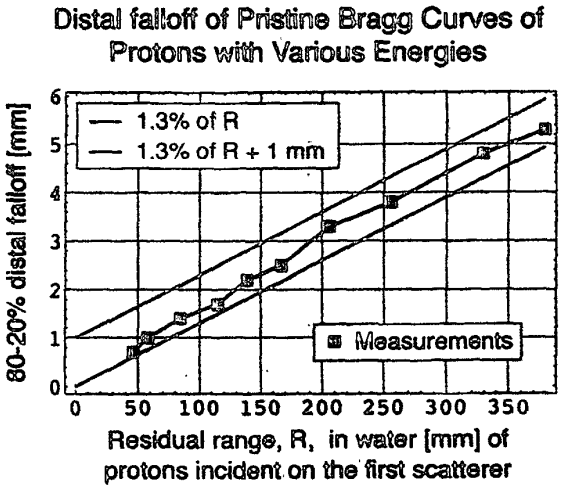
Beam quality measurements of the ga

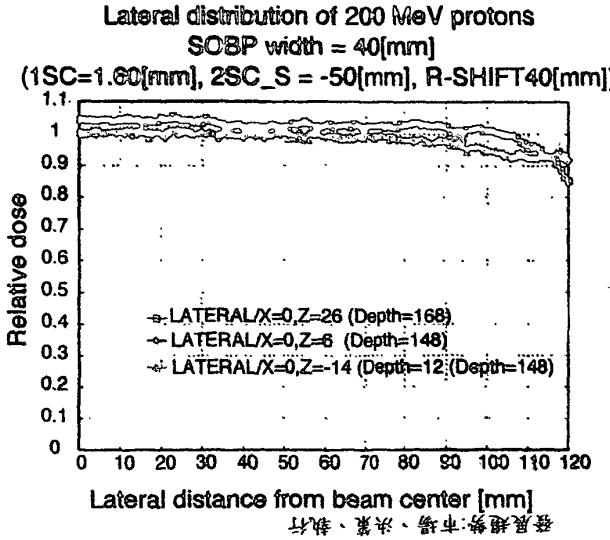
Yoshihisa Takada, Kiyoshi Yasuoka[1], Akihiro Nohtomi, Ta
(Institute of Applied Physics, [1] Institute of Basic Me
[3] Proton Medical Research Center,

ract

ose distributions of the gantry beam at the new Proton Medical Research Center (PMRC), University sukuba, have been extensively measured using a silicon semi-conductor sensor scanned in a water vessel. iform fluence distribution is formed by a double scattering method using a uniform first scatterer and a -ring second scatterer. Depth-dose distributions of the broad beam have been measured for beam with ten rent energies. Based on the measured Bragg curves, we designed ridge filters. We prepared two series of e filters. Whereas the one series are optimized for 200-MeV protons, the other series are optimized for MeV protons. Depth-dose distributions of the range-modulated beam are measured and compared with ulations. Basic quantities such as lateral penumbras and distal falloffs are measured and compared with ulations. We found that measurement results agreed well with the calculations. As expected from calcula- s, dose distributions of beam with lower incident energy were found to be largely affected by insertion of a e filter and a range shifter.







gantry beam at new PMRC, Tsukuba

ıi, Takeji Sakae[2], Akira Maruhashi[2], Toshiyuki Terunuma[3]
: Medical Sciences, [2] Institute of Clinical Medicine,
ıter, University of Tsukuba, Japan)

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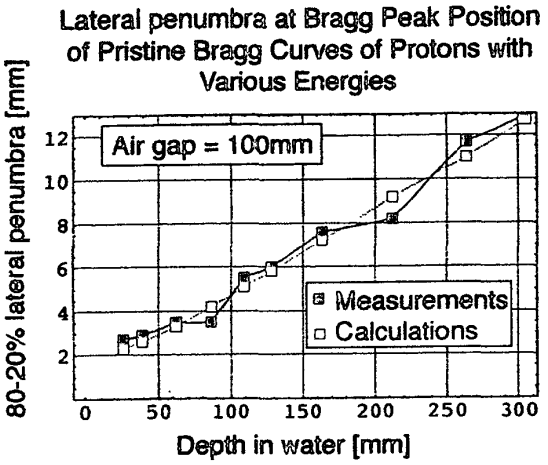
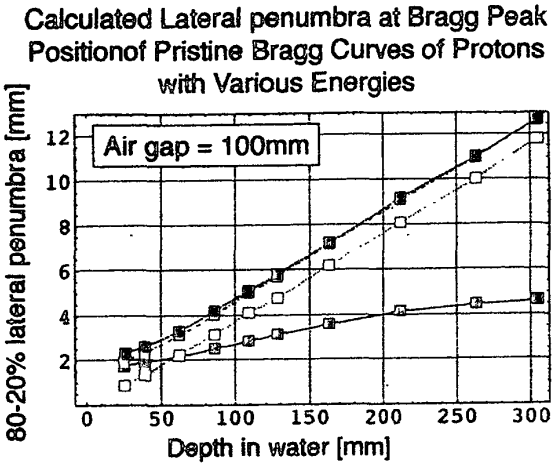
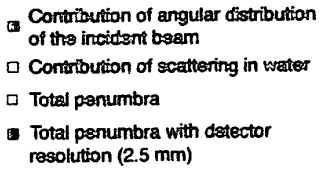
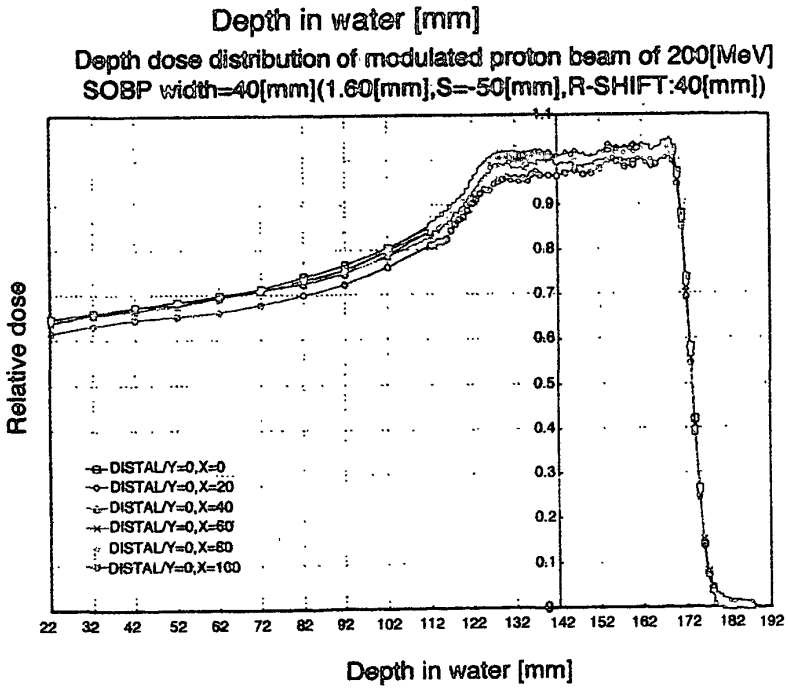
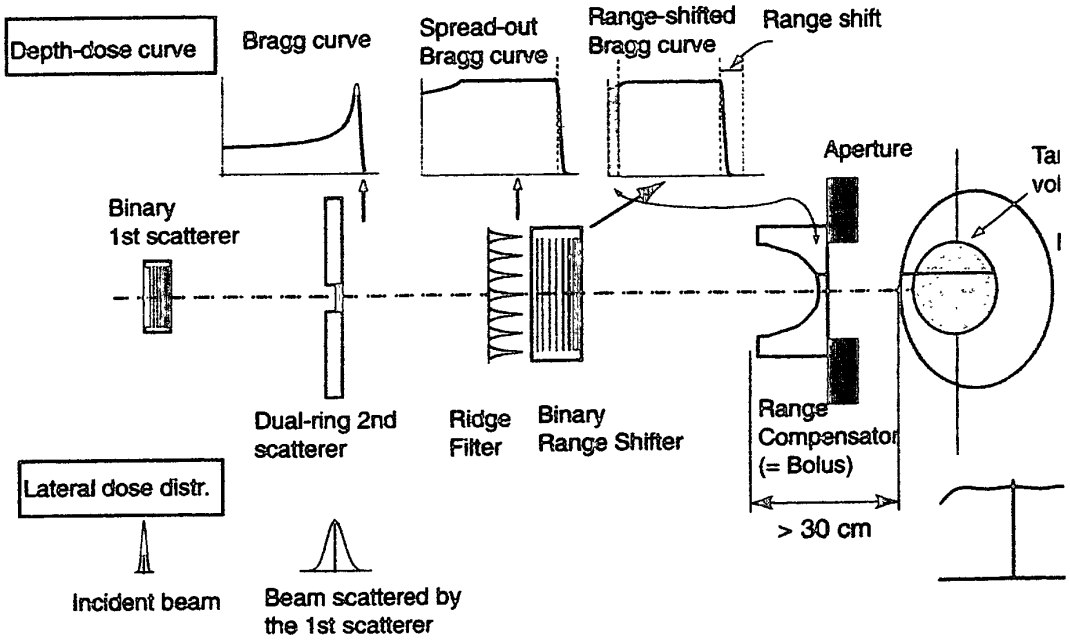




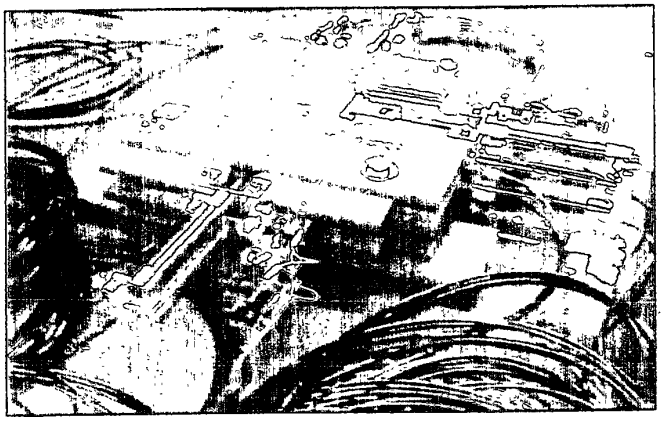




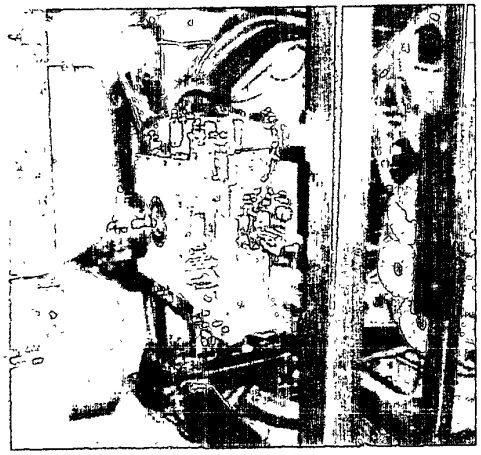
Proton Beam Delivery System (Fixed modulation) Using Double Scattering Syst
Ridge filter, Range shifter, Range compensator and Aperture



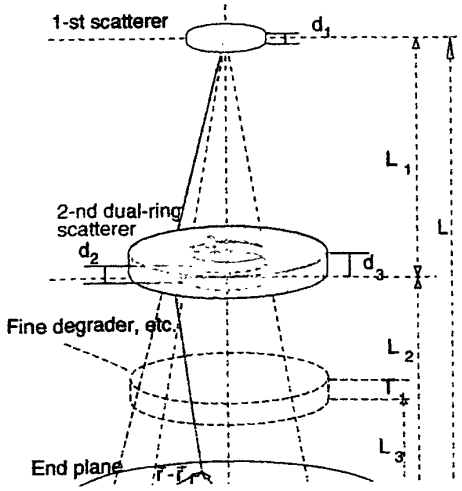
Binary first scatterer made of tungsten



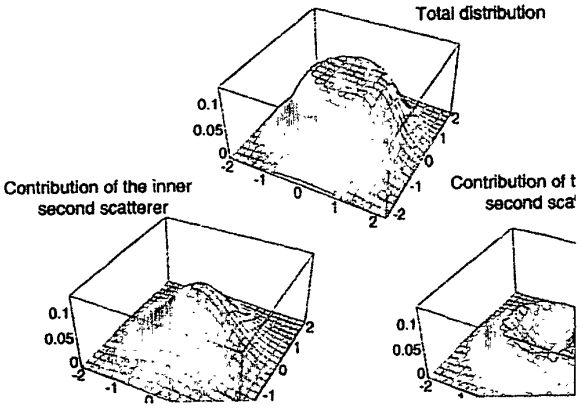
The 1st and 2nd scatterer

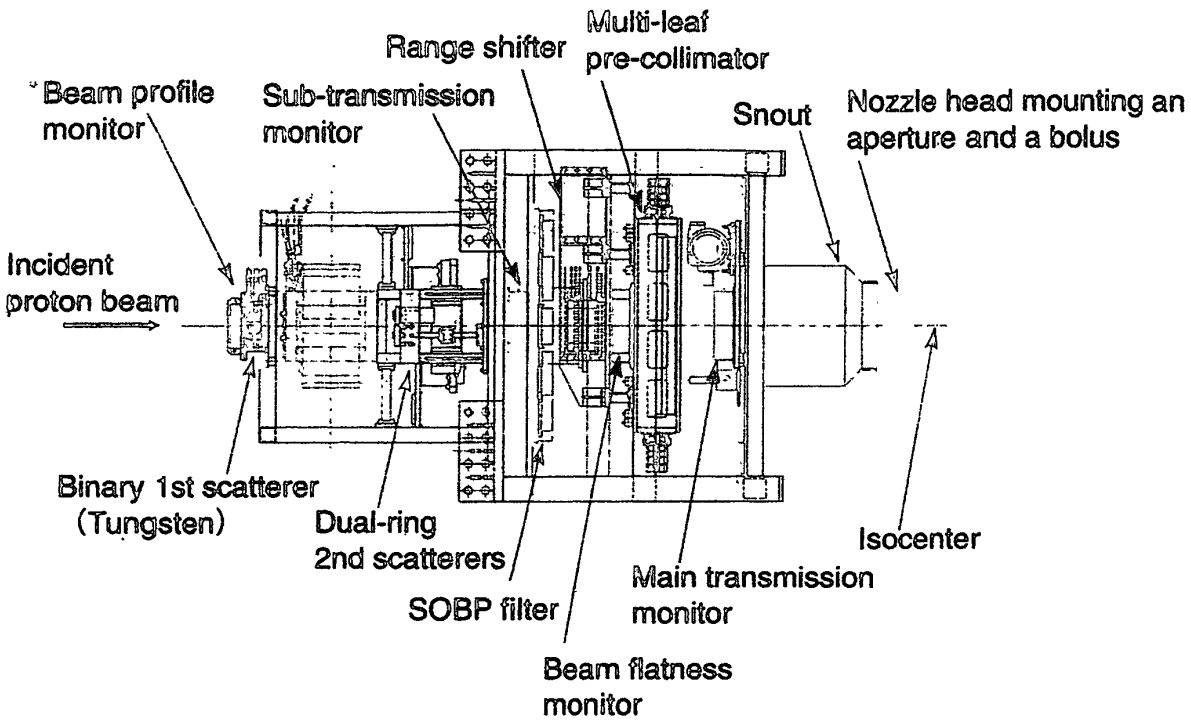


Arrangement of scatterers



Lateral fluence distribution formed by the dual-ring double scattering system

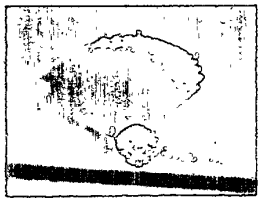




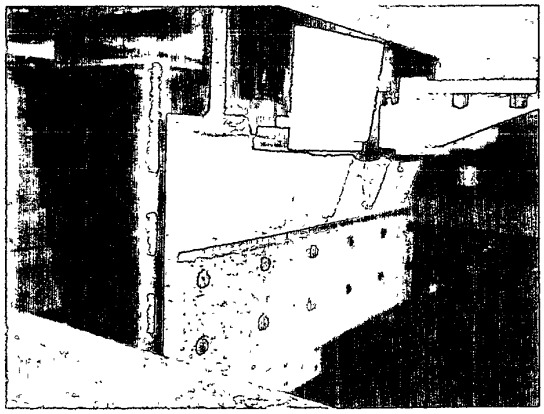
Mounting tray of SOBP filters

Multi-leaf pre-collimator (Leaf width = 25 mm)

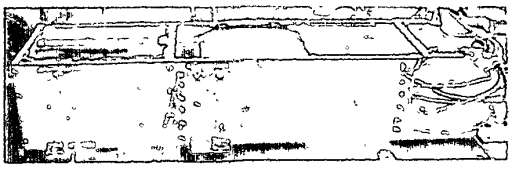
A SOBP filter made of aluminum



Snout with a stroke of 40cm



Binary range shifter made of ABS-resins (0-127 mm Water Equivalent Thickness)



附錄二、國立癌病中心東醫院平時院方設備自行檢測一覽表。

附録

陽子線治療装置インターロック点検記録

点検年月日	年　月　日				
部屋	大項目	小項目	内容	チェック	コメント
加速器室	電動遮蔽扉（冷却装置室側）	扉開	キーロックスイッチからキーを解除しないと開かない		
			扉制御板のスイッチ「入り」でないと開かない		
			扉開で加速器停止		
			放射線「高」では開かない		
			手動「開」可能（内側）		
			手動「開」可能（外側）		
		扉閉	キーロックスイッチ全数返却で閉可能		
			扉閉動作中はパトライト点灯		
	ビーム	ビームオン	対応する部屋のすべての扉閉でオン可能		
			「加速器運転中」表示点灯		
		ビームオフ	室内非常停止スイッチにてビーム停止		
			加速器制御室の非常停止スイッチにてビーム停止		
			キースイッチ解除で停止		
			扉開で停止		
			ロスビーム積算値が一定値以上で停止		
第一照射治療室	電動遮蔽扉	扉開	キーロックスイッチからキーを解除しないと開かない		
			扉制御板のスイッチ「入り」でないと開かない		
			扉開で加速器停止		
			放射線「高」では開かない		
			手動「開」可能（内側）		
			手動「開」可能（外側）		
			パトライト点灯		
		扉閉	キーロックスイッチ全数返却で閉可能		
	ビーム	ビームオン	対応する部屋のすべての扉が閉でオン可能		
			「照射中」表示点灯		
		ビームオフ	室内非常停止スイッチにてビーム停止		
			対応する制御コンピュータの非常停止スイッチにてビーム停止		
			キースイッチ解除で停止		
			扉開で停止		

陽子線治療装置インターロック点検記録

第二照射治療室	電動遮蔽扉	扉開	キーロックスイッチからキーを抜かないと開かない		
			扉制御板のスイッチ「入り」でないと開かない		
			扉開で加速器停止		
			放射線「高」では開かない		
			手動「開」可能（内側）		
			手動「開」可能（外側）		
		扉閉	キーロックスイッチ全数返却で閉可能		
			パトライト点灯		
	ビーム	ビームオン	対応する部屋のすべての扉が閉でオン可能		
			「照射中」表示点灯		
		ビームオフ	室内非常停止スイッチにてビーム停止		
			対応する制御コンピュータの非常停止スイッチにてビーム停止		
			キースイッチ解除で停止		
			扉開で停止		
第三照射治療室	電動遮蔽扉	扉開	キーロックスイッチからキーを抜かないと開かない		
			扉制御板のスイッチ「入り」でないと開かない		
			扉開で加速器停止		
			放射線「高」では開かない		
			手動「開」可能（内側）		
			手動「開」可能（外側）		
		扉閉	キーロックスイッチ全数返却で閉可能		
	ビーム	ビームオン	対応する部屋のすべての扉が閉でオン可能		
			「照射中」表示点灯		
		ビームオフ	室内非常停止スイッチにてビーム停止		
			対応する制御コンピュータの非常停止スイッチにてビーム停止		
			キースイッチ解除で停止		
			扉開で停止		
点検者	＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿印				
安全管理責任者	＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿印				
放射線取扱主任者	＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿＿印				

陽子線治療棟自主点検記録（１）

点検日　　年　　月　　日　　国立がんセンター東病院

区分	点検項目	点検結果	記事	実施者
施設の位置等	設置位置の地崩れ、浸水の恐れ、周囲と地形変化との対比	適　・　否		管理区域担当者 施設管理担当者 安全管理担当者
主要構造部等	構造物の突起、くぼみ、亀裂および材料変更の有無	適　・　否		同上
遮蔽	構造、および材料の亀裂等構造変化の有無	適　・　否		管理区域担当者 安全管理担当者
管理区域全般	区画壁の破損、隙間等	適　・　否		管理区域担当者 施設管理担当者 安全管理担当者
	閉鎖設備の破損等	適　・　否		
	床・壁等の表面仕上げの腐食、目地、隙間、亀裂、破損等	適　・　否		
	標識の位置、破損等	適　・　否		
	室内の換気が負圧になっているか	適　・　否		
汚染検査室	洗浄設備と排水設備の連結および腐食、破損等	適　・　否		管理区域担当者 安全管理担当者
	更衣設備の上着、スリッパ、手袋	適　・　否		
	除染器材（除染材、ブラシ）	適　・　否		
	放射線測定器（ハンドフットクロズモニター）作動	適　・　否		
	放射線測定器（サーベイメータ、ポケット線量計）作動	適　・　否		
	汚染検査室の標識、破損等	適　・　否		
排気設備	設置位置と空気汚染の現状対比	適　・　否		施設管理担当者
	負圧監視装置の作動	適　・　否		
	床・壁等の表面仕上げの腐食、目地、隙間、亀裂、破損等	適　・　否		
	排気浄化装置の各種フィルター目詰まり、損傷の有無	適　・　否		
	排気ファン、ファンベルト等の機能状況	適　・　否		
	排気ダクト、排気口の腐食、亀裂、ボルト締め付け等、気密保持の状況	適　・　否		
	排気監視装置の作動状況	適　・　否		
	標識（排気浄化設備・排気口）、破損等	適　・　否		
	排気ダクトの「排気管」の標識の損傷	適　・　否		
排水設備	設置位置の地崩れ、浸水のおそれ等の現状対比	適　・　否		施設管理担当者
	床・壁等の構造、防水の状況	適　・　否		
	排水浄化槽の流入状況、ポンプ作動、漏れ、腐食の状況、蓋の状況、排水経路の状況	適　・　否		
	貯留槽・希釈槽の水漏れ、腐食等の状況	適　・　否		
	貯留槽・希釈槽のポンプ、排水バルブ、給水等の作動状況	適　・　否		
	貯留槽・希釈槽の槽等の損傷状況	適　・　否		
	排水管の水漏れ、損傷の状況	適　・　否		
	標識（配水設備、排水管）、破損等	適　・　否		

陽子線治療棟自主点検記録（１）

使用装置自主点検
点検総括および措置の内容
備考

国立がんセンター東病院放射線障害予防規定運用細則第７条ならびに第８条に基づき陽子線治療棟の巡視ならびに自主点検を実施した。

点検実施者

管理区域担当者＿＿＿＿＿＿＿＿＿＿＿＿印

施設管理担当者＿＿＿＿＿＿＿＿＿＿＿＿印

安全管理担当者＿＿＿＿＿＿＿＿＿＿＿＿印

確認

安全管理責任者＿＿＿＿＿＿＿＿＿＿＿＿印

放射線取扱主任者＿＿＿＿＿＿＿＿＿＿＿＿印

陽子線治療棟自主点検記録（２）－加速器(1)室

点検日　　年　　月　　日　　国立がんセンター東病院

区分	点検項目	点検結果	記事	実施者
放射線発生装置使用室	設置位置の地崩れ、浸水の恐れ、周囲と地形変化との対比	適　・　否		管理区域担当者
	床・壁等の構造物の亀裂、落剥等	適　・　否		
	線量当量の測定結果の評価	適　・　否		
管理区域	閉鎖設備破損等	適　・　否		
放射線測定器	（サーベイメータ等の保守点検状況）		汚染検査室で一括管理	
標識	「管理区域・放射線発生装置使用室」の標識、位置、破損	適　・　否		
注意事項	従事者用、患者用の内容、位置、破損	適　・　否		
自動表示装置	（装置使用と自動的に連動の動作確認）		インターロックで施行	
インターロック	（作動状況）		インターロックで施行	
消火設備	消化器の個数、有効期限等の確認	適　・　否		
安全装置	緊急時に出入口扉が内側から手動で開けられるか	適　・　否		
使用装置自主点検				
点検総括および措置の内容				
備考				

国立がんセンター東病院放射線障害予防規定運用細則第8条に基づき加速器室の自主点検を実施した。

点検実施者

管理区域担当者＿＿＿＿＿＿＿＿＿＿＿＿印

施設管理担当者＿＿＿＿＿＿＿＿＿＿＿＿印

安全管理担当者＿＿＿＿＿＿＿＿＿＿＿＿印

確認

安全管理責任者＿＿＿＿＿＿＿＿＿＿＿＿印

放射線取扱主任者＿＿＿＿＿＿＿＿＿＿＿＿印

陽子線治療棟自主点検記録（３）－第１照射治療室

点検日　　年　　月　　日　　国立がんセンター東病院

区分	点検項目	点検結果	記事	実施者
放射線発生装置使用室	設置位置の地崩れ、浸水の恐れ、周囲と地形変化との対比	適　・　否		管理区域担当者
	床・壁等の構造物の亀裂、落剥等	適　・　否		
	線量当量の測定結果の評価	適　・　否		
管理区域	閉鎖設備破損等	適　・　否		
放射線測定器	（サーベイメータ等の保守点検状況）		汚染検査室で一括管理	
標識	「管理区域・放射線発生装置使用室」の標識、位置、破損	適　・　否		
注意事項	従事者用、患者用の内容、位置、破損	適　・　否		
自動表示装置	（装置使用と自動的に連動の動作確認）		インターロックで施行	
インターロック	（作動状況）		インターロックで施行	
消火設備	消化器の個数、有効期限等の確認	適　・　否		
安全装置	緊急時に出入口扉が内側から手動で開けられるか	適　・　否		
使用装置自主点検				
点検総括および措置の内容				
備考				

国立がんセンター東病院放射線障害予防規定運用細則第8条に基づき第１照射治療室の自主点検を実施した。

点検実施者

管理区域担当者　　印

施設管理担当者　　印

安全管理担当者　　印

確認

安全管理責任者　　印

放射線取扱主任者　　印

陽子線治療棟自主点検記録（４）－第２照射治療室

点検日　　年　　月　　日　　国立がんセンター東病院

区分	点検項目	点検結果	記事	実施者
放射線発生装置使用室	設置位置の地崩れ、浸水の恐れ、周囲と地形変化との対比	適　・　否		管理区域担当者
	床・壁等の構造物の亀裂、落剥等	適　・　否		
	線量当量の測定結果の評価	適　・　否		
管理区域	閉鎖設備破損等	適　・　否		
放射線測定器	（サーベイメータ等の保守点検状況）		汚染検査室で一括管理	
標識	「管理区域・放射線発生装置使用室」の標識、位置、破損	適　・　否		
注意事項	従事者用、患者用の内容、位置、破損	適　・　否		
自動表示装置	（装置使用と自動的に連動の動作確認）		インターロックで施行	
インターロック	（作動状況）		インターロックで施行	
消火設備	消化器の個数、有効期限等の確認	適　・　否		
安全装置	緊急時に出入口扉が内側から手動で開けられるか	適　・　否		
使用装置自主点検				
点検総括および措置の内容				
備考				

国立がんセンター東病院放射線障害予防規定運用細則第8条に基づき第２照射治療室の自主点検を実施した。

点検実施者

管理区域担当者＿＿＿＿＿＿＿＿＿＿＿＿＿＿印

施設管理担当者＿＿＿＿＿＿＿＿＿＿＿＿＿＿印

安全管理担当者＿＿＿＿＿＿＿＿＿＿＿＿＿＿印

確認

安全管理責任者＿＿＿＿＿＿＿＿＿＿＿＿＿＿印

放射線取扱主任者＿＿＿＿＿＿＿＿＿＿＿＿＿＿印

陽子線治療棟自主点検記録（５）－第３照射治療室

点検日　　年　　月　　日　　国立がんセンター東病院

区分	点検項目	点検結果	記事	実施者
放射線発生装置使用室	設置位置の地崩れ、浸水の恐れ、周囲と地形変化との対比	適　・　否		管理区域担当者
	床・壁等の構造物の亀裂、落剥等	適　・　否		
	線量当量の測定結果の評価	適　・　否		
管理区域	閉鎖設備破損等	適　・　否		
放射線測定器	（サーベイメータ等の保守点検状況）		汚染検査室で一括管理	
標識	「管理区域・放射線発生装置使用室」の標識、位置、破損	適　・　否		
注意事項	従事者用、患者用の内容、位置、破損	適　・　否		
自動表示装置	（装置使用と自動的に連動の動作確認）		インターロックで施行	
インターロック	（作動状況）		インターロックで施行	
消火設備	消化器の個数、有効期限等の確認	適　・　否		
安全装置	緊急時に出入口扉が内側から手動で開けられるか	適　・　否		
使用装置自主点検				
点検総括および措置の内容				
備考				

国立がんセンター東病院放射線障害予防規定運用細則第8条に基づき第３照射治療室の自主点検を実施した。

点検実施者

確認

管理区域担当者＿＿＿＿＿＿＿＿＿＿印

施設管理担当者＿＿＿＿＿＿＿＿＿＿印

安全管理担当者＿＿＿＿＿＿＿＿＿＿印

安全管理責任者＿＿＿＿＿＿＿＿＿＿印

放射線取扱主任者＿＿＿＿＿＿＿＿＿＿印

陽子線治療棟自主点検記録（6）－場所の測定

点検年月日	年　月　日		
管理区域担当者	＿＿＿＿＿＿＿＿印	放射線取扱主任者	＿＿＿＿＿＿＿＿印
施設管理担当者	＿＿＿＿＿＿＿＿印	安全管理責任者	＿＿＿＿＿＿＿＿印
安全管理担当者	＿＿＿＿＿＿＿＿印		

線量当量測定とインターロックのチェック

測定点（図参照）	運転条件	左記条件時の線量当量計算値　/サイクロ1nA当たりの線量当量(B)	点検時のサイクロ電流量(A) /　=A*B	サーベイメータ読み値	各照射室の使用中ランプの表示とドアインターロック動作試験
A （第２照射治療室内・サイクロトロン側壁）	第1照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし、ガントリー角度0度	75.1μSv/h	nA	GM・電離箱・シンチ μSv/h	
		0.395μSv/h・nA	μSv/h	中性子　μSv/h	
B （廊下・第1照射治療室側壁）	第1照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし、ガントリー角度0度	43.2μSv/h	nA	GM・電離箱・シンチ μSv/h	加速器室1 適・否
		0.227μSv/h・nA	μSv/h	中性子　μSv/h	
C （第1照射治療室入口）	第1照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし、ガントリー角度0度	2.2 μSv/h	nA	GM・電離箱・シンチ μSv/h	第1照射治療室 適・否
		0.012μSv/h・nA	μSv/h	中性子　μSv/h	
D （3階受付・床）	第1照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし、ガントリー角度0度	21.9 μSv/h	nA	GM・電離箱・シンチ μSv/h	
		0.115μSv/h・nA	μSv/h	中性子　μSv/h	
E （第1照射治療室内・第2照射治療室側壁）	第2照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし、ガントリー角度0度	20.9 μSv/h	nA	GM・電離箱・シンチ μSv/h	
		0.194μSv/h・nA	μSv/h	中性子　μSv/h	
F （第2照射治療室入口）	第2照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし、ガントリー角度0度	0.9μSv/h	nA	GM・電離箱・シンチ μSv/h	第2照射治療室 適・否
		0.0084μSv/h・nA	μSv/h	中性子　μSv/h	
G （第3照射治療室入口）	第3照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし	94.9μSv/h	nA	GM・電離箱・シンチ μSv/h	第3照射治療室 適・否
		1.40μSv/h・nA	μSv/h	中性子　μSv/h	
H （棟南側外壁）	第3照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし	53.3μSv/h	nA	GM・電離箱・シンチ μSv/h	
		0.28μSv/h・nA	μSv/h	中性子　μSv/h	
I （棟東側遮蔽扉外壁）	第3照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし	46.4μSv/h	nA	GM・電離箱・シンチ μSv/h	
		0.24μSv/h・nA	μSv/h	中性子　μSv/h	
J （棟東側第3照射室外壁）	第3照射室、ESSエネルギー110MeV、SOBP6cm、ファインデグレーダなし	25.5μSv/h	nA	GM・電離箱・シンチ μSv/h	
		0.38μSv/h・nA	μSv/h	中性子　μSv/h	

国立がんセンター東病院放射線障害予防規定運用細則第11条に基づき陽子線治療棟の放射線の量の測定を行った。

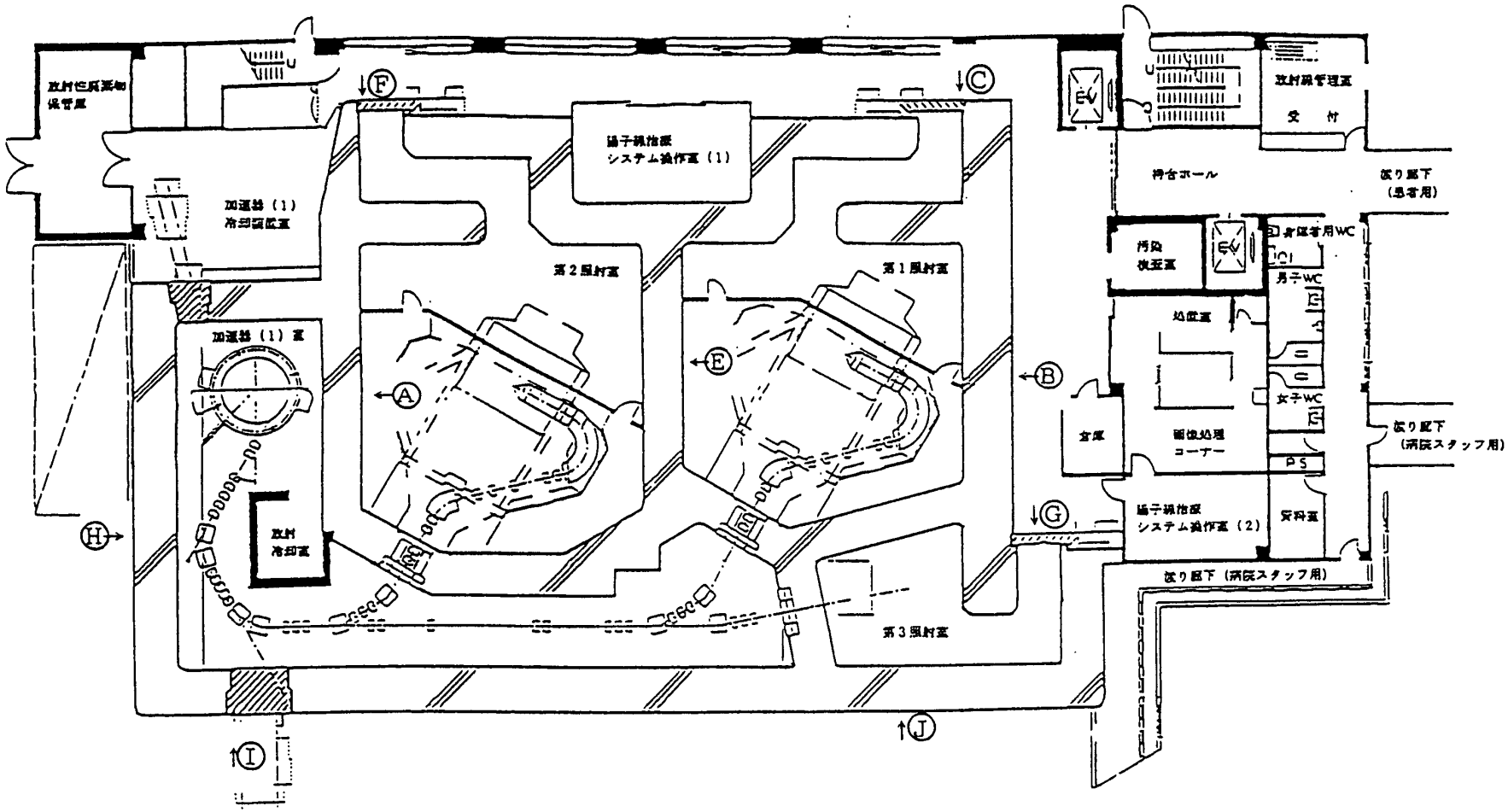
線量当量計算値の算出根拠は別紙「線量当量計算値」を参照すること。

測定の場所は別紙「陽子線治療棟平面図」に記してある該当するアルファベットを参照すること。

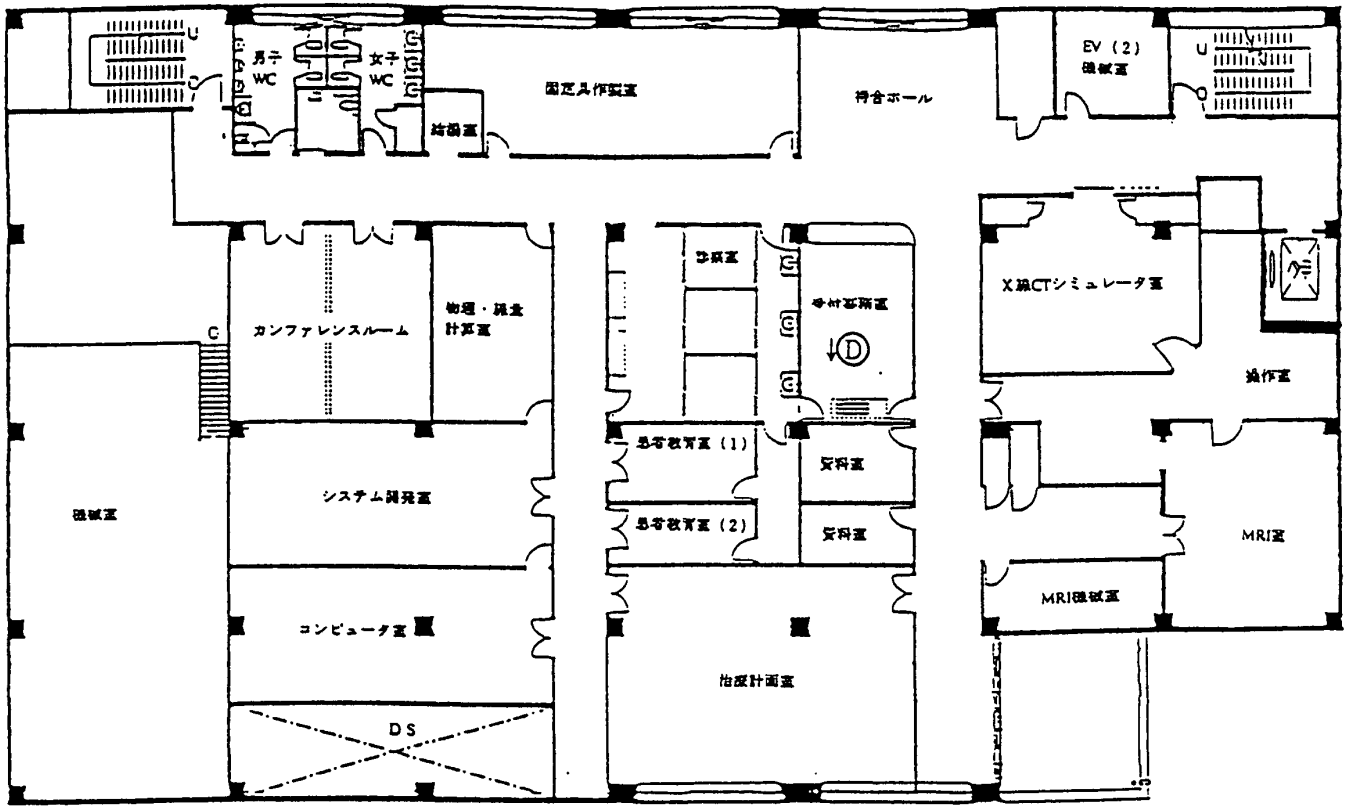
線量当量計算値

測定点			サイクロ電流値	積算電流量(A)	漏洩線量(B)	インターロック上限(C)	インターロック上限での漏洩線量	漏洩線量
点検記録	申請書	線源条件	nA	(nA*min/w)	(μSv/w)	(nA*min/w)	[=B*C/A] (μSv/w)	(μSv/h)
A	CD	サイクロトロン	190	1,915,200	12,610	30,250	199.2	75.1
B	CG2	G1	190	130,042	7,255	2,525	140.9	43.2
C	A1	G1	190	130,042	371	2,525	7.2	2.2
D	CT3	G1	190	130,042	3,680	2,525	71.5	21.9
E	CF	G2	107.5	73,576	3,504	2,011	95.8	20.9
F	A2	G2	107.5	73,576	148	2,011	4	0.9
G	A3	G3	67.7	46,336	15,948	103	35.5	94.9
H	CB2	サイクロトロン	190	1,915,200	8,951	30,250	141.4	53.3
I	CC2	サイクロトロン	190	1,915,200	7,803	30,250	123.2	46.4
J	CC3	G3	67.7	46,336	4,277	103	9.5	25.5

陽子線治療棟 1階測定点



陽子線治療棟 3階測定点



附錄三、國立癌病中心東醫院質子治療設備申請許可時，送日本科學技術廳之部分資料。

附録

5　放射線遮蔽

放射線遮蔽の検討フローを下図に示す。
検討は下図の手順（　1）～7）　）に従って実施した。

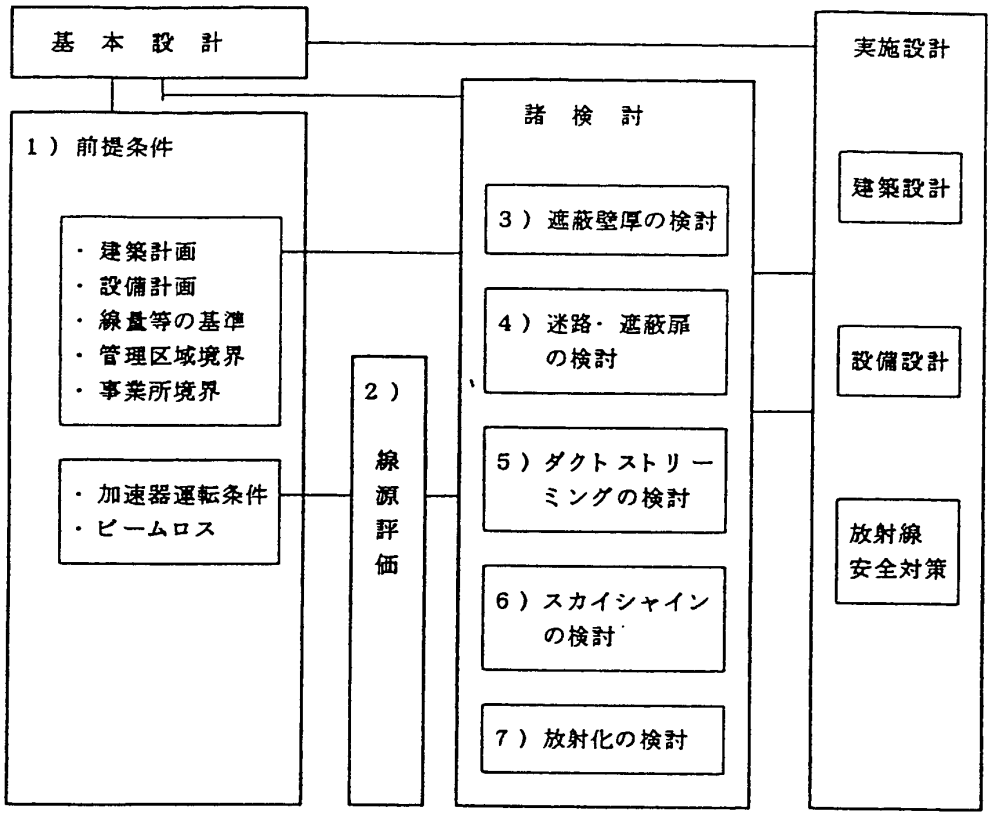


図5　－1　放射線遮蔽の検討フロー

５．１　前提条件

本施設の放射線遮蔽設計等の安全対策を検討する際の前提条件を以下の順に述べる。

１）建築計画・設備計画について

２）線量当量限度等の基準について

３）管理区域境界及び事業所境界について

４）陽子線のビーム強度スケジュールについて

５）ビームロスについて

５．１．１　建築計画・設備計画の基本的考え方

①本施設では、サイクロトロンを用いて２３５ＭｅＶの陽子線を生成する。生成される陽子線のエネルギーは固定であるが、必要に応じて加速器（１）室に設置されたエネルギーセレクションシステムを用いて陽子線のエネルギーを減少させて照射治療室に輸送する。陽子線の一部は加速器（１）室で失われ、照射治療室に輸送された陽子線は照射野を形成する過程で一部分が失われ残りの陽子線も最終的に患者の患部内で全て失われる。サイクロトロンから引き出された２３５ＭｅＶの陽子線が種々の物質に衝突する過程で最大２００ＭｅＶを越える高エネルギー中性子が発生する。本施設における放射線遮蔽の対象は、透過性の強い高エネルギー中性子線となる。

②サイクロトロン等が設置される加速器（１）室並びに第1照射治療室及び第2照射治療室及び第3照射治療室はコンクリート製の厚壁及び天井で放射線を遮蔽する。遮蔽壁の厚さが各所で複雑に変化する建屋構造は、施設建築上現実的ではない。そこで、遮蔽壁は大部分が補助的な追加遮蔽を施さなくても済む共通の遮蔽壁厚さをベースとし、特に厳しい遮蔽条件となる部分に鉄等の局所遮蔽を設置する（図５．３－７参照）。このように遮蔽壁と局所遮蔽体を分離することで、局所遮蔽体を中性子発生点の近傍に設置することが可能になり、効率的遮蔽を行うことができる。

③各照射治療室の出入口部分は迷路構造にし、治療関係者の出入りを容易にするため遮蔽扉の厚さは遮蔽壁より薄くする。

④加速器（１）室及び各照射治療室の空調換気は循環方式とし、また大気に対して負圧を維持する。

⑤管理区域の室内負圧制御系の吸気側にはHEPAフィルターを設け、排気側にはHEPAフィルター及びチャコールフィルターを設ける。

⑥サイクロトロン及びビーム輸送電磁石の冷却水ループは閉じているので管理区域から大量の水を廃棄することはない。メンテナンス時にでる管理排水は受槽の後貯留槽を設け、モニタリングの後構内排水管本管に放流する。

⑦加速器（１）室で発生した放射化物は加速器（１）室内に設けられた放射化物の保管室に保管し、各照治療射室で発生した放射化物は各照射治療室の隅等に保管する。

５．１．２　線量基準等

①本施設の放射線遮蔽設計にあたって線量当量限度等の基準は、放射線障害防止法（昭和６３年４月１日に改正・発布、平成元年４月１日施行）に拠るものとする。

②中性子のフルエンスから線量当量への変換は告示別表第５第二欄のテーブルを用いて行った。但し、告示別表５では中性子のエネルギーが２０ＭｅＶ以下であるため、２０ＭｅＶを超える中性子エネルギーの変換係数はＩＣＲＰ－５１のデータを用いた。中性子のフルエンスから線量当量への変換係数を表５．１－１及び図５．１－１に示す。

③当面の間中性子に対する線質係数を２倍にするようにという行政通達に従い、②で算出された線量当量を２倍した値を本施設の放射線遮蔽評価に用いる線量当量の値とした。

④放射線障害防止法では管理区域境界、事業所境界及び管理区域の人が常時立入る場所の線量当量限度は各々３００μＳｖ／週、２５０μＳｖ／３月及び１ｍＳｖ／週である。本施設では、安全側の評価のために、それぞれの限度の１／２すなわち１５０μＳｖ／週、１２５μＳｖ／３月及び５００μＳｖ／週を超えないように放射線遮蔽設計を行った。

５．１．３　管理区域境界及び事業所境界

図５．１－２に事業所境界を、また図５．１－３から図５．１－５に管理区域境界を示す。

５．１．４　陽子線の生成・輸送とビームロス

加速器であるサイクロトロンは、２３５ＭｅＶの陽子線を供給する。陽子線の電流量は可変であり、最大値は３００ｎＡである。尚、サイクロトロンから引き出されるエネルギーは固定（２３５ＭｅＶ）である。

サイクロトロンから引き出された陽子線は、サイクロトロンと同室に設置されたエネルギーセレクションシステム（以下ＥＳＳと略す）で必要に応じてエネルギーを減少した後、各照射治療室に輸送される。ＥＳＳはデグレーダ並びに発散角制限スリット及び運動量分析スリットで構成されている。陽子線は炭素製のデグレーダを貫通することによりそのエネルギーが減少する。デグレーダ通過により増大した発散角及び運動量分散をそれぞれ発散角制限スリット及び運動量分析スリットで調整する。デグレーダ並びに発散角制限スリット及び運動量分析スリットは共に陽子線の衝突を受けるので中性子発生源になる。

照射治療室に必要な陽子線電流量並びにサイクロトロンから引き出す陽子線電流量及びＥＳＳでカットされる陽子線電流量を求める。

年間治療患者数　　：　４００人
１人当り照射門数　：　２５門
年間照射門数　　：４００×２５＝１０，０００門
年間稼働日数　　：２００日
１日当り照射門数　：１０，０００÷２００＝５０門
１週間当り照射門数：５０×５＝２５０門

とした想定[1]に基づき本施設の１週間当たりの照射門数を定め、図５．１－６に示した照射仕様と輸送ビームとの関係から照射治療室に必要な陽子線電流量並びにサイクロトロンか

告示（放射線を放出する同位元素の数量等を定める件）：別表第５

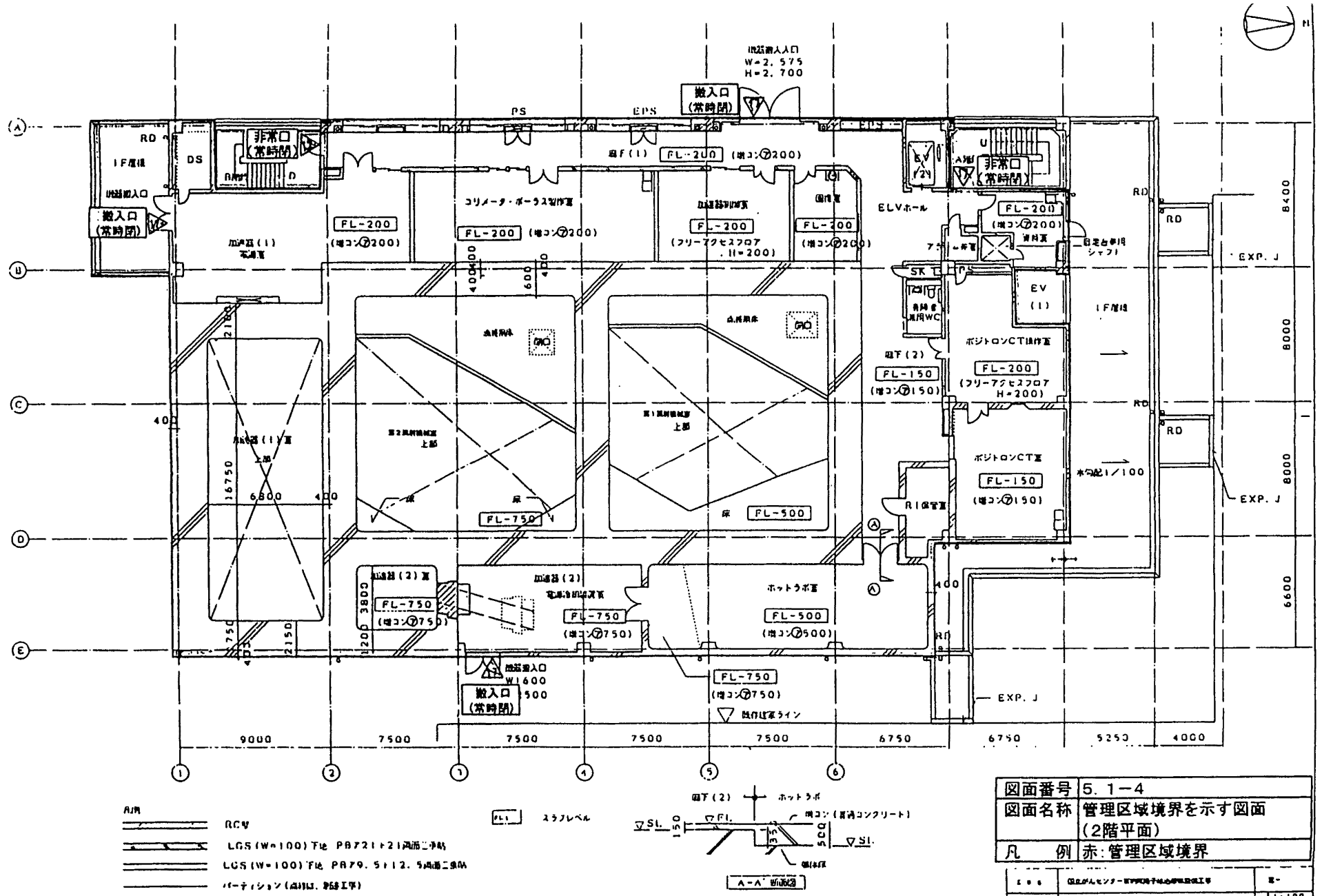
別表第５（第31条関係）

自由空間中の粒子フルエンスが１平方センチメートル当たり10^{12}個である場合の線量当量

第一欄	第二欄	第三欄	第四欄
中性子のエネルギー (MeV)	１センチメートル線量当量 (Sv)	３ミリメートル線量当量 (Sv)	70マイクロメートル線量当量 (Sv)
2.5×10^{-8}	8.00	8.80	7.20
1.0×10^{-7}	10.4	8.50	5.50
1.0×10^{-6}	11.2	6.90	3.70
1.0×10^{-5}	9.20	5.30	2.80
1.0×10^{-4}	7.10	4.40	2.50
1.0×10^{-3}	6.20	3.90	2.80
1.0×10^{-2}	8.60	9.20	8.90
2.0×10^{-2}	14.6	18.3	18.2
5.0×10^{-2}	35.0	48.1	46.6
1.0×10^{-1}	69.0	95.0	95.0
2.0×10^{-1}	126	186	168
5.0×10^{-1}	258	266	219
1.0	340	332	292
1.5	362	344	292
2.0	352	335	283
3.0	380	358	305
4.0	409	387	329
5.0	378	358	301
6.0	383	364	302
7.0	403	384	312
8.0	417	407	341
1.0×10^{1}	446	446	368
1.4×10^{1}	520	520	359
1.7×10^{1}	610	610	421
2.0×10^{1}	650	670	516

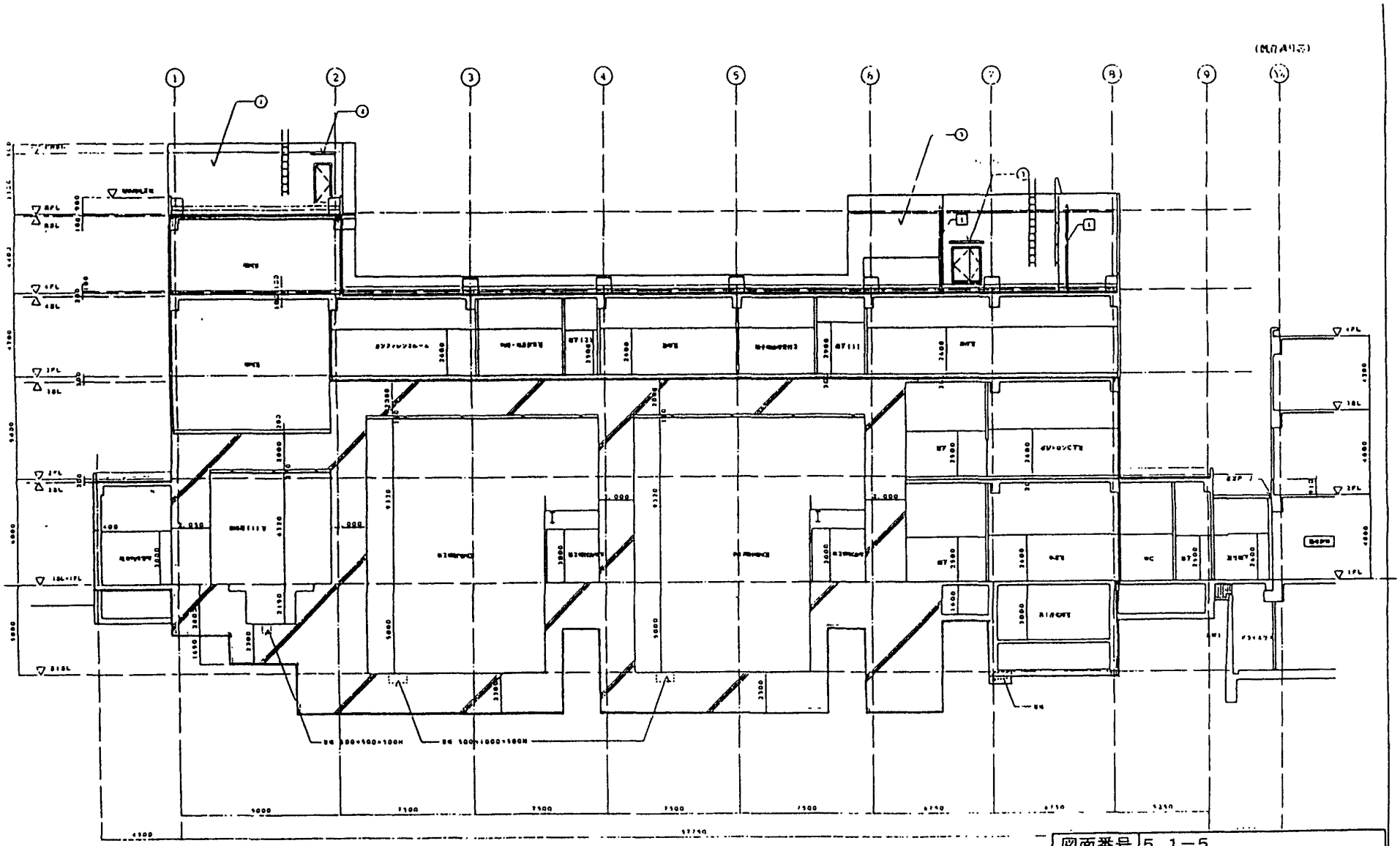
備考　該当値がないときは，補間法によって計算する。

表番号	５．１－１
表名称	中性子線量当量変換係数（告示別表第５）
凡　例	エネルギー：２０ＭｅＶ以下



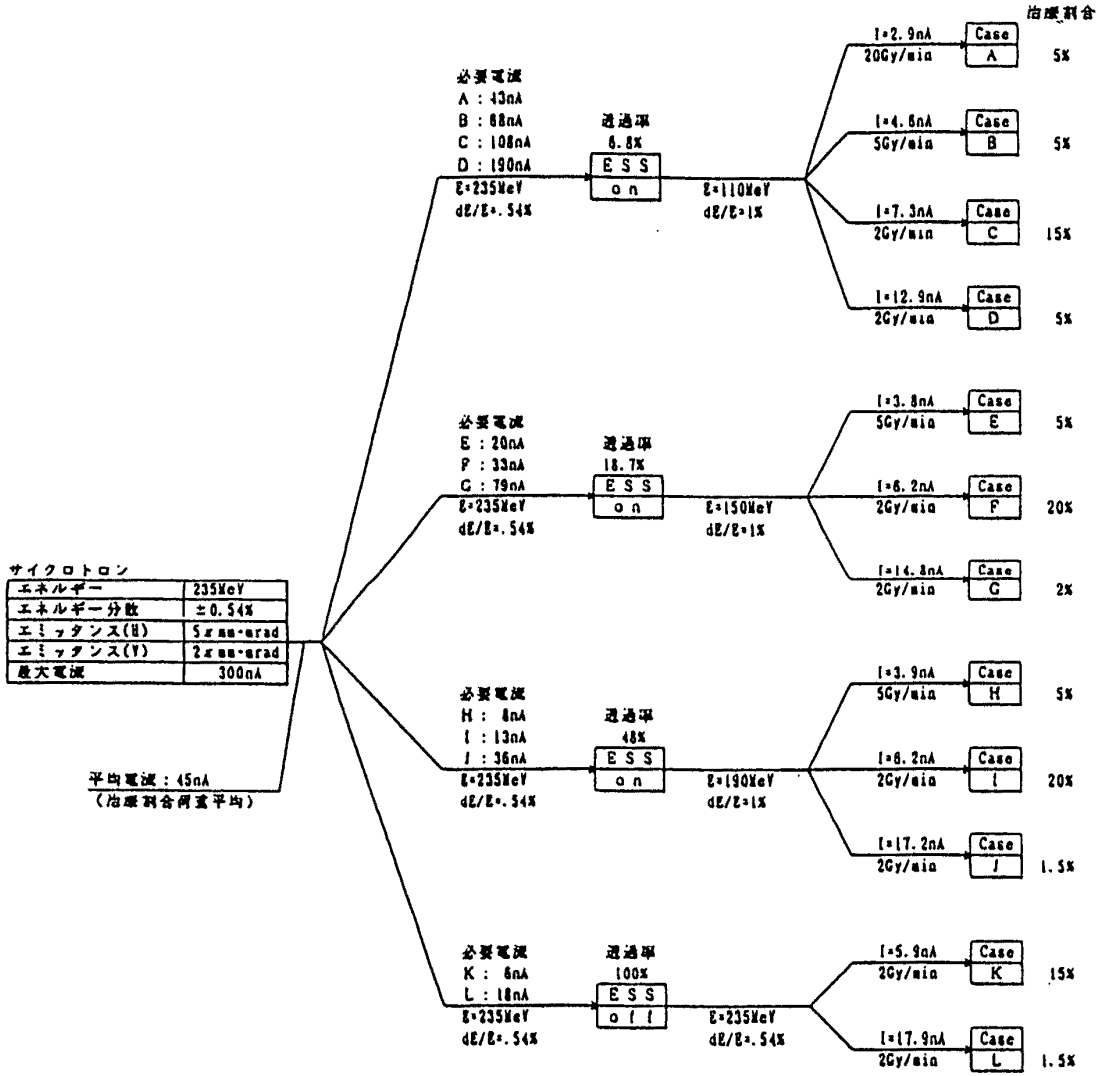
図面番号	5. 1−4
図面名称	管理区域境界を示す図面 (2階平面)
凡　例	赤:管理区域境界

工事名	国立がんセンター東病院陽子線治療施設棟工事	縮尺
図面名	2階平面図	1:100



図面番号	5．1－5
図面名称	管理区域境界を示す図面 （建屋断面）
凡　　例	赤：管理区域境界

工事名	国立がんセンター[illegible]	縮尺	1：100
図面名	[illegible]		



図面番号	5．1－6
図面名称	照射仕様と輸送ビームとの関係
凡　例	

ら引き出す陽子線電流量及びＥＳＳでカットされる陽子線電流量を各々１週間単位で算出する。但し、照射部に必要な陽子線電流量には、ビーム輸送の調整及びドジメトリ（線量測定）に用いるビーム量として治療照射時の電流量の５０％を加えるものとする。

サイクロトロンから引出されたビームの形状は必要に応じてビームプロファイルモニターＢＰＭ2（図5．１－8参照）で確認できる。本ビームプロファイルモニターの直後には陽子線を吸収する炭素製のビームダンプが設置されている。本ビームダンプは中性子源になり得るので、ビームダンプに輸送する陽子線の量を７５（ｎＡ・ｍｉｎ／週）以下に規制する。

本計算で得られた陽子線電流量の関係を表5．１－2に示す。

表5．１－2　陽子線電流量一覧

	第1照射治療室	第2照射治療室	第3照射治療室	ビームダンプ	合計
サイクロトロン電流量 (nA・min/週)	１６６１８	１２６７６	８８１	７５	３０２５０
照射治療室電流量 (nA・min/週)	２５２５	２０１１	１０３	０	４６３９
ＥＳＳカット量 (nA・min/週)	１４０９３	１０６６５	７７８	７５	２５６１１

表5．１－2よりサイクロトロンから引き出すサイクロトロン電流量は合計で３０２５０ｎＡ・ｍｉｎである。これにはビーム輸送の調整及びドジメトリー（線量測定）に用いる電流量として治療照射の５０％が加えられており、更にビームダンプに輸送する電流量として７５ｎＡ・ｍｉｎが加えられている。つまり、サイクロトロン電流量の内訳は

治療照射に用いる電流量　：　２０１１７ｎＡ・ｍｉｎ
ドジメトリーに用いる電流量　：　１００５８ｎＡ・ｍｉｎ
ビームダンプに輸送する電流量　：　７５ｎＡ・ｍｉｎ

となっている。

尚、サイクロトロンの運転時間を参考値として求めておく。照射仕様と輸送ビームとの関係（図5．１－6）より、治療照射の時にサイクロトロンから引き出す陽子線の平均電流値は４５ｎＡである。ビーム輸送の調整及びドジメトリーでは使用する電流値は小さくてよく、ビーム輸送の調整及びドジメトリーの時にサイクロトロンから引き出す陽子線の平均電流値を４．５ｎＡとする。また、ビームの形状を確認するためにビームダンプに輸送する電流値を１ｎＡとする。このとき１週間当たりのサイクロトロン運転時間は、

サイクロトロン運転時間＝（２０１１７／４５）／６０
＋（１００５８／４．５）／６０
＋（７５／１）／６０
≒４５．９時間／週

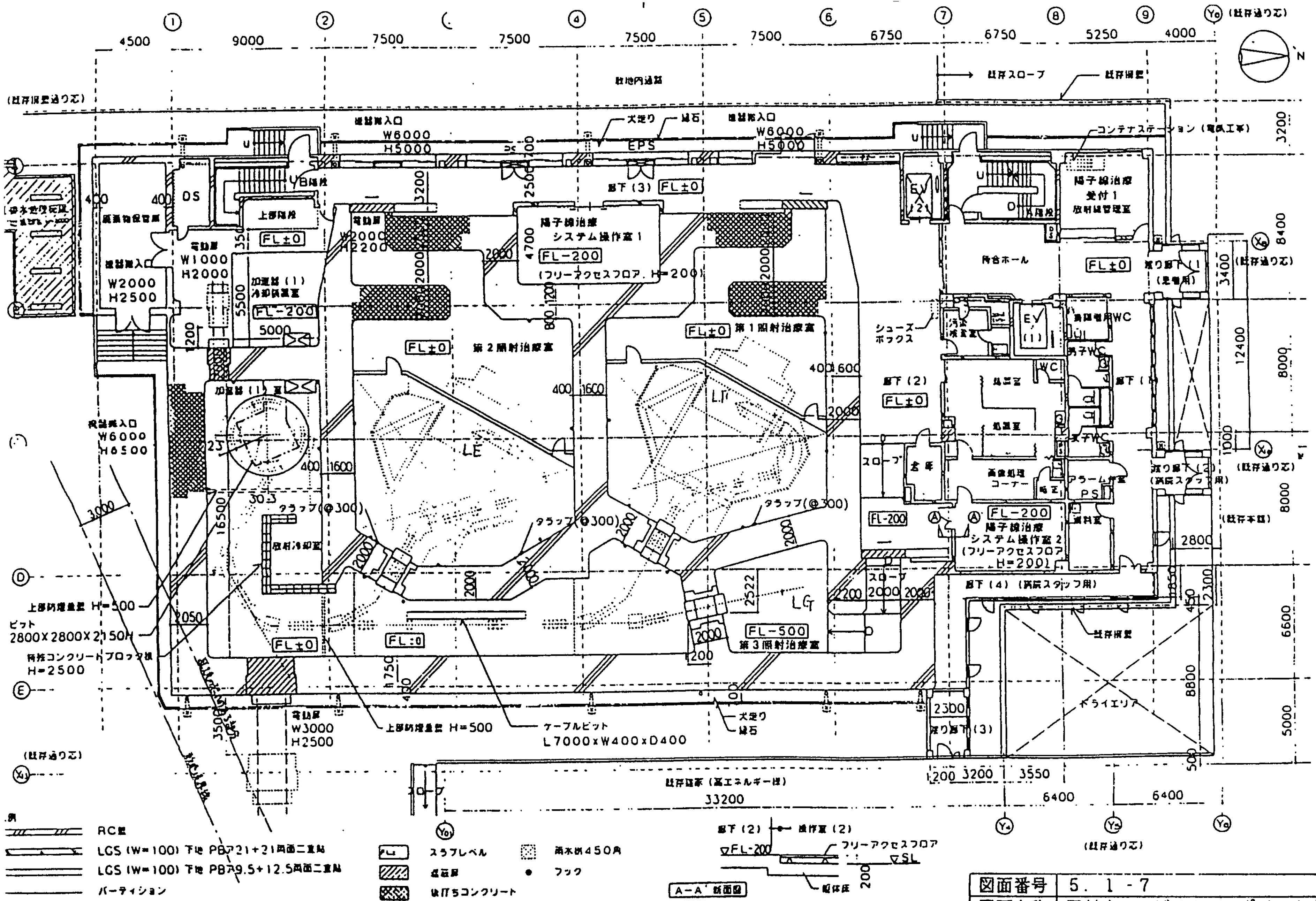
である。このときサイクロトロンから引き出すサイクロトロン電流を平均すると、

サイクロトロン電流＝３０２５０／（４５．９×６０）
≒１０．９８ｎＡ

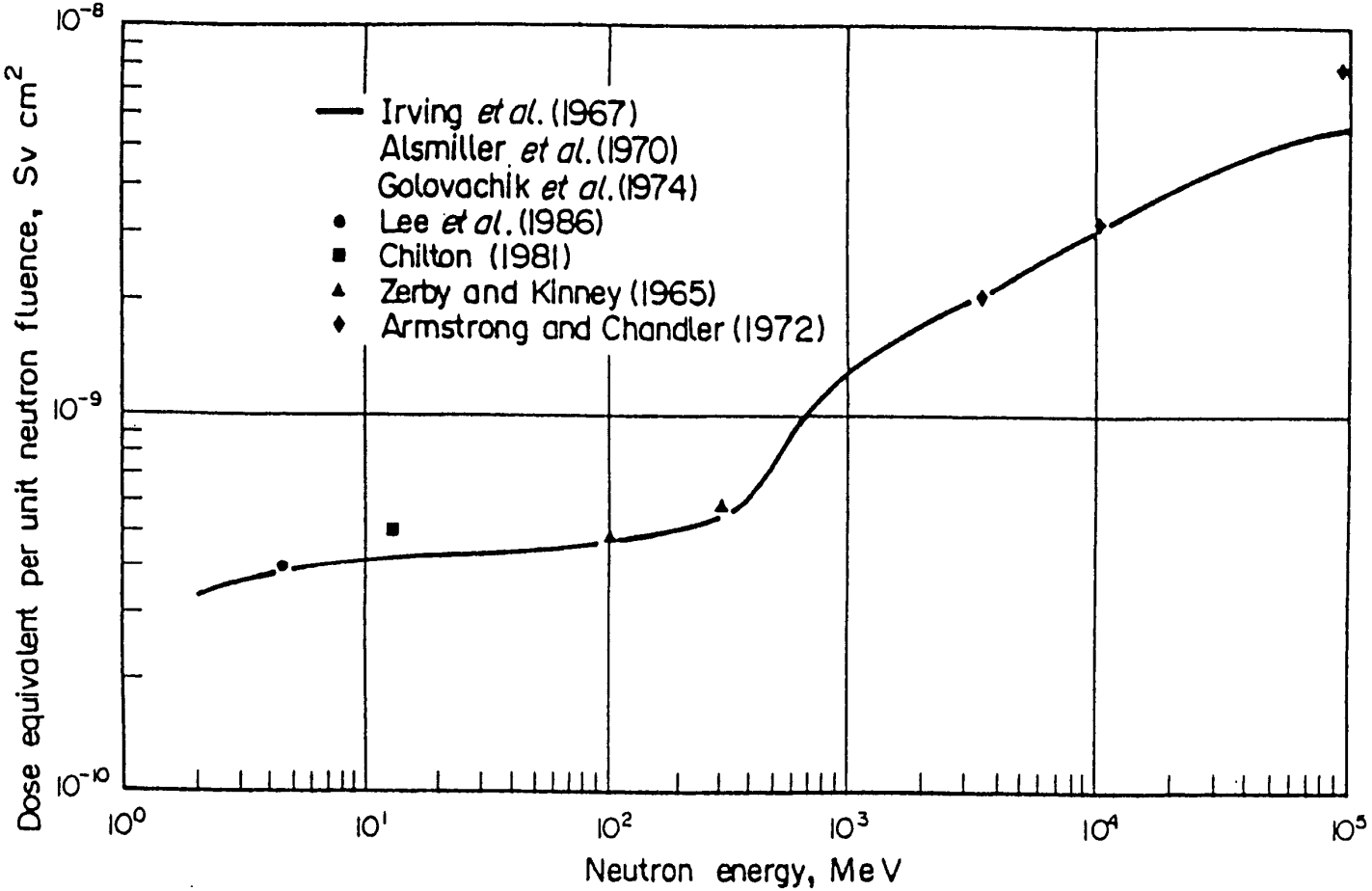
となる。

ビームロスポイントと建屋との位置関係を示す。本施設で、陽子線が物質に衝突して中性子が発生するところは次の通りである。記号で示したそれぞれのビームロスポイントの建屋との位置関係を、各照射治療室に関しては図5．１－7に示し、サイクロトロンとＥＳＳ及びビームダンプに関しては図5．１－8に示す。

サイクロトロン
・サイクロトロン全周にわたる一様ロス　・・・・・ＬＡ
・デフレクターにおける点状ロス　・・・・・ＬＢ

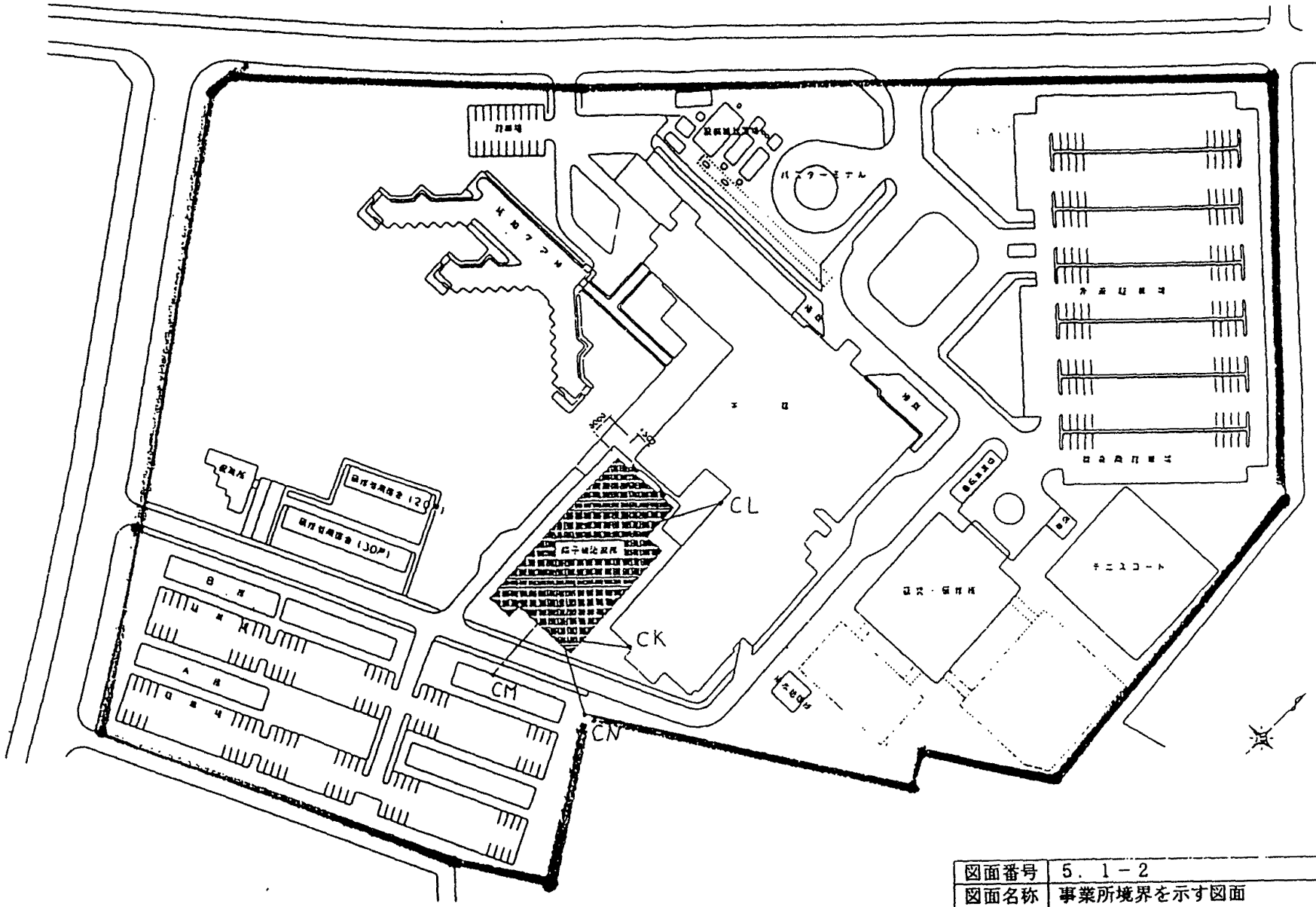


図面番号	5．1－7
図面名称	照射室でのビームロスポイントを示す図面

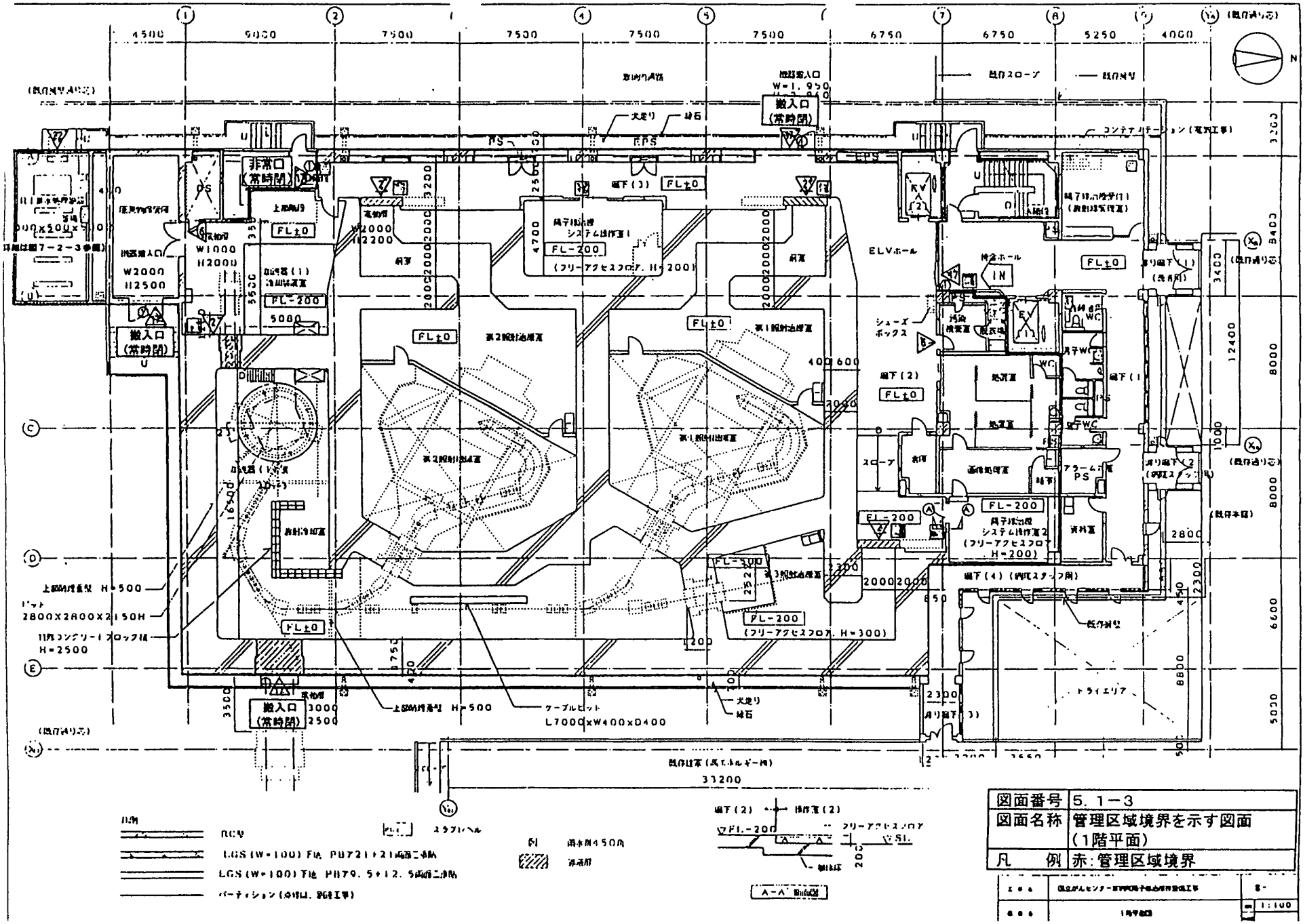


Maximum dose equivalent per unit fluence for neutrons incident in a plane parallel beam on a 30 cm thick semi-infinite slab phantom. See footnote to Table 23 for further information.

図面番号	5．1－1
図面名称	中性子線量当量変換係数（ＩＣＲＰ－５１）
凡　例	エネルギー：２０ＭｅＶを超える

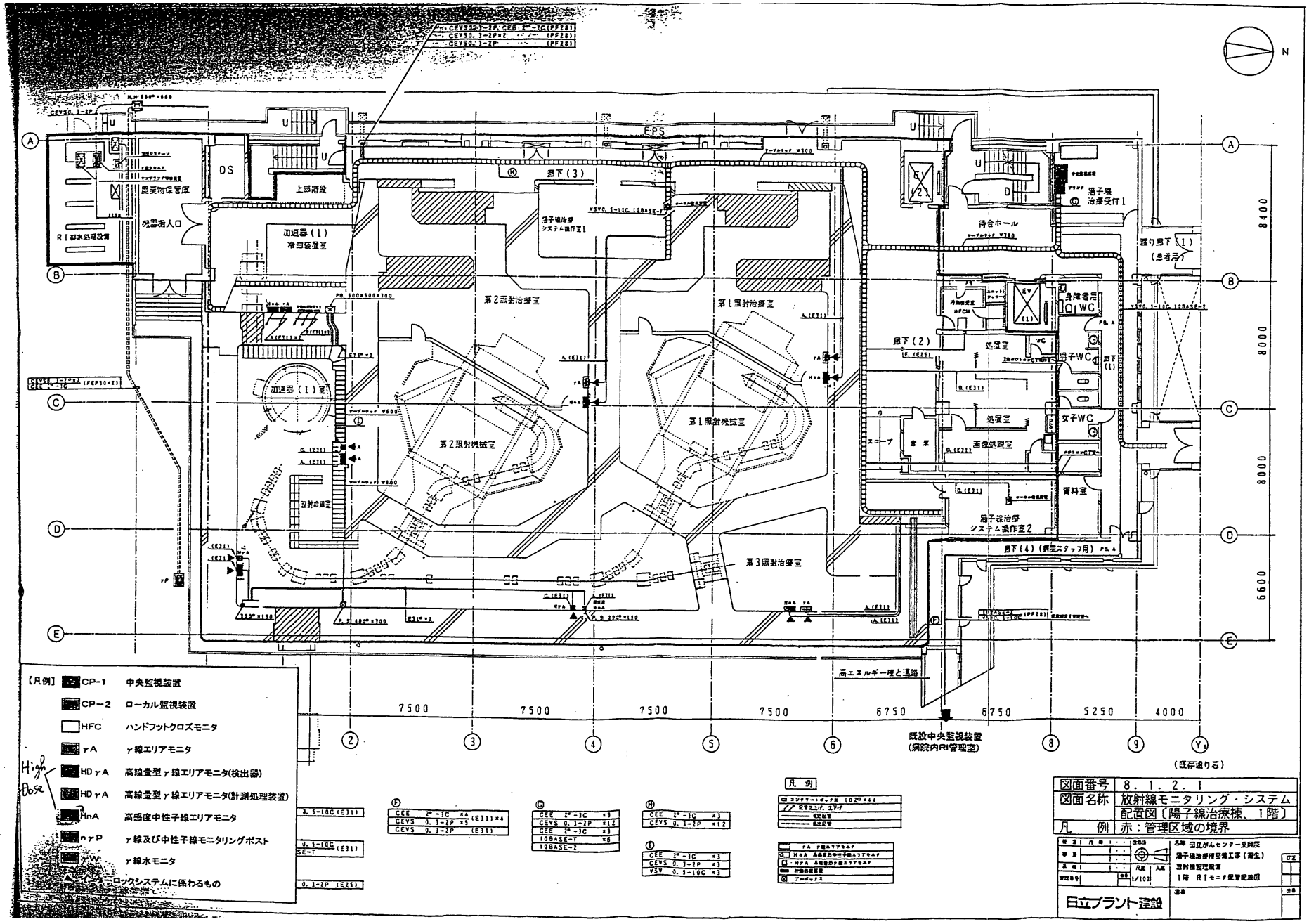


図面番号	5．1－2
図面名称	事業所境界を示す図面
凡　　例	緑：事業所境界



図面番号	5. 1−3
図面名称	管理区域境界を示す図面 (1階平面)
凡　例	赤:管理区域境界

工事名	国立がんセンター東病院陽子線治療施設新営工事	縮尺	1:100
図面名	1階平面図		



図面番号	8．1．2．1
図面名称	放射線モニタリング・システム
	配置図〔陽子線治療棟、1階〕
凡　例	赤：管理区域の境界

日立プラント建設

名称 日立がんセンター東病院
陽子線治療棟整備工事（衛生）
放射線監視設備
1階 R I モニタ配置図
尺度 1/100

附錄四、第三十五屆質子治療研討會議程。

附録四

PTCOG XXXV

Schedule

Wednesday, November 14, 2001

9:10-9:15	Welcome to Tsukuba
9:15-9:25	President's speech
9:25-9:55	Current Status of Particle Therapy Facilities in Japan
9:55-11:55	Focus Session 1. Results of Proton Therapy for Tumors in the Body Trunk
11:55-12:55	Lunch
12:55-14:10	Session 1: Accelerator, and Beam optics
14:10-14:25	Coffee Break
14:25-15:55	Session 2: Clinical Studies
15:55-18:30	Visit to Proton Medical Research Center and Supper
19:00-21:00	Violin Concert

Thursday, November 15, 2001

7:00-8:30	Steering Committee
9:05-10:50	Focus session 2. RBE for Proton Beams
10:50-11:30	What I Expect for Proton Therapy : from Surgical Oncologist's Point of View
11:30-13:35	Lunch and Poster Session
13:35-13:45	Report of the Steering Committee
13:45-15:15	Session 3: Beam preparations and miscellaneous
15:15-15:35	Coffee Break
15:35-16:50	Session 4: Dose calculation and Dosimetry
18:00-20:00	Banquet

Friday, Nov. 16, 2001

9:05-12:20	Focus session 3 Quality Assurance: Protocol, Practice & Future Development
10:40-10:55	Coffee Break
	Focus session 3 continued
12:20-12:25	Concluding Remark

Place University Hall, University of Tsukuba

Program

Wednesday, November 14, 2001

9:10-9:15

Welcome to Tsukuba, Akine Y (University of Tsukuba)

9:15-9:25

President's speech, Goitein G

9:25-9:55
Current Status of Particle Therapy Facilities in Japan
Kawachi K., Nuclear Safety Technology Center, Japan
Chairperson: Sakae T (University of Tsukuba)

9:55-11:55
Focus Session 1. Results of Proton Therapy for Tumors in the Body Trunk
Chairpersons: Akine Y and Tokuuye K (University of Tsukuba)

9:55-10:10
Clinical Results of Proton-beam Radiotherapy for Non-small Cell Lung Cancer
Shioyama Y 1), Tokuuye K 1), Okumura T 2), Hasezawa K 1), Kagei K 1), Sakae T 1) and Akine Y 1). 1)PMRC, University of Tsukuba, 2)Department of Radiology, Central Hospital of Ibaraki Prefecture

10:10-10:25
Long-term Results of Proton Beam Therapy for Carcinoma of the Uterine Cervix
Kagei K, Okumura T, Ohara K, Shioyama Y, Hasezawa K, Sugahara S, Tokuue K and Akine Y. University of Tsukuba

10:25-10:40
Clinical Results of Proton Radiation Therapy for Cancer of the Esophagus
Okumura T 1) , Akine Y 2), Hasezawa K 2), Shioyama Y, 2), Koyama S2),
1)Central Hospital of Ibaraki Prefecture and 2)University of Tsukuba

10:40-10:55
Short Course Radiotherapy with Carbon Ions for Hepatocellular Carcinoma
Kato H, Tsujii H, Hirai F, Yamada S, Ohto M, Research Center for Charged Particle Therapy, National Institute of Radiological Sciences, Chiba

10:55-11:10
Preliminary results of a phase II study of proton therapy for hepatocellular carcinoma
Mitsuhiko KAWASHIMA (1), Takashi OGINO (1), Junji FURUSE (2), Masaru KONISHI (3), Keiji NIHEI (1), Satoshi ISHIKURA (1), Hiroshi ISHII (2), and Hiroshi IKEDA (1)
Department of Radiology (1), Medical Oncology (2), Surgery (3), National Cancer Cennter Hospital East, Kashiwa, Chiba, Japan

11:10-11:25
Results of Proton Therapy for Hepatocellular Carcinoma at University of Tsukuba
Tokuuye K 1), Matsui R 1), Akine Y 1), Shioyama Y 1), Kagei K 1), Hasezawa K 1), Sugawara S 1), Ohara K 1) and Okumura T 2). 1)Radiation Oncology G., Univ. of Tsukuba Hospital, 2)Department of Radiology, Central Hospital of Ibaraki Prefecture

11:25-11:40
Proton radiation therapy of lesions of the trunk: Experience at PSI
Goitein G., Lomax T and Team Radiation Medicine

11:40-11:55
Discussion

11:55-12:55 Lunch

12:55-14:10 Session 1: Accelerator and Beam optics
Chairperson: Mori Y. (High Energy Accelerator Research Organization:KEK)

12:55-13:10
PROSCAN: A Long-Term Commitment for the Advancement of Technology in the Field of Proton Therapy at PSI
Martin Jermann

13:10-13:25
Respiration Synchronized Operation of the Accelerator System in PMRC, Univ. of Tsukuba
Masumi Umezawa (Hitachi, Ltd.) , Collaboration of Hitachi, Ltd. and PMRC, Tsukuba

13:25-13:40
FFAG Accelerator for Proton Therapy
S.Machida, Y.Mori (KEK)

13:40-13:55
Implementing a smooth-beam extraction control method in a synchrotron-based PBTS for active and gated beam treatments
David Lesyna, Optivus Technology Inc, CA

13:55-14:10
Beam optics for a scanned proton beam at Loma Linda
Courtrakon, G, Hubbard J, Koss P, Sanders E (LLUMC), Lesyna D (Optivus Technology

Inc.).

14:10-14:25 Coffee Break

14:25-15:55
Session 2: Clinical Studies
Chairperson: Goitein G.

14:25-14:40
CT and MR imaging in the detection of early radiation-induced hepatic injury
Hiroaki Onaya,1) Takashi Ogino1), Mitsuhiko Kawashima1), Hiroshi Ikeda1) Yukihisa Saida2), Yasushi Matsuzaki2) , 1)Diagnostic Radiology Div., National Cancer Center Hospital East, Kashiwa, Chiba, 2)Department of Radiology, Institute of Clinical Medicine, University of Tsukuba, Tsukuba, Ibaraki

14:40-14:55
Evaluation of Hepatocellular Carcinoma Following Proton Radiotherapy using Contrast Enhanced Power Doppler Ultrasonography Observation
G.Niizawa, Y. Matsuzaki, E.Tohno, Y.Saitou1), J Shoda, M Abei, N.Tanaka, Y.Itai, Y Akine. Institute of Clinical Medicine, Univ. of Tsukuba, Tsukuba Medical Center Hospital.

14:55-15:10
Analysis of Lung Toxicity in Carbon Ion Therapy for Non-Small Cell Lung Cancer
M. Koto, H. Tsujii, M. Wakaisami, N. Yamamoto, T. Miyamoto (NIRS)

15:10-15:25
Targeting accuracy of respiration-gated proton beam irradiation for hepatocellular carcinoma
Takashi Ogino, Shigeyuki Murayama, Keiji Nihei, Mitsuhiko Kawashima, Satoshi Ishikura, Munefumi Shimbo, Teiji, Nishio, Hiroshi Ikeda (National Cancer Center Hospital East)

15:25-15:40
The Dose Volume Histogram analysis for the bone and soft tissue sarcoma
Yanagi T, Tsujii H, Kamada T, Tsuji H, Tanabe. Research Center of Charged Particle Therapy, National Institute of Radiological Sciences

15:40-15:55
Long term results of proton irradiation of uveal melanoma patients at Harvard Cyclotron 1975-1997

Munzenrider JE, Mass. General Hospital

15:55-18:30
Visit to Proton Medical Research Center and Supper

19:00-21:00
Violin Concert

Thursday, November 15, 2001

7:00-8:30 Steering Committee at the Okura Frontier Hotel

9:05-10:50
Focus session 2. RBE for Proton Beams
Chairperson: Ando, K (NIRS)

9:05-9:35
RBE Values for Proton Beam Therapy
Paganetti, H (MGH)

9:35-9:50
The riddle of proton RBE: New approaches to an old problem
Reinhard W. Schulte, Department of Radiation Medicine, Loma Linda University Medical Center

9:50-10:05
Biological effectiveness of high energy protons at three facilities in Japan
Koichi Ando(1), Yoshiya Furusawa(1), Takashi Ogino(2),Kazufumi Kagawa(3) and Go Kagiya(4). (1) Natl Inst Radiol Sci, Chiba, (2) Natl Cancer Center Hospital East, Kashiwa, (3) Hyogo Ion Beam Medical Center, Hyogo, (4) Wakasa Energy Research center, Tsuruga, Japan

10:05-10:20
Experimental in vitro proton RBE values (relative to 137 Cs gamma-ray) at PMRC :Preliminary report
Akira Maruhashi 1, Koji Tsuboi 1, Norio Kubota 2, Akihiro Nohtomi, Masaru Satoh 1, Toshiyuki Terunuma 1, Makiko Miyakawa 1, Yasuyuki Akine . (1 University of Tsukuba, 2 Ibaraki Pref. Univ. of Health Science, Japan)

10:20-10:35
Preclinical biological assessment of proton and carbon ion beamas at Hyogo Ion Beam Medical Center
Kagawa K, Murakami M, Hishikawa Y, Abe M, Akagi T, Yanou T, Ando K, Furusawa Y, Nojima K, Aoki M and Kanai T. Department of Radiology, Hyogo Ion Beam Medical Center, Hyogo, JAPAN, Laboratory of Heavy-ion Radiobiology for Therapy, and Division of Accelerator Physics and Engineering, National Institute of Radiological Sciences, Chiba, JAPAN.

10:35-10:50
Discussion

10:50-11:30
What I Expect for Proton Therapy : from a Surgical Oncologist's Point of View
Chairperson: Maruhashi A (University of Tsukuba)
Co-chairperson: Okumura T (Central Hospital of Ibaraki Prefecture)

As a Neurosurgeon: Tsuboi K (University of Tsukuba)

As a Pediatric surgeon: Ohkawa H (Ibaraki Children Hospital)

11:30-13:35 Lunch and Poster Session

13:35-13:45
Report of the Steering Committee
Goitein G.

13:45-15:15
Session 3: Beam preparations and miscellaneous
Chairperson: Dan Jones (NAC)

13:45-14:00
Treatment planning system using a multilayer energy filter for proton therapy
Takeji Sakae, Akihiro Nohtomi, Masaru Sato, Yoshikazu Tsunashima, Toshiyuki Terunuma, Ryosuke, Kohno, Akira Maruhashi and Yoshiyuki Shioyama, PMRC, Univ. of Tsukuba

14:00-14:15
Use of a miniature ripple filter for filtering ripple found in the distal part of SOBP

Yoshihisa Takada, Kiyoshi Yasuoka 1, Toshiyuki Terunuma 2, Institute of Applied Physics, 1 Institute of Basic Medical Sciences, 2 PMRC, Univ. of Tsukuba

14:15-14:30
Membrane Type Liquid Variable Compensator
Yoshinori Hayakawa, Dept.Biomed.Eng., Toin University of Yokohama

14:30-14:45
Performances of a Test Model of a Compact Parallel Beam Scanner for Proton Therapy
Y.H. Pu, T. Nakanishi, T. Kim, and S. Nakamura, R&D Center, Mitsubishi Electric Corp., Amagasaki

14:45-15:00
Proposal of a Cylinder Type Liquid Variable Compensator
Makoto Ochiai and Yoshinori Hayakawa, Dept.Biomed.Eng., Toin University of Yokohama

15:00-15:15
New Patient Positioner for Proton Beam Therapy
M. F. Moyers, S. Rightnar, R. Arellano, R. W. Schulte, D. W. Miller, R. P. Levy. Loma Linda University Medical Center, K. Westerlund, C. Sandin, U. Osterberg, MDS Nordion

15:15-15:35 Coffee Break

15:35-17:05
Session 4: Dose calculation and Dosimetry
Chairperson: Muller, RG (University of Erlangen-Nuremberg)

15:35-15:50
Range Measurement System of Patient Body using Positron Camera in Heavy Ion Therapy
Hideyuki Mizuno, Yuzuru Kutsutani-Nakamura (Saitama Cancer Center), Yasushi Iseki (Toshiba Co.),Tatsuaki Kanai, Atsushi Kitagawa, Mitsutaka Kanazawa, Takehiro Tomitani, Mitsuru Suda,Eriko Urakabe , Fuminori Soga (Nat. Inst. Rad. Sci.) Youichi Hirata (Accelerator Engineering Co.)

15:50-16:05
A simple pencil beam dose calculation module for daily treatment planning
S.Fujitaka, Y.Nagamine, K.Matsuda, H.Akiyama, T.Sakae* and Y.Akine*, Hitachi, Ltd. Power & Industrial Systems R&D Labo., *PMRC, Univ. of Tsukuba

16:05-16:20
The pixel ionisation chamber: a detector for beam monitor and dosimetry
A.Boriano[1,2], F.Bourhaleb [1,3], R.Cirio[1], M.Donetti[1,4], F.Marchetto[1], C.Peroni[1], C.Sanz[1*]
[1] Dipartimento di Fisica Sperimentale and INFN, Via P.Giuria 1, I-10125 Torino, Italy
[2] ASP, Viale S.Severo 65, I-10125 Torino, Italy, [3] ICSC WorldLab, 32 Ch. De Mornex, CH-1003 Lausanne, Switzerland, [4] Fondazione TERA, Via Puccini 1, I-28100 Novara, Italy

16:20-16:35
Proton dose calculations in heterogeneous media: Pencil beam scaling versus Monte Carlo
Hanitra Szymanowski and Uwe Oelfke, German Cancer Research Center (DKFZ), Dept. of Medical Physics, Heidelberg, Germany

16:35-16:50
Implementation of an Pencil Beam Algorithm for Proton Treatment Using Different Kernels
R.G. Mueller (Inst. Med. Phys. Univ. Erlangen-Nuremberg,Germany), H.J. Borchert (Inst. Med. Phys. Univ. Erlangen-Nuremberg, Germany) , U. Lambrecht (Radiooncology Univ. Erlangen-Nuremberg, Germany), M. Schmidt (Inst. Med. Phys. Univ. Erlangen-Nuremberg, Germany), N. Achterberg (Inst. Med. Phys. Univ. Erlangen-Nuremberg, Germany)

18:00-20:00 Banquet

Friday, Nov. 16, 2001

9:05-12:05
Focus session 3. Quality Assurance: Protocol, Practice & Future Development
Chairperson: T. Kanai (NIRS)

9:05-9:40
Introductory Talk (Overview): Quality Assurance Applied to Proton Beam Therapy
Michael Moyers, Loma Linda University Medical Center, USA

Protocol
9:40-9:55
QA Protocol in Japanese Particle Therapy Facilities
Tatsuaki Kanai, National Institute of Radiological Sciences, JASTRO QA Working Group of Particle Therapy, Japan

Practice

9:55-10:10
QA Practice at PSI
Eros Pedroni, and Team Radiation Medicine, Paul Scherrer Institute, Villigen, 5232, Switzerland

10:10-10:25
Quality Assurance Practically Applied at New PMRC
Kiyoshi Yasuoka, Takeji Sakae[1)], Akihiro Nohtomi[2)], Akira Maruhashi[1)],, Yoshihisa Takada[2)], Masaru Sato[3)], Toshiyuki Terunuma[3)], Yoshikazu Tsunashima[3)], Katsuhisa Hosono[3)] ; Institute of Basic Medical Sciences, 1)Institute of Clinical Medicine, 2)Institute of Applied Physics, 3)Proton Medical Research Center, University of Tsukuba, Ibaraki, Japan

10:25-10:40
Implementation of Quality Assurance Procedures at NPTC
Uwe Titt, W. D. Newhauser, Massachusetts General Hospital, 30 Fruit Street, NPT-100, Boston, MA 02114, USA

10:40-10:55 Coffee Break

10:55-11:10
Procedure of calibration of dose monitor at NCC, Kashiwa
Munefumi Shimbo, T. Nishio, S. Katsuta, S. Kawasaki, T. Ogino, K. Ikeda
National Cancer Center Hospital East, 6-5-1 Kashiwanoha, Kashiwa, Chiba 277-8577, Japan

11:10-11:25
The proton therapy quality assurerance program at NAC
D. Jones, A N Schreuder, E A de Kock, J E Symons, A Tourovsky, National Accelerator Centre, P.O.Box 72, Faure 7131, South Africa,D. Jones, National Accelerator Centre

11:25-11:40
Quality assurance in the heavy-ion therapy at GSI
Eike Rietzel for the Ion-Therapy Group of GSI

Application
11:40-11:55
National Cancer Institute funded Resource Center for Emerging Technologies (RCET) at University of Florida

J. Palta and V. Frouhar, Department of Radiation Oncology, University of Florida, Gainesville, Florida 32610, USA

11:55-12:10
The Proton Users Network at PSI: Patient Referral and Data Sharing
G. Goitein, Paul Scherrer Institut, Div. of Radiation Medicine, Villigen 5232, Switzerland

12:10-12:20
All participants Discussion

12:20 -12:25
Concluding remark
Goitein, G

Poster session Program

Facility & Future System

DEVELOPMENT AND APPROBATION OF TECHNICAL MEANS AND METHODS OF PROTON RADIATION THERAPY OF PROSTATE AND OROPHARYNX CANCER
S.A. Belov 2), I.N. Brikker 1), M.F. Lomanov 3), A.N. Makhson 2), A.R. Mirzoyan 1), N.A. Novikova 2), G.A. Pan'shin 4), O.B. Ryazantsev 3), E.V. Khmelevsky 4), V.S. Khoroshkov 3), B.B. Shvartsman 3).
1)AGAT Science and Production Union, 105275 Moscow; 2)Moscow City Oncological Hospital #62, 143423 Moscow Region; 3)Institute for Theoretical and Experimental Physics, 117259 Moscow;4)The Russian Science Center of Roentgen Radiology of theRussian Federation Ministry of Health, 117837 Moscow.

A New and Dedicated Accelerator and Beam Transport System for the Proton Therapy at the Paul Scherrer Institute (PSI) / Switzerland
J. Duppich, R. Doelling, G. Goitein, F. Jenni, M. Jermann, U. Kalt, E. Pedroni, H. Reist, U. Rohrer, M. Schippers, P. Sigg, H. J. Temnitzer, M. Werner (PSI)

Proton 3D-conformal radiation therapy of intracranial tumors: new clinical program at the Dubna Proton therapy facility
Luchin Ye.I., Yu.G. Budjashov, E.P. Cherevatenko, V.N. Gaevsky, A.V. Iglin, A.G. Molokanov, G.V. Mytsin, S.V. Shvidky, Yu.V. Traschenko, V.P. Zorin (Joint Institute of Nuclear Research, Dubna, Moscow Region, Russia), D.W. Miller, S.M. Vatnitsky (Loma Linda University Medical Center, Loma Linda, CA, USA)

REQUIREMENTS and OPPORTUNITIES of MASS HADRON-THERAPY DEVELOPMENT
Boris V. ASTRAKHAN. Russian Cancer Research Center of Russian Academy of Medical Sciences

Accelerator Facility PATRO at Hyogo Ion Beam Medical Center
A. Itano, T. Akagi and A. Higashi, Hyogo Ion Beam Medical Center

THE SURVEY FOR BUILDING PROTON THERAPY FACILITIES IN YOKOHAMA
I.Ogino, M.Hata, M.Omura, I.Koike, T.Inoue, S.Matsubara, Yokohama City University, Yokohama

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Clinical Result of Proton-Beam Radiotherapy for Non-small Cell Lung Cancer

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PURPOSE: To determine clinical result of proton-beam radiotherapy for patients with non-small cell lung cancer (NSCLC). PATIENTS & METHODS: In Proton Medical Research Center of Tsukuba University, fifty-one patients with non-small cell lung cancer were treated by proton-beam radiotherapy using 250 MeV proton delivered from booster synclotron at National Laboratory for High Energy Physics from 1983 until 2000. The clinical stage by the International Union against Cancer (UICC, 1997) was stage I in 28, stage II 9, stage III 8, and stage IV 1. Five was recurrent cases. Histopathologically, 33 were squamous cell carcinoma, 17 adenocarcinoma and 1 large cell carcinoma. The median total and fraction doses were 76.0 Gy ranging from 49.0 Gy to 93.0 Gy and 3.0 Gy ranging from 2.0 Gy to 6.0 Gy, respectively. RESULTS: The overall survival at 1 and 5 year for the entire group of 51 patients was 73.9% and 23.7%, respectively. The 5-year cause-specific survival according clinical stage was 41.1% for stage I-II patients. For 28 patients with stage I, the overall and cause-specific survival at 5 year was 23.3% and 33.1%, respectively. In comparison between 9 patients with stage IA (cT1N0) and 19 patients with stage IB (cT2N0), the prognosis was better in stage IA than in stage IB: 5-year overall and disease-free survival was 62.5% and 85.7% for stage IA, and was 14.5% and 16.2% for stage IB, respectively ($p < 0.05$). The 5-year in-field local control rate also tended to be higher in stage IA (87.5%) than in stage IB (34.6%). Loco-regional recurrence including lymphnode metastasis outside of radiation field was observed in 8 of 19 patients with stage IB (50%) during follow-up periods (3-40 months). No serious lung toxicities were observed. CONCLUSION: Proton-beam radiotherapy is considered as a safe and effective treatment for NSCLC. However, optimal method of this treatment remains to be established in future.

LONG-TERM RESULTS OF PROTON BEAM THERAPY FOR CARCINOMA OF THE UTERINE CERVIX.

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Purpose: To examine the long-term results of patients with carcinoma of the uterine cervix treated with proton beam therapy in order to determine whether proton beam therapy can be an alternative to intracavitary irradiation.
Methods and Materials: From 1983 to 1991, 25 patients with squamous cell carcinoma of the uterine cervix treated with curative intent by proton beam therapy. Nine patients had stage IIB, 15 stage IIIB, and one stage IVA. All patients underwent photon beam irradiation to whole pelvis with or without center shielding combined with proton beam therapy to primary tumors. Doses to the primary tumor ranged from 70.7 to 101Gy (median: 86.2Gy). Proton beam therapy was delivered either by single anterior field in 4 patients or two angled fields with an anterior and a lateral field in 21 patients.
Results: Follow-up times ranged from 11 to 184 months (median: 139 months). Fourteen patients were followed more than 10 years. The 10-year overall survival rates for all patients, stage IIB and stage IIIB/IVA were 59%, 89% and 40%, respectively. The 5-year local control rates for all patients, stage IIB, and stage IIIB/IVA were 75%, 100% and 61%, respectively. Thirteen patients (52%) developed late complication for small/large intestine and/or urinary bladder. Only one patient (4%) experienced severe late complication for small/large intestine and bladder requiring surgical intervention.
Conclusion: Proton beam therapy could produce the equivalent local control and survival to intracavitary

irradiation. As compared with intracavitary irradiation, the incidence of severe late complication was similar, although that of mild late complication was higher. Therefore, proton beam therapy could be an alternative to intracavitary irradiation in the treatment of cervical cancers in terms of long-term follow-up results.

Clinical Results of Proton Radiation Therapy for Cancer of the Esophagus

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Purpose: To describe the outcome of proton radiation therapy for patients with carcinoma of the esophagus.
Methods and Materials: Fifty-two patients with cancer of the esophagus who were treated with 250 MeV protons with or without x-rays were analyzed; they were chosen from among 59 such patients treated at our institution between 1985 and 2000. All were locoregionally confined and had squamous histology but one adenocarcinoma. The median tumor length was 4.7 cm (range,
1.5-15). Six patients received proton radiation therapy alone (75 Gy - 89.5 Gy, median 82 Gy) over 33 - 62 days (median 54 days), and forty patients received combination of x-rays and protons (69.1 Gy - 87.4 Gy, median 76 Gy) over 44 - 99 days (median 61 days) with conventional fractionation. The remaining six patients were treated with concomitant boost technique (73 Gy - 79.8 Gy, median 75.1 Gy) over 38 - 53 days (median 48 days). The median follow-up period was 30 months.
Results: Five-year actuarial survival for the 52 patients, and for patients with T1 (n=26) or T2 - 4 (26) were 39.4%, 57.7%, and 22.0%, respectively. The disease-specific survival for the 52 patients, and for patients with T1 or T2 - 4 were 70.2%, 95.8%, and 40.2%, respectively. Two-year local control rates for patients with T1, T2/3 lesions were 90.5%, and 61.4%, respectively. Median follow-up time of the patients with T4 lesion was so short as 8 months that local control for these patients was not assessed. The sites of first treatment failures were local-regional for 16 patients, and distant organs for 2 patients. Acute esophageal reactions were modest. Forty-nine percent (21/ 43) of the patients developed treatment-related esophageal ulcer, and the ulcers subsided with
conservative treatment in 67% of these cases.
Conclusions: The results suggest that proton radiation therapy is a feasible and effective modality for patients with locally confined esophageal cancer. Further studies will be needed to determine the optimal total dose, fractionation schedules, and better combinations of protons and
conventional x-rays.

Short-Course Radiotherapy with Carbon Ions for Hepatocellular Carcinoma

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Purpose: To evaluate safety and clinical efficacy of short-course radiotherapy with carbon-ion beams in hepatocellular carcinoma (HCC).
Methods and Materials: Between April 1997 and March 2000, 82 patients with HCC (most of them were associated with liver cirrhosis) were treated in a Phase I/II dose escalation study using short-course carbon-ion therapy : 33 patients were treated with 12 fractions / 3 weeks, 22 patients with 8 frs./ 2 wks., 27 patients with 4 frs./ 1 wk.). These patients had a history of previous unsuccessful treatments or had tumors not suited for other modalities including surgery, TAE or ethanol injection. Radiation-related morbidity was evaluated using RTOG/EORTC criteria and Child-Pugh's grading score. The tumor effect was assessed by local control rates and cumulative survival rates.

Results: Median follow-up time was 22 (range 4-54) months. So far, none of the patients developed severe morbidity. There were no treatment-related deaths. Local control rates were 94.1% at 1 year and 87.2% at 2 and 3 years after the treatment. The overall and cause-specific survival rates at 2 years were 71.0% and 77.4%, respectively.
Conclusion: It is preliminarily concluded that, based on the results of Phase I/II trials, the short-course carbon-ion therapy is a safe and effective method in the management of HCC not suited for other treatments.

Preliminary results of a phase II study of proton therapy for hepatocellular carcinoma

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Backgrounds: Proton therapy is thought to be a promising method for local cure even for patients with HCC that is not amenable to surgical resection or local ablation therapy.
Patients and Methods: Twenty-two patients with localized HCC had been already enrolled in this study between May, 1999 and May, 2001. A total dose of 76 GyE / 20 fractions was administered with 3.8 GyE, once-daily fractionation from Monday through Thursday in a week, using respiration-gated irradiation system. Relative biological effectiveness was estimated as 1.1.
Results: Histological confirmations were obtained in all but 2 patients with fine needle biopsy. All patients were completed their treatments. For 11 patients who were followed-up for more than 1 year, all but 1 were locally controlled. Four out of the 11 patients died of multicentric inntrahepatic recurrence (1), lung metastasis (1), and liver failure (2).
Conclusion: High efficacy of proton therapy for local cure in patients with HCC was suggested. Predicting a risk of treatment-related liver failure is the problem of subsequent study. Expected total number of patients enrolled is 30.

Results of proton therapy for hepatocellular carcinoma at University of Tsukuba

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Purpose: To retrospectively evaluate the effectiveness of proton therapy for hepatocellular carcinoma.
Materials and methods: From August 1983 to March 2000, 236 patients were treated with proton therapy with or without transarterial embolization and /or percutaneous ethanol injection. The majority of patients were unresectable because of liver dysfunction or other medical reasons and received 72 Gy in 16 fractions during 3.2 weeks.
Results: Overall median and actuarial 3-year survival rates were 29 months and 43 %, respectively. For 137 patients who underwent proton therapy as the initial therapy, overall median and actuarial 3-year survival rates were 40 months and 56 %, respectively. Actuarial 3-year local control rates for all patients and patients who underwent proton therapy as the initial therapy were 93 % and 97 %, respectively. Prognostic factors for the latter associated with survival rates were clinical stage, tumor size and performance status. Twenty one patients were treated with proton therapy repeatedly without deteriorating liver functions.
Conclusions: High local control and low morbidity rates suggested that proton therapy is effective and safe modality, even for patients with liver dysfunction.

Proton radiation therapy of lesions of the trunk: experience at PSI

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Between 1996 and December 2000, 72 patients underwent proton radiation therapy for deep-seated tumors at PSI. Of these, sixteen patients suffered from various lesions in the trunk, one patients mentioned here presented with multiple lesions based on neurofibromatosis, one of whom was irradiated after complete resection in the upper leg. Histologies : 2 chondrosarcomas (pelvis, neck), 6 sacral chordomas, 1 huge sacral metastasis of a rectal cancer, 2 osteosarcomas, 5 soft tissue sarcomas (2 retroperitoneal, 1 shoulder, 1thorax/neck, 1 leg). Age varied from 16 to 80 years, mean 51.8, 6 females, 10 males. Most lesions were substantially large, PTVs ranged from 12 to 3903 cc, mean 1235 cc. Most patients received combined photon – proton treatment, mainly due to limitations of the beam time at PSI. Therefore, the proton doses varied between 16.2 and 74 CGE, mean 43.2 CGE.
Four patients (treatments 1997) died from generalization. Of the 12 patients alive (10 – 46 months, mean 17m.), 1 patient presented with tumor regrowth at 8m after a phase of partial regression and clinical improvement. The patient with neurofibromatosis was controlled for 20 m., now we see a marginal relapse beside multiple new lesions of unclear dignity in the abdomen. So far we have not seen any toxicity greater grade 2 in the patients alive. One patient with a huge pelvic chordoma with skin invasion developed a fistula within this region. The histological examination showed tumor necrosis.
The irradiation of tumors of the trunk is often characterized by a) large volumes, b) moving targets, c) complicated postoperative situations including metal implants, unclear surgical margins. Protons offer an excellent tool for highly conformal, high dose irradiation of these challenging lesions.

PROSCAN: A Long-Term Commitment for the Advancement of Technology in the Field of Proton Therapy at PSI

Martin Jermann

Based on the past developments and successes of the proton therapy at the Paul Scherrer Institute (PSI) we decided in 2000 to expand the activities in this field and we founded and started the project PROSCAN. The overall objective of PROSCAN is to implement and operate at PSI a base technology laboratory for the advancement of proton therapy system techniques and applications. This long-term program, which is based on the experience with the PSI compact spot-scanning Gantry, aims to optimise the irradiation and treatment technique and to prepare the compact Gantry system for a transfer into a 'marketable product' for hospital applications. Within the project an expansion of the technical infrastructure will be realized: The existing spot-scanning Gantry will be connected through a new beam transport system to a dedicated 250 MeV compact proton cyclotron, which was decided and ordered in May 2001. An advanced compact Gantry will be developed, with the objectives, (a) to optimise the irradiation technique and the precision of tumour treatments, and (b) to upgrade the patient positioning and handling procedures. A horizontal beam area, used for the treatment of ocular lesions and for R&D of other specific tumour indications, will also be connected to the new cyclotron. With an extended, but limited clinical R&D program, which runs in parallel to the technological developments, we intend to contribute in the international framework with other centres to the demonstration of the strengths and the potential of this treatment method in a lager number of cancer patients. In parallel, with our ten years program we aim to support the education of technical and medical specialists for the introduction of this new and advanced therapy method in the hospitals. In the presentation we will explain, how we implemented the above strategy for the advancement of proton therapy technologies as part of the activities of a national research centre.

Respiration Synchronized Operation of the Accelerator System in PMRC, Univ. of Tsukuba

M. Umezawa, Collaboration of Hitachi, Ltd. and PMRC, Univ. of Tsukuba

We realized the respiration synchronized operation by controlling the synchrotron with variable repetition rate and flat-top period and applying transverse RF driven slow extraction. The synchrotron is operated by two trigger signals generated from the patient's respiration. Beam injection and acceleration sequence starts by receiving the "pre-trigger". This means the variable repetition rate. After the end of acceleration, synchrotron waits the "trigger for beam extraction". This means the variable flat-top period. When this trigger ends, the extracted beam can be stopped very quickly within 0.2msec by the termination of transverse RF. In this operation, the repetition rate can be changed from 0.15Hz to 0.5Hz and the flat-top period can be extended to 5sec. The present scheme is being applied to clinical trials with satisfactory function and stability.

FFAG Accelerator for Proton Therapy

S.Machida, Y.Mori (KEK)

FFAG (Fixed Field Alternating Gradient) synchrotron has a enormous potential for medical applications. It is easy to operate, easy to change beam energy with high repetition rates, and can deliver high average beam current. We will present the recent development of a FFAG synchrotron and show an example of medical applications.

Implementing a smooth-beam extraction control method in a synchrotron-based PBTS for active and gated beam treatments

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Active beam delivery and intensity-modulated proton therapy requires improved techniques for spatial and intensity control, as compared to passively scattered treatments. Ability to gate beam intensity is also desired for improved dose conformity when treating targets with motion. For synchrotron-based accelerator sources, feedback control is needed to compensate for natural variations in the slow resonant extraction process. Trade-offs can be made to determine the optimal allocation of intensity control performance requirements for accelerator and beam delivery systems. For the LLUMC Proton Beam Treatment System, a smooth extracted beam intensity goal of 5% uniformity up to 1 kHz frequency was established. Preliminary test results of a non-destructive intensity monitor and extraction control magnet already demonstrate the ability to monitor and regulate the extraction process to better than 15%. Additionally, beam gating capability has been demonstrated, and achieved turn-on times of less than 2 milliseconds, and turn-off times of less than 1 millisecond. Suggestions for follow-on work to further improve performance of the system are also presented. The achieved results thus far demonstrate the ability to achieve good beam intensity and gating control while also providing the safety and electronic beam energy selection capabilities using a synchrotron-based proton accelerator.

Beam Optics for a Scanned Proton Beam at Loma Linda

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The next nozzle at Loma Linda will use two scanning magnets which will be installed on one of the three Loma Linda gantries. This will require a small beam at isocenter which can be swept across the tumor with the scanning magnets. The accelerator group has developed magnetic quadrupole solutions in the gantry beam lines which can deliver a small beam (less than 6 mm diameter) to isocenter. The strategy has been to find a solution for one energy, at one gantry angle, in one room and then find a general solution which can be used for all energies, all gantry angles and any gantry room. The simulation program TRANSPORT, first developed at Stanford Linear Accelerator Center, was used to find magnetic quadrupole strengths along the beam lines which must satisfy multiple constraints including a small beam at isocenter. Starting with the first gantry, we present a small beam solution for 155 MeV and compare TRANSPORT predictions with beam size measurements at nine positions along the beam line. Due to passive scattering systems in the nozzles, a small beam measurement at isocenter in the gantry rooms is not possible at this time. However, the research room has been instrumented with scanning magnets and allows for small beam measurements at the appropriate distance to the patient. Small beam measurements and two dimensional patterns using the scanning magnets will be presented in this report.

CT and MR imaging in the detection of early radiation-induced hepatic injury

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Purpose: CT and MRI have been widely used to evaluate patients with radiation-induced hepatic injury. However, CT and MR imaging in the detection of early radiation-effects on the liver in the acute period within 6 months after completion of radiotherapy is little known. Therefore, we investigate the CT and MR findings in the detection of radiation-induced hepatic injury in the acute period.
Materials and Methods: Nine patients with proved hepatocellular carcinoma underwent proton irradiation using a 150-190 MeV beam at a mean actual dose of 76.0Gy/20 fractions between May, 1999 and June, 2000. CT and MRI study was performed immediately, 3 months, and 6 months after completion of radiotherapy. For CT scans, a multidetector CT was used to perform five phases study (precontrast and postcontrast, including arterial, portal venous, equilibrium, and late phases). MR images included precontrast T1-, T2-, and T2*-weighted images, Gd-DTPA-enhanced multislice dynamic study covering all the liver, and ferumoxides-enhanced MR images. Changes in the irradiated area were visually compared with those in the surrounding non-irradiated areas.
Results: Immediately (within one week) after radiotherapy completion, contrast- enhanced MR images revealed an early radiation-induced hepatic area missed by all CT scans (n=8). The radiation effects on the liver appeared as high intensity on Gd-DTPA-enhanced images and as less decreased signal intensity area on ferumoxides-enhanced images. Among MR imaging, ferumoxides-enhanced T2*-weighted images showed the highest contrast and contrast-to-noise ratio. In two of three patients examined by CT and MR during radiotherapy (at the time of 38 Gy irradiated), ferumoxides-enhanced T2*-weighted images detected the irradiated area that Gadolinium-enhanced T1-weighted images missed.
Conclusion: Ferumoxides-enhanced T2*-weighted images was the most sensitive among all the images done in this study and can demonstrate hepatic parenchymal changes immediately after proton beam radiotherapy completion, even during radiotherapy.

Evaluation of Hepatocellular Carcinoma Following Proton Radiotherapy using Contrast Enhanced Power Doppler Ultrasonography Observation

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[Background & Aims] We have reported that the proton radiotherapy for hepatocellular carcinoma (HCC) is safety and effective therapeutic option. However, it is difficult to evaluate its effect in some cases. Although there is no obvious change in the image of the irradiated lesion one or two months after proton radiotherapy, we have good therapeutic effects one year later. Recently, it is reported that the usage of contrast enhanced color Power Doppler ultrasonography(CE-power Doppler US) , which is reinforcing the signal by the contrast agent, can improve the diagnosis accuracy for the hepatic tumor and the effect evaluation for the transcatheter arterial embolization and the percutaneus ethanol injection therapy. The aim of the present study is to establish the method of the assessment of the therapeutic effect of proton radiotherapy for HCC by CE-power Doppler US.
[Method] The examined cases were 11 patients with HCC (5 males and 6 females) who have been treated the proton radiotherapy (total dose 50-75Gy) and 11 lesions, with a diameter of 15-80mm (an average of 34mm). We inspected both the unenhanced and the enhanced color Doppler ultrasonography by using the color Doppler ultrasonography apparatus (HDI, ATL-Hitachi Co.) and the electronic convex probe, just before the proton radiotherapy, just after that and after the completion of that. We infused 8ml of the galactose-air-microbubble US contrast agent(Levovist®; Schering, Berlin, Germany) at 300mg/ml concentration intra-venously in all patients by bolus injection (0.5ml/second). Quantitative analysis was used by computerized imaging analyzer. Furthermore, we compared 3 phase CT at the same time.
[Result] 1) We have recognized the increase of blood flow in tumor and around it just after proton radiotherapy by CE-power Doppler US in 7 cases (63.6%) except 4 cases. The one case had no tumor blood flow , other 3 cases of tumor blood flow have decreased.
By Unenhanced Color Doppler, there has been no obvious change in all cases. According to 3 phase CT images at the same time, we have recognized a clear tumor stain in arterial phase after proton radiotherapy. 2) The cases 3 month

after proton radiotherapy had the significant decrease of blood flow and reducing its size compared to these before treatment by CE-power Doppler US. We have also confirmed an attenuation of tumor stain by 3 phase CT.
[Conclusion] There is a possibility of the evaluation of blood flow in HCC by CE-power Doppler US. It is suggested that the enhanced color Doppler sonography might be a simple and non-invasive newly assessment method as same as 3 phase CT for the proton radiotherapy for HCC.

Analysis of Pulmonary Morbidity in Carbon Ion Therapy for Non-small Cell Lung Cancer.

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Purpose: To evaluate clinically relevant parameters and to identify stage1 non-small cell lung cancer patients at risk for acute pulmonary morbidity (RTOG≧Grade2) when treated with carbon ion therapy.
Methods and Materials: Eighty stage1 NSCLC patients were treated between November 1994 and January 1999 in phase I/II dose escalation study. Forty-six patients were treated with a total dose of 59.4GyE-95.4GyE in 18 fractions over six weeks, and 34 patients with a total dose of 68.4GyE-79.0GyE in 9 fractions over three weeks. The normal tissue responses were scored using acute RTOG scoring system. The comparative treatment plannings were also done for multiple plans using carbon ions and X-rays.
Results: Eight patients developed acute pulmonary morbidity of Grade 2 or 3 in 3 months after treatment. It revealed that risk factors for the development of ≧Grade2 acute pulmonary morbidity included the use of two opposing fields, the highest dose(95.4Gy/18 fractions and 79.2GyE/9 fractions), and associated idiopathic interstitial pneumonia. Lung function tests including %vital capacity, %forced expiratory volume, and oxygen pressure, the use of respiratory gated irradiation, past history of pulmonary operation, and DVH curves of the lungs were not able to predict who was at risk for acute pulmonary morbidity development. Comparative study has revealed that carbon ions were substantially superior to X-rays in dose distribution of the CTV and lungs. In carbon ion therapy, field number of 3 or 4 appeared to be satisfactory in terms of the dose distribution.
Conclusion: Carbon ion therapy was safely carried out for the patients who had poor lung function. Based on this study, four fields irradiation without opposing fields and the total dose of 72GyE/9fr were adopted in the following protocols, and we are using respiratory gated irradiation in an effort to further reduce the irradiated volume. The patients with IIP should be carefully treated or excluded from protocol study.

Targeting accuracy of respiration-gated proton beam irradiation for hepatocellular carcinoma

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Purpose: To clarify targeting accuracy of respiration-gated (RG) proton beam irradiation by using a strain gauge.
Materials and Methods: Data set of 275 sessions of irradiation in 15 patients who received proton beam radiotherapy for hepatocellular carcinoma was analyzed. Metallic markers were inserted near the target in all the patients. Following data were used for the analysis; 1) A series of digital radiographies (7.5 frames/sec) for positioning verification before each irradiation, 2) timing of gating signal (gated at the end-exhalation phase) and markers' displacement on digital radiographies, and 3) actual respiration-gating status during treatment.
Results: Maximum target displacement including non-RG phase was 15.4 (range: 10-22) mm in average. Maximum target displacement during RG phase was 3.6 (range: 1.4-5.4) mm in average. Gating duration of a respiratory cycle was 2.1 (range: 1.1-3.8) sec. Beam utility rates was 33.4 (range: 25.3-50.3)%.
Conclusions: Targeting accuracy during respiration-gated proton beam irradiation by strain gauge for hepatocellular carcinoma was 5 mm in cranio-caudal direction. Therefore, internal margin to the cranio-caudal direction of 5 mm was estimated to be appropriate.

THE DOSE-VOLUME HISTOGRAM ANALYSIS FOR THE BONE AND SOFT TISSUE SARCOMA.

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<Purpose> Dose-volume histogram (DVH) analysis of skin reactions for patients with bone and soft tissue sarcoma treated by carbon ion radiotherapy was carried out in order to predict the skin damage and optimize treatment planning.
<Materials and Methods> Sixty four lesions in fifty seven patients with bone and soft tissue sarcoma were treated with carbon ions between 1996 and 2000. DVHs of the skin in forty five lesions were calculated and analyzed in relation to the skin reactions.
<Results> Acute skin reaction of grade three was observed in eight lesions (13%, 8/64), and late skin reaction of grade three was observed in six lesions (10%, 6/60). In DVH analysis, the grade three skin reactions were correlated with the irradiated dose and volume, though the difference was not statistically significant. It was also considered that site of the body irradiated such as gluteal fold was one of the risk factors for sever late skin reactions.
<Conclusions> DVH analysis was useful to predict the skin reactions in carbon ion therapy for bone and soft tissue sarcoma, and was one of the useful methods for evaluation of treatment planning.

RBE VALUES FOR PROTON BEAM THERAPY

A survey on RBE dependencies on physical and biological parameters *in vitro* and *in vivo*

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Clinical proton beam therapy has been based on the use of a generic RBE and that has been 1.0 -1.1. A generic RBE has been used because the available evidence has been interpreted as indicating that the magnitude of RBE variation with treatment parameters is small relative to our abilities to determine RBEs. As substantial clinical experience and additional experimental determinations of RBE have accumulated and the number of proton radiation therapy centers is projected to increase, it is appropriate to re-assess the rationale for the continued use of a generic RBE and for that RBE to be 1.0-1.1. That a generic RBE cannot be the true RBE for each tissue, dose/fraction etc has long been recognized due to the fact of variation in experimentally determined RBEs for both *in vitro* and *in vivo* systems. The question is: are proton RBE variations of sufficient degree to be important clinically?
Results of experimental and theoretical determinations of RBE of *in vitro* and *in vivo* systems are examined and then several of the considerations critical to a decision to move from a generic to tissue-, dose/fraction- and LET-specific RBE values are assessed.
The published RBE values, using colony formation as the measure of cell survival, from *in vitro* studies indicate a substantial spread between the diverse cell lines. The mean value over all dose levels is ≈1.2. Most of the *in vitro* data indicate an increase in RBE as dose/fraction is reduced below 4 Gy. By contrast, for *in vivo* systems, there was no increase in RBE as dose was reduced below 4 Gy. The mean RBE value *in vivo* is ≈1.1. There is agreement that there is a measurable increase in RBE over the terminal few mm of the Spread Out Bragg Peak (SOBP). This rise in RBE is quite steep in the trailing edge of the final Bragg peak, which results in an extension of the bio-effective range of the beam in the range of 1-2 mm.
In conclusion, at present, there is too much uncertainty in the RBE value for any human tissue to propose RBE values specific for tissue, dose/fraction, proton energy etc. The experimental *in vivo* and clinical data have been interpreted as indicating that continued employment of a generic RBE value and for that value to be 1.1 is reasonable. However, there is a local "hot region" over the terminal few mm of the SOBP and an extension of the biologically effective range. This needs to be considered in treatment planning, particularly for single field plans or when an end of range of one or more beams is in or close to a critical structure. There is a clear need for prospective assessments of normal tissue reactions in proton irradiated patients and determinations of RBE values for several late responding tissues in laboratory animal systems, especially as a function of dose/fraction in the

range of 1-4 Gy. Elucidation of the evident divergence between *in vivo* and *in vitro* RBEs may also be of mechanistic interest.

THE RIDDLE OF PROTON RBE: NEW APPROACHES TO AN OLD PROBLEM

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The relative biological effectiveness (RBE) of protons remains an issue of continued discussion. It is generally accepted that the proton RBE in the spread-out Bragg peak (SOBP) region is in the order of 1.1 with respect to high-energy photon or ^{60}Co beams, but an enhanced biological effectiveness is expected in the distal SOBP region. Since proton treatment planning systems display physical dose but not biologically effective dose, the treatment planner is not alerted to situations where critical tissues may be exposed to doses of relatively higher biological effectiveness. One of the major problems of the RBE concept is that it represents a ratio of doses for a given isoeffect level rather than a ratio of biological effectiveness for different types of radiation. Determinations of RBE also depend on the choice of the biological endpoint and the selection of physical beam parameters. Non-linear dose response relationships further complicate the RBE issue by making RBE dependent on dose and effect level. In this presentation, some of the inherent weaknesses of the RBE concept will be demonstrated and illustrative clinical examples will be presented. Recent insights into the repair mechanism of radiation-induced DNA damage will be reviewed and new approaches to describing the radiobiological quality of therapeutic proton beams will be discussed.

Biological effectiveness of high energy protons at three facilities in Japan

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Proton therapy in Japan is booming. National cancer center Hospital East at kashiwa installed a therapy-dedicated cyclotron in1997. Hyogo Ion Beam Medical Center installed a therapy-dedicated synchrotron in 2000. Wakasa Energy Research center is now completing installation of a multipurpose synchrotron that would be used for therapy. A facility with proton accelerator needs its own biological data prior to start therapy. Relative biological effectiveness (RBE)of therapeutic proton beams is not a single value, but depends on both physical factors such as proton energy and biological factors including endpoints and fractionation method. A requirement to pre-clinical studies is to provide, within limited time, a single RBE value representative to all beam path including entrance plateau and Spread-Out-Bragg-Peak. We planed to obtain data in short time using highly reproducible endpoints including normal tissue damages. Reference beams to compare with protons would be linac X rays rather than low energy X rays or cobalt-60 gamma rays. For 235 MeV protons at National cancer center Hospital East, we used mouse intestinal crypt cells and three in vitro cell lines, including SCC61 human squamous cell carcinoma, NB1RGB human fibroblasts and V79 Chinese hamster cells. The dose responses after irradiation at either the entrance plateau or the middle portion of SOBP were compared with those after linac 6 MV X-ray irradiation. At Hyogo Ion Beam Medical Center, HSG human salivary gland tumor cells and mouse intestinal crypt cells were irradiated at several points along a 190 MeV proton. HSG cells and mouse intestinal crypt cells were also used at Wakasa Energy Research center for 180 MeV proton beams. RBE values obtained for the three proton beams would be presented and discussed.

Experimental in vitro proton RBE values (relative to 137 Cs gamma-ray) at PMRC (Preliminary report)

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We report experimental proton RBE values measured at the new Proton Medical Research Center (PMRC), University of Tsukuba. These RBE values were obtained as results of colony formation probability of single cells irradiated with the modified proton beam of the initial energy of 200-MeV and with 137Cs gamma-ray (662 keV) used as a reference radiation. Four cell lines, 3 cultured cells of human origin (SQ-5, TK-1 and Becker) and one of mouse origin (V-79) were used in this experiment. Monoenergetic pencil proton beam was modified as a beam of 6 cm SOBP and the maximum range of 16 cm in water. Cells inoculated in culture bottles were irradiated in the center of the SOBP of this modified proton beam. Both dose rates of proton and gammma-ray used in this experiment were about 1 Gy/min. As results, it was shown that all RBE values obtained in this experiment are between 0.97 and 1.05 for end points of SF2 and 10% survival level.

PRECLINICAL BIOLOGICAL ASSESSMENT OF PROTON AND CARBON ION BEAMS AT HYOGO ION BEAM MEDICAL CENTER

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Purpose: To assess the biological effects of proton and carbon ion beams before clinical use.
Methods and Materials: Cultured cells from human salivary gland cancer (HSG) were irradiated at 5 points along a 190 MeV proton and a 320 MeV carbon ion beam with Bragg peaks modulated to 6 cm widths. A linac 4 MV X-ray was used as a reference. RBE values at each point were calculated from survival curves. Cells were also irradiated in a cell-stack phantom to identify that localized cell deaths were observed at predefined depth. Total body irradiation of C3H/He mice was performed and the number of regenerating crypts per jejunal section was compared to calculate intestinal RBE values. Mouse right legs were irradiated by 4-fractional treatment and followed-up for skin reaction scoring.
Results: RBE values calculated from cell survival curves at D10 ranged from 1.01 to 1.05 for protons and from 1.23 to 2.56 for carbon ions. The cell-stack phantom irradiation revealed localized cell deaths at predefined depth. The intestinal RBE values ranged from 1.01 to 1.08 for protons and from 1.15 to 1.88 for carbon ions. The skin RBE value was 2.16 at C320/6cm SOBP center.
Conclusions: Expected biological depth-dose distributions were observed on both proton and carbon ion SOBP beams.
Key Words: Proton, Carbon ion, Biological RBE, Clinical RBE.

What I Expect for Proton Therapy: from a Surgical Oncologist's Point of View. As a Neurosurgeon

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Tumors of the central nervous system comprise a complex classification of neoplasms, and various multidisciplinary therapeutic approaches have been conducted to achieve favorable outcomes. Among these treatments, stereotactic radiotherapy is an essential tool not only for malignant but also for benign intracranial tumors, because it is possible to obtain the best relative therapeutic effect by maximally sparing normal brain or cranial nerves. Proton radiotherapy is one of the modalities that can achieve this aim. A very sharp Bragg peak ionization curve enables proton beams to yield very attractive dose distributions, especially for intracranial tumors with irregular shapes regardless of volume. At the University of Tsukuba, we have been applying 250 MeV/u proton

beans to intracranial tumors since 1983 with certain favorable results. Included in these cases are 24 malignant gliomas, 12 chordomas and 8 pituitary adenomas. A thorough review of these cases with reference to the results from other facilities is essential for developing improved treatment protocols for intracranial tumors. We at the new Proton Medical Research Center, University of Tsukuba are especially working on new strategies against intracranial tumors which are incurable by other modalities, and new detailed protocols could be applied with ethical approval. At the same time, further investigation regarding proton radiobiology, i.e. the mechanisms of radio-necrosis and sensitivity of brain tumor cells, is necessary to achieve better prognosis of the patients with intracranial tumors.

PROTON THERAPY FOR PEDIARTRIC SURGICAL CASES

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With great advancement of chemotherapy for the pediatric solid tumors, the role of radiotherapy has been reduced in the multi-modal treatment schedule. Recently we have used more of an intra-operative irradiation and a proton beam irradiation for the support of pediatric surgical cases. I am discussing here on the experience of proton beam irradiation, using old Proton Medical Research Center of University of Tsukuba.

Proton beam of 250 MeV was equipped both from vertical and horizontal direction. We treated 14 cases in pediatric age, out of whole number of 593 cases including various adult malignant tumors. Among pediatric tumors, there were 6 rahabdomyosarcomas and one spindle cell carcinoma in the naso-pharyngeal portion, one Ewing's sarcoma and 2 neuroblastomas, one hepatoblastoma with huge tumor of the central lobe of the liver and one hepatocarcinoma after the biliary atresia treatment, and one fibromatosis.

Mostly the tumors were treated successfully except two cases of Ewing's sarcoma and rhabdomyosarcoma. Large and inoperable tumors around the nasopharynx area were most effectively treated without any damage on both eye's visual ability.

Precise irradiation on the confirmed target with large volume was achieved by proton irradiation. Further possibility on the pediatric tumors must be investigated.

Treatment planning system using a multilayer energy filter for proton therapy

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A treatment planning system to realize a three-dimensional conformal irradiation by a new method is developed for charged particle radiotherapy. The new filter can yield a static irradiation field where the width of the spread-out Bragg peak is adjusted to the target as a two-dimensional continuous function in the transverse plane. The system calculates the outward forms of the bolus and the new filter by using three-dimensional data of computer tomography. The parallel broad beam method is utilized to decide the design parameters for real human cancers. Comparisons between the traditional ridge filter and the new filter is shown in the calculated results of dose distribution on the CT images.

Use of a miniature ripple filter for filtering ripple found in the distal part of SOBP

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When a ridge filter optimized for a certain proton energy is used for beam with lower energy, we observe a ripple in the depth-dose curve especially at the distal part of the curve. This is due to the mismatch between the

individual Bragg curves comprising the SOBP and the Bragg curves assumed at the design. Ridge filters are designed based on the raw Bragg curve which is dependent of the incident beam energy. Therefore a large number of ridge filters are required in principle to obtain optimized SOBPs for different incident beam energies. Since reduction of numbers of ridge filters is usually imposed from practical reasons, some compromise is made. We propose use of an additional miniature ripple filter for filtering ripple found in the distal part of SOBP. The filter broadens the energy spread so as to match the energy of the incident beam with the used ridge filter. For that purpose, we manufactured a miniature ripple filter optimized for 125 MeV beam when ridge filters optimized for 155 MeV beam. The ripple filter is made from a aluminum alloy ,the pitch and height are 2.4 mm and 2.85 mm, respectively. A cross section of one unit is 7-step up and down stairs. Since it requires precise machining, it took about one month to complete the machining. It is placed at 40-50 cm upstream the patient surface. Measurement results are shown

Membrane Type Liquid Variable Compensator

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Conventional compensators are time consuming due to mechanical machining for production, replacement for each irradiation and storage. To simplify the process, a membrane type liquid variable compensator is proposed. Elastic membrane in which liquid is enclosed is controlled of its shape by strong threads. Deformed liquid serves as a variable compensator. Strong threads to deform the elastic membrane are to be controlled by a controlling system depending on the treatment planing of irradiation. The form of membrane is to be monitored by ultrasound reflection technique to ensure the quality assurance.

Performances of a Test Model of a Compact Parallel Proton Beam Scanner for Proton Therapy

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As part of the effort to realize an inexpensive and compact rotational irradiation system for proton therapy, we have been developing a compact beam scanning system. This scanning system is composed of a pair of scanning magnets which can scan the incident beams over a 16 cm ϕ field while keeping the beam parallel to the axis all the time. The immediate advantage of this modality which is characterized by an infinite SAD length is about 20% reduction of skin dose compared with the conventional divergent scanning method. The total length of this parallel beam scanner is designed to be 1.2 m and the gantry size equipped with this scanner is shown to be 3 m in radius. We will report the design details in both mechanical and electrical aspects. Test results of a fabricated model scanner will be presented with the help of a digital movie.

Proposal of a Cylinder Type Liquid Variable Compensator.

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Conventional compensators are time consuming due to mechanical machining for production, exchange for each irradiation and storage. To simplify the process, a cylinder type liquid variable compensator is proposed. Hexagonal cylinders are arranged in honey-comb structure. Each hexagonal cylinder is divided with a piston separating fluids of different electron densities. The energy of protons penetrating the cylinder depends on the length of two fluids in this cylinder. By changing the position of the piston in the cylinder the energy of the transmitted protons is changed. A controlling cylinder is connected with the upper part and the lower part of each hexagonal cylinder with pipes filled with liquids. A control rod moves an inner piston in the controlling cylinder. If the piston in the controlling cylinder moves, the position of the piston in a hexagonal cylinder moves. The control

rods are moved by computer control depending on the treatment planning of the patients.

New Patient Positioner for Proton Beam Therapy

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All existing isocentric proton therapy gantries have large pits directly beneath the isocenter preventing the use of most standard radiotherapy patient positioners. A computer-controlled radiotherapy positioner has been modified and extended for use with precision proton therapy. The positioner has a 0.05 mm relative accuracy for translational moves and pitch and roll capabilities up to $\pm 5^0$. A description of positioner features and changes in the facility necessary for installation will be given.

Range Measurement System of Patient Body using Positron Camera in Heavy Ion Therapy

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The positron camera system has been developed for use in the secondary beam course of HIMAC to measure heavy-ion ranges in patient bodies. There are a few percent errors in the estimation of the range in patient body now. Using the range measurement system, we can measure the beam stopping point with error less than 1mm. ^{11}C generated by projectile fragment reaction from ^{12}C beam, is selected by bending two pairs of a magnet and a slit and is further collimated and irradiated to the patient. ^{11}C emits the positron at the end of its range and the pair gamma-rays produced by positron annihilation are detected by the positron camera. It consists of two Anger cameras in coincidence and is set both side of the beam line. Positron camera is deficient of the position information along the direction perpendicular to the camera surface, yet we can measure the beam stopping point in three-dimensions by setting the beam direction at will. In practice, we irradiate a few percent of the fractionation dose (one fraction of about 20 separated irradiation) to a patient before the treatment and confirm the stopping point with the one calculated by CT. After confirmation, treatment starts. Thus, we expect therapy of better precision.

Each Anger camera consists of 60 cm diameter and 3 cm thick NaI(Tl) crystal. 109 Puts are attached to the crystal with 1.3 cm light guide. The outputs of the PMTs are converted to digital data from which the position of gamma-ray incidence is calculated by the center of gravity. The size and the thickness of the camera were decided to maximize the spatial resolution by numerical simulation. The camera was set last year and is now under test. The spatial resolution of the camera measured by a pin-type ^{22}Na source is about 6 mm in standard deviation. At beam test, we irradiated 50 % of daily therapeutic dose to the polyethylene block and after irradiation we measured the range for 7 minutes. The beam was 350 MeV/n ^{11}C of about 3500k particles and the range straggling is about 4 mm and the diameter of the collimator was 5 mm. Result was that we could measure the range precisely within the experimental error though it is still a preliminary data. The problem is high background and now we try to decrease it and increase S/N ratio to use the system under practical dose level (a few percent of therapeutic dose).

A simple pencil beam dose calculation module for daily treatment planning

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For daily treatment planning, an adequately accurate and a reasonably fast dose calculation is strongly needed. We have developed a dose calculation module based on a simple pencil beam technique which includes multiple-scattering effect in the complex heterogeneities in the human body. This dose calculation module calculates a longitudinal depth-dose and a lateral beam spread independently along the ray-path from a point source. A depth-dose distribution measured in a water-phantom is applied to voxel by voxel reflecting its CT-value and a lateral spread is calculated assuming a finite source size. Then the total dose is computed by convoluting the depth-dose and the lateral distribution. Also, this module is implemented on a fully 3D basis, that is, beams of any direction to a plane of CT slice can be handled corresponding to non-coplanar irradiation. Computation time is typically several minutes with 1-mm voxel size on a COMPAQ Alpha 21264 (667MHz) workstation. Comparison between calculation results and water-phantom measurements has shown that the present module has sufficient accuracy for daily treatment planning.

The pixel ionisation chamber: a detector for beam monitor and dosimetry

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The control and dosimetry of intensity modulated beams need detectors with good spatial resolution, high granularity and fast readout. As an improvement of the Magic Cube, we have developed a parallel plate ionisation chamber with one of the two electrodes segmented in pixels and a fast readout. The chamber features 24x24cm^2 sensitive area, divided in 1024 square pixels with 7.5mm side. The water equivalent thickness of the chamber is 1mm. The whole chamber is readout with custom designed VLSI electronics, 16 chips each with 64 recycling integrator channels, dead-time free read-out, 16-bit dynamic range and charge resolution variable between 100fC and 800fC. The front-end electronics is read-out using fast memories and real time CPU; the total time needed to read-out the 1024 channels can be as fast as 100□s and the read-out operations are performed without introducing any dead-time in the measurement.
A description of the detector will be presented, along with the results of a beam test performed on the Carbon beam at GSI Darmstadt.

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Proton dose calculations in heterogeneous media: Pencil beam scaling versus Monte Carlo

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Two methods to account for tissue inhomogeneities with proton pencil beam algorithms have been assessed by using Monte Carlo simulations.
Starting point is the dose distribution for a proton pencil beam computed in water. The corresponding dose distribution for a heterogeneous medium is derived from the dose for a homogeneous water phantom via two different scaling methods.
The first approach is the well known one-dimensional pathlength scaling applied along the central axis of the pencil beam. Only the energy loss due to the material traversed is considered, but neither the depth nor the scattering properties of the inhomogeneities are taken into account. The lateral spread of the pencil beam at a given depth in a heterogeneous medium is simply equal to the spread in water at the depth where protons have the same residual energy.
Second, we present a two-dimensional scaling method, which combines a pathlength scaling with an additional lateral scaling. The factors influencing the lateral scaling are derived from Highland's and Gottschalk's formulas for the description of multiple Coulomb scattering for protons. This scaling approach depends on the radiation lengths

and the stopping powers of the traversed materials, and also on the depth location of the inhomogeneities.
Dose distributions are computed for both scaling methods in homogeneous non-water media and for various slab geometries. Next, the results are compared to Monte Carlo simulations performed with the GEANT3 code. A good agreement between the results of the new two-dimensional scaling method and the simulations was observed (less than 2.0 %). These results were found to improve the conventional pathlength scaling of proton pencil beams, which showed in some cases non negligible dose deviations of maximal 10.0%, e.g., observed for a 2 cm large air cavity.

Implementation of a Pencil Beam Algorithm for Proton Treatment Using Different Kernels

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Aim of this is to use an unique platform for treatment planning including photon, electron and proton beams.
Using Pinnacle^3 we have implemented 2 analytic pencil beam kernels. The simpler and faster one ("ray casting") is appropriate for defining a geometric grid corresponding to a given energy selection on the basis of a real CT volume. With the second one ("fluence-dose") we are able to simulate realistic dose distributions on real CT-based density matrices without any geometric constrains. We are ready for calculating spread-out-bragg-peaks (SOBP). The ongoing work is the implementation of a Monte-Carlo based kernel including inelastic scattering (s. our poster). We are also developing an optimisation algorithm for the SOBP and for fluence modulated proton therapy (IMPT).

Quality Assurance Applied to Proton Beam Therapy

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Loma Linda University Medical Center

The introduction of any new technology will be accompanied by a barrage of measurements. After some time using the technology, the measurement effort required to have confidence in its use will decrease. Published references and the experience of others may be useful in decreasing the time and effort to obtain this level of confidence. This presentation will describe categories of measurements performed, the frequency and level of testing, and types of periodic tests. In addition, examples of tests that are critical when using proton beams will be described.

QA Protocol in Japanese Particle Therapy Facilities

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National Institute of Radiological Sciences JASTRO QA working group of particle therapy

In Japan, particle therapy using proton beams or carbon ions are carried out at four facilities, and other two facilities will join this group in one or two years. Then, it is very important for this Japanese particle therapy society to establish a quality assurance system of the treatment. In Japanese Society for Therapeutic Radiology and Oncology (JASTRO), a working group for this QA program of particle radiotherapy has started its activity and to show a standard guideline for the particle therapy.
In this report, outline of the protocol for Japanese QA program will be presented.

QA practice at PSI

E. Pedroni for the team of radiation medicine Paul Scherrer Institute Switzerland

The approach to QA of PSI is in many aspects rather unusual, since it is based on the spot scanning technology. It is quite difficult to summarize in a short abstract all aspects relevant to QA. We will therefore just mention here the points, which we suppose to be quite different than at other institutions.
Most of the requirements on safety and accuracy are automatically satisfied by the architecture of our beam delivery system. We use redundant independent computers system to control the beam delivery. The most relevant tests for the beam delivery are performed at the end of each spot, on line during the application of the treatment. In addition to these tests, we perform also off line retrospective checks using the logging file of each treatment, a file which contains measured data for each spot, including also interrupted spots (spot by spot bookkeeping of the dose delivery). If necessary the dose can be recalculated from the logging file.
Each new steering file (our treatment planning predicts dose as absolute dose) is checked with an array of ionization chambers (dose profiles measured underneath a water column) before the file is used for the actual patient treatments.
Each day the machine is checked with daily-check procedures (to guarantee a proper startup of the machine using checklists, safety interlocks tests and dosimetric tests).
In addition we perform yearly, monthly, weekly, and daily QA tests.
Typical QA procedures include the maintaining of the data of the mechanical system of the gantry (definition of coordinates and linearity of the axis including the transfer of coordinates from the CT to the gantry – which is done on the basis of fixed absolute coordinates).
Fortunately for the beam delivery we can rely on the exact reproducibility of the beam settings without any need to retune manually the beam. The precise position of the actual beam is checked with submillimetric precision with an ionization chamber with strips (strip monitor). Task of the QA is to guarantee that checking the centering of the beam on the strip monitor is equivalent to centering the beam at the tumor location. QA is also used to provide reproducible small corrections needed to guarantee the exact centering of the beam at different gantry angles (typical corrections < 1 mm).
The control of the dose is based on the calibration of the flux monitors in front of the patient with a Faraday cup and on the physical modeling of the dose distribution of the pencil beam. The official definition of the dose is however taken over from measurements using ionization chambers calibrated in a Cobalt beam according to the accepted international code of practice (the consistency of the two methods is within few percent).
The definition of the range (energy of the beam) is based on the reproducibility of the tuning of the beam line, is measured also by Hall probes in large magnets and controlled by the position of the beam on the strip monitor in front of the patient. Each tune is regularly checked for consistency with regard to the properties of the beam of the gantry (by measuring depth dose curves in water, the beam parallelism of scanned beam and the phase space of the beam at different gantry angles and energies).
The calibration of the CT from photon attenuation coefficients into proton stopping power is another item which must be regularly maintained (the calibration is done using both, "tissue equivalent materials" and biological probes from organs of animals).
Concerning treatment planning we can use a specialized Monte Carlo code to simulate dose distributions in complex anatomical structures (effects of density heterogeneities). Procedures to guarantee the integrity of the data are implemented and we continue to improve our dose error algorithms. The dose distribution is regularly recalculated from the steering file using an independent dose calculation. The basic safety is however guaranteed by verification dosimetry applied on each steering file.

Quality assurance practically applied at new PMRC

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Early in this fall, the first patient has been treated in our new proton therapy facility. After completing treatment of at least six patients in the clinical trial in several months, we are required to improve treatment process more efficient so as to make more patients available in daily treatment routine. In the new treatment system, including

a treatment planning, a bolus machining, an exposure planning, a beam delivering, a patient positioning, an exposure controlling, and a database managing system, most of important parameters required in each patient treatment are automatically set in each sub system and protected from unnecessary changes against planned values. Human errors in treatment process are strongly reduced with a friendly support of the computer control system in proton therapy. Prior to each patient treatment, three kinds of measurements are required with absolutely-calibrated thimble ionization chambers and imaging plates; 1) daily calibration of main and sub parallel-plate ionization chambers in the nozzle of two individual gantries, 2) range and partial dose distribution, and 3) a rehearsal of patient treatment with a water-equivalent phantom and determination of dose-charge conversion ratio at a certain depth in each exposure target. Detailed comparison of these measurements with predictions, which are calculated from the treatment planning and some simulation programs, makes it available to enhance preventing the proton treatment system from setting undesirable condition. We present here our quality assurance practically applied in the treatment, and usefulness of range detectors and two redundant dose monitors, one set at upstream of the beam delivery system and the other at downstream. In addition, we discuss how accurate we can deliver dose in each patient target and what we really need or not in keeping high quality assurance in the next stage, where we may expect treatment of large number of patients; 2 to 4 patients an hour at each gantry.

Implementation of Quality Assurance Procedures at NPTC

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Starting August 2001, a set of quality assurance procedures, which include mechanical and radiation isocentricity tests, proton range measurements, modulation width measurements, beam flatness and dose constancy checks, are regularly carried out in treatment room 1 at NPTC. Procedures for measuring the reproducability of couch movements, Light field vs. radiation field coincidence, X-ray tube alignment and X-ray/radiation coincidence, laser alignment as well as nozzle ionization chamber checks are currently under development. We will present the first results of the measurements, and report on how the measurements helped to find bugs and problems in the software and hardware of the mechanical patient positioning system and also in the beam modification systems.

Procedure of calibration of dose monitor at NCC, Kashiwa

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In our facility, the dose monitor is calibrated against a reference ionization chamber, which is traceable to SSDL in Japan. Output factor should be obtained through this measurements. In this calibration procedure, up-stream devices, for example, first and second scatterer, fine degrador, and so on, should be set as the same as the condition of treatment. There are various discussions about the conditions of the down-stream devices, collimator and compensator. In our canter center, the collimator are set on the irradiation port at the calibration procedure and polyethylene sheet corresponding to the thickness of the patient compensator at center axis. In this report, we will discuss about the accuracy of the calibration procedure adapted in our facility.

THE PROTON THERAPY QUALITY ASSURANCE PROGRAM AT NAC

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The proton therapy facility at the National Accelerator Centre (NAC) utilizes the 200 MeV beam from the separated sector cyclotron. A fixed horizontal confirguration is used mainly for stereotactic radiosurgical procedures. Treatments are presently conducted on two days per week. The beam delivery system uses standard passive beam

modification methods and produces field sizes up to 100 mm in diameter. An automatic system using digital stereophotogrammetric techniques is used for patient positioning in the beam and monitoring patient movement during treatment. Quality assurance of this latter system consists of weekly calibrations of the CCD camera positions and daily checking of the positioning accuracy of the system (± 0.5 mm) with a special calibration frame mounted on the backrest of the treatment chair. Additional daily quality assurance procedures include dose constancy verification (± 2%), patient collimator alignment (±0.5 mm) and axial and lateral laser alignment. Between treatments the beam energy spread is monitored by a multilayer Faraday cup (FWHM < 3.5 MeV) and the beam range by a range ionization chamber (± 0.4 mm). The range is adjusted by inserting or removing plastic trimmer plates 0.07 g/cm^2 thick to achieve the clinical range in water of 24.00 ±0.04 cm (50% level of distal edge of Bragg peak). Other procedures undertaken less frequently include, beam flatness (±5%) and symmetry (±0.05%) measurements [weekly], registration of portal x-ray with proton beam (< 1 mm), absolute monitor calibration (± 1%), calibration of ionization chambers in ^{60}Co (with respect to secondary standard), calibration of double-wedge degrader (± 0.1 mm) and calibration of range monitor (± 0.4 mm) etc. For patient treatment a barcode system is used with a laser scanner to ensure that the correct modulation propeller and field-specific collimator are used for each treatment field.

Quality assurance in the heavy-ion therapy at GSI

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In the heavy ion tumor therapy project at GSI patients are irradiated with high-energy carbon ions. The carbon ion beam is applied by the raster-scanner beam delivery system and the active energy variation of the accelerator. Therefore the target volume is divided into slices of equal ion ranges. For each of the slices a pencil beam with the energy corresponding to the radiological depth of the slice is requested from the accelerator. Within each of these slices the pencil beam is scanned across the different voxels. The scanning speed is controlled by the applied intensities, this means the scanner moves the beam to the next point whenever the desired number of particles has been directed to one of the voxels. After all of the points within one slice have been irradiated the beam is dumped. The next beam will be requested with an energy corresponding to the next slice.
As a consequence of the novel completely active beam delivery technique dedicated quality assurance procedures have been developed. The main focus of the talk will be about the special QA procedures concerning dosimetry, beam monitoring and treatment planning.

National Cancer Institute funded Resource Center for Emerging Technologies (RCET) at University of Florida

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RCET has developed an infrastructure for distributed database, visualization and analysis system for collecting, sharing and distributing information generated by institutions participating in clinical trials. The system consists of a centralized database, web server, 3D data visualization, ActiveX and Java browser components and an object transaction server. The software modules enable users to share multidimensional treatment planning and Quality Assurance (QA) data objects, which include 3D visualization and imaging information, as well as conventional database objects.
RCET system provides a set of services for institutions that participate in clinical protocols. Using RCET client software, NetSys, participants of a clinical trial can send required study data for each case. The submitted information becomes readily available for remote review using a Web browser. In addition, users can perform retrieval of original archived data for visualization; modification and analysis similar to a DICOM-RT based PAC system. The RCET system provides a unique opportunity for PTCOG member institutions to participate in cooperative clinical trials and share data electronically for rapid remote review. It also provides the opportunity for remote peer review.

Network-wide application sharing as part of an electronic patient referral system.

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Introduction.

The current state-of-the-art in radiotherapy provides a rich variety of methods by which radiation can be applied to lesions. Patients can currently be treated with either fractionated photons and/or electrons (conventional or IMRT), protons (conventional or IMPT), or with stereotactically guided radiosurgery techniques. Within each of these groups, there are a wide spectrum of possible treatment methods. Taking stereotactic treatments as an example, there is currently the possibility of delivering conformal treatments with a LINAC, using either arc therapy or mini-multileaf collimated static fields, or alternatively with a dedicated radiosurgery system such as the GammaKnife. However, although each particular technique is often aimed at fulfilling a certain role in radiotherapy, it is also not necessarily the case that a particular treatment method will prove to be the most appropriate for *all* patients with a given indication.

Given the current diversity of treatments becoming available, it is extremely unlikely that any one institute can have access to all treatment possibilities. However, different treatment possibilities may well be available at other, possibly widely distributed treatment centres. If the potential of these specialised treatment centres are to be exploited, then it is necessary to put in place methods by which competing treatment methods can be assessed on a patient by patient basis across institutes.

Here we describe the use of network-wide application sharing software, in conjunction with radiotherapy data exchange standards, for the interactive assessment of treatment plans by two or more remotely situated treatment centres.

Materials and methods.

At the Paul Scherrer Institute, we are currently treating patients with protons using the spot scanning technique. However, the institute itself is a physics research institute, and as such, we must rely on patients being referred from external radiotherapy clinics, within or outside of Switzerland. To facilitate the selection of patients, we have previously described an electronic patient referral system [1], by which 'core' radiotherapy data sets can be transferred between the proton planning system at PSI and a number of commercial planning systems that have installations in clinics within Switzerland. In this system, the results of evaluation plans performed at PSI, in the form of 3D dose distributions, can be electronically transferred back to the referring institute's planning system, where the proton plan can be carefully compared to the treatment possibilities at the local centre. However, there is inevitably still a need to discuss the competing plans and, if a patient is accepted for treatment, the details of the treatment itself, interactively with the referring clinic. For this purpose, we have started to use software for sharing applications over local and wide area networks. With this software, we can make available our proton therapy planning system to remote users, such that they can interact with it exactly in the same way as a user at our institute. That is, both the local and remote users can interact with the same program, thus facilitating meaningful discussions between the different parties.

Data conferencing standards have been defined by the International Telecommunication Union (ITU) in T.120 and H.323. [2] Software conforming to these standards has become available for a range of computer platforms. We are currently using Microsoft's NetMeeting on Win95/98/NT4.0. [3,4].

NetMeeting conforms to the above mentioned standards and allows application sharing and basic audio/video conferencing over TCP/IP. Data encryption for transfer over public networks is possible. NetMeeting can be downloaded from Microsoft's website along with a Resource Kit containing detailed technical documentation.

In a typical session we want to discuss patient data on PSI's therapy planning system with a remote referring institution [Fig. 1]. At both sites, a Windows PC with NetMeeting installed is connected to the Internet. The therapy planning system is typically running on a separate, VMS workstation. By running an X server on the PC and directing the workstation's display to it, we are able to take control over the planning system and, through NetMeeting, share it with the remote partner. Sharing in this context means not only that both sites may look at the same picture. Rather, that the remote site may completely take control over the planning application and, for example, modify VOIs.

At PSI we have set up one PC as a dedicated workstation for NetMeeting sessions [Fig. 2]. Along with the required software (Windows95, NetMeeting 3.01 and a X server) it has appropriate hardware (graphics card and a large monitor) to display medical images. A small camera (ViCAM from Vista Imaging, Inc.) transmits video images of the discussion partners. Close to the PC is a telephone with external microphone and loudspeakers. The PC is located in the room used for therapy planning where eventually required additional documents (MRI, CT) are readily available.

Discussion.

During 1999, NetMeeting in the configuration described above has been used frequently for the interactive discussion of patient data and therapy plans between PSI, referring clinics and other treatment centres. Inside Switzerland we could mostly rely on the Swiss academic network which offers bandwidths up to 155 Mbps. However, we also conducted interactive sessions over transatlantic links during busy hours or with dial-in links over analog telephone lines without problems.

Abstracts of poster presentation

DEVELOPMENT AND APPROBATION OF TECHNICAL MEANS AND METHODS OF PROTON RADIATION THERAPY OF PROSTATE AND OROPHARYNX CANCER

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Basic results are presented of research carried out on the base of the operating Proton Therapy Facility of the Institute for Theoretical and Experimental Physics (ITEP). The research done makes it possible to start clinical approbation in horizontal fixed beams of the proton radiation therapy of malignant tumors of the oropharynx, laringopharynx, oral cavity and pharynx (T2-4NanyMO), and prostate (T1c-3NO-1MO). In 1996, these tumor localizations were registered in 7.42% of new patients.

In the course of the preparation for the clinical approbation, the following R&D have been carried out: the transfer of pre-irradiation preparation (topometry) results in the required format into the planning system done; problems of patient immobilization and positioning solved, complicated in the case of irradiation of oropharynx tumors by patient inadequate position in topometry (supine position) and in irradiation (seated position); basic dose fields formed, measured and entered into the planning system database, the first home dose planning system for proton therapy developed; technology developed for the on-line manufacturing (with a dosimetry planning system) of individual boluses and collimators, and Radiation Treatment Protocols developed. The design of the treatment units provides for proton irradiation to be done from two or more directions using the chair rotation (irradiation of oropharynx cancer in seated position), and bench rotation (prostate cancer irradiation) with patient about the vertical axis. The Protocols suggest combined (p^+ and gamma) irradiation of patients and the increase of the tumor dose while retaining the traditional dose level to the regional lymph nodes, prophylactic irradiation zones, adjacent organs and structures. This should lead to the increase of the tumor local control frequency, decrease of recurrencies without the increase in the level of post-irradiation complications.

A New and Dedicated Accelerator and Beam Transport System for the Proton Therapy at the Paul Scherrer Institute (PSI) / Switzerland

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In 2000 the decision was taken to start a new long-term commitment in the field of proton therapy at PSI. The project PROSCAN was started with the objective to implement and operate at PSI a base technology laboratory for the advancement of proton therapy techniques and clinical applications. Within the project an expansion of the facility and technical infrastructure has to be realized. The new facility has to fulfil particular requirements from the medical and technical point of view. These will be achieved with:
An independent dedicated cyclotron that meets high standard specifications and qualifications for the application of advanced and improved irradiation techniques. Special

attention was given to the beam quality, beam stability, extraction efficiency, diagnostics, safety, activation, reliability, operability, maintainability and operation costs.
A beam transport system from the cyclotron to the treatment rooms that meets the requirements such as implementation of a fast raster scanning of the depth dose in addition to that of the lateral dose. For that the beam line has to be adjustable to rapid sequence of different beam energies in short time scales.
A fast beam degrader system that permits a rapid setting of different beam energies, and additionally should be applicable in hospital environments in respect of maintenance and activation. Magnets and power supplies which enable the desired rapid change of the beam setting in order to transport the beam properly in respect to beam quality and position stability needed at the therapy rooms.
A steering and control system that is adaptable to cyclotron, beam lines and treatment facilities, combined with an independent safety system.
On the poster presentation it will be shown how the ambitious goals set are being realized within the frame of the PROSCAN project, including the time schedule.

PROTON 3D-CONFORMAL RADIATION THERAPY OF INTRACRANIAL TUMORS: NEW CLINICAL PROGRAM AT THE DUBNA PROTON THERAPY FACILITY

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Introduction. One of the most suitable target locations for conformal proton irradiation are intracranial lesions. Proton conformal radiation therapy proved to be safe and effective treatment method for various critically located, complex shape intracranial tumors such as skull base chordomas and chondrosarcomas, meningiomas (especially atypical and anaplastic), gliomas, metastasis and some others. Large irregular shape arteriovenous malformations are also good candidate for proton radiosurgery.
Hardware and equipment. During last 18 months one of the procedure room at the Joint Institute of Nuclear Research (JINR) have been modified to satisfy requirements for precision radiation treatments. Room is equipped with horizontal proton beam line with particles energy of 150 MeV. Depth penetration of the beam in water is 149-151 mm depending of the used ridge filter. Beam has 6x6 cm rectangular shape. Recently, size of the beam has been increased up to 8x8 cm. Final collimation of the beam in accordance with target shape is performed by micro-multyleaf collimator for 6x6 cm beam (leaf width - 0.5 cm) and 0.7 cm leaf-width collimator for 8x8 cm beam. Several ridge filters with plateau region 2-5 cm can be used for beam modulation. Patient positioner represents the treatment chair with 4 degrees of freedom. Head of the patient immobilized by the perforated thermoplastic mask and X-ray translucent head holder. System for target alignment and beam centration includes orthogonal laser beams and X-ray tube for introscopic alignment. Films of the skull during treatment are double exposed by X-ray and treatment proton beam.

Treatment planning. We are using three-dimensional treatment planning system "TPN" that has been developed at the Loma Linda University Medical Center. This is early version of the "OptiRad-3D" system that is now presented at the market. The system was modified to incorporate the Dubna proton beams. The series of dosimetry experiments have been performed to verify calculation algorithm with good coincidence of calculated and

measured dose distributions. At the same time treatment plans have been duplicated with local planar planning system.

Technological chain. After individual mask manufacturing treatment planning CT with up to 70 narrow slices have been performed. "Siemens" "Somatom" CT was calibrated to reflect proton stopping power of the CT-pixel. Physician outlines target, critical structures, alignment bone landmarks. 3D structure models are calculated by "TPN". Three to six beams located at the axial plane are calculated. Beams features are individual shape with multyleaf collimators and beam's-eye-view function, complex shape boluses to conform distal contour of the beam to the target shape. Digital reconstructed radiographs (DRRs) with projection of target, isocenter and bone landmarks were calculated and printed. Alignment Rx-films were compared with DRRs during irradiation sessions. Alignment accuracy was about 1-2 mm. This is first experience in Russia of using 3D treatment planning and beam formation for proton radiation therapy.

First clinical experience. Since April 2001 eight patients with ten targets received proton conformal radiation therapy at JINR. There were 6 meningiomas (2 benign, 3 atypical, 1 anaplastic), 2 malignant gliomas, 2 metastasis. Hypofractionated regimen of 12-14 fractions have been used, depending on the time of accelerator run, usually 2.5 weeks. 3-4 GyE with traditional for proton RBE=1.1 were delivered for one fraction. Total equivalent doses were calculated by the linear-quadratic formula and were equal to 56-60 GyE-a/b to the target margin. Early results demonstrated that developed technique of irradiation allow to deliver proton dose to the target volume precisely. One metastasis completely disappeared, one glioblastoma demonstrated gradual decreasing in size during 1 and 3 month MRI follow-up, another malignant glioma shows localized planning necrosis exactly at the place of location of dose distribution. Meningioma patients need longer follow-up to evaluate the results.

REQUIREMENTS and OPPORTUNITIES of MASS HADRON-THERAPY DEVELOPMENT

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Therapy with hadron beams remains extremely expensive. Value of Modern Proton Therapeutic Complex (PTC) is $ 90-120 million, and the Therapeutic Complex for heavy ions (ITC) - some hundred million $. The lion's share of charges falls to its medical-technical part, and is connected to use of engineering GANTRY. Meanwhile, in Russia annually 110000 new oncological patients require hadron-therapy. It is impossible to satisfy these needs due to installations with GANTRY, - owing to their huge cost. Such position is kept everywhere in the world. For example, USA have only two large Hadron Therapeutic Complexes now, while their general need is about 100 copies. We offer essentially new <<AntyGANTRY>>-SYSTEM (<<AG>>) for realization of rotatory-scanning proton therapy of malignant tumors. The patient it is fixed in a thin-walled capsule with the vacuumed bags filled with plastic grains. Patients are prepared for an irradiation in several Preliminary Procedural rooms simultaneously. The computer aided transport system controlled by computer, delivers the next patient from Preliminary to Radiating room and back without breaking of fixing quality. During a therapeutic irradiation the vertically located patient is rotated under narrow horizontal scanning beam of hadrons. "AG"-SYSTEM is universal and may work with any accelerators of any heavy particles. Replacement GANTRY by "AG"-SYSTEM will lower PTC cost in tens, and ITC cost - in hundreds times. Serial PTC (1200 patients/year) with the miniature accelerator (p+ 250-320 MeV) and "AG"-SYSTEM

should cost $ 3,5-4 million. For less developed Countries it is possible to come into mass proton therapy not only thout additional financing, but also with simultaneous reduction of the inevitable expenses in 1,5 times. It can be made if the telegamma-units (which have served its time and become archaic) will be replaced not with linear electron accelerators (as they do usually), but with our cheap PTC.

Accelerator Facility PATRO at Hyogo Ion Beam Medical Center

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Hyogo prefecture government has started a design and construction of accelerator facility PATRO (Particle Accelerator for Therapy, Radiology and Oncology) for hadrontherapy (Particle therapy) in 1995. Our medical center is located in Harima Science Garden City of Hyogo prefecture, about 75 km northwest of Kobe. The facility consists of two 10GHz-ECR ion sources, 1MeV/u RFQ linac, 5MeV/u Alvarez linac (200MHz operation frequency), synchrotron with 93.6m circumference, high-energy beam transport system and patient irradiation system. Beam is extracted from synchrotron by slow extraction scheme and can be gated by human breezing motion. Beam particles for patient treatment are proton (230Mev, 30cm range in human tissue) and carbon (320MeV/u, 20cm range). We have 5 treatment rooms:

A. Oblique (45-deg) beam port,
B. Horizontal and Vertical beam ports,
C. Horizontal port with patient seated position, (A -C, for carbon and proton) and
G1 and G2. Two isocentric gantry ports for proton beam.

Beam test was started from 2000 and we have now a full intensity beams, with a dose rate about 5GyE/min. We have now 150, 190 and 230MeV extracted proton beams and 250 and 320MeV/u extracted carbon beams to cover the clinical requirement. Transverse dose uniformity is obtained by the wobbling method. The ridge filter is used to obtain a spread out Bragg peak (SOBP).

Clinical trial by proton beam has successfully started this May 2001. On weekday beams are delivered to the treatment rooms from 9 to 17 o'clock for patient treatment. In September, 15 patients are treated per day. Typical proton beam intensity is 7.5 nA. Dosimetry is checked every day for each patient and also at all treatment ports to obtain statistical data on stability and reproducibility. Clinical trial by carbon beam is expected to start this year after the completion of the proton trial.

THE SURVEY FOR BUILDING PROTON THERAPY FACILITIES IN YOKOHAMA

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We are planning to build a hospital based proton center in Yokohama City. Yokohama City located in eastern Kanagawa Prefecture. It will be 25 minutes travel from Tokyo station to Yokohama station by Tokaido line. Yokohama, the second largest city in Japan, has a population of just over 3.4 million. The city extends approximately 33.1km from north to south and 23.6km from east to west. Yokohama's total land area is 434.71km^2.
The survey was done by sending questionnaire forms to the radiation oncologists of 10

facilities in Yokohama. Number of patients treated with radiation therapy in Yokohama city was 2700 between January 1999 and December 2000. We estimated annually 500-600 patients in Yokohama city would be good candidate for proton therapy.

Present Status of Proton Therapy Project at The Wakasa Wan Energy Research Center

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Proton cancer therapy project has been proceeded at The Wakasa Wan Energy Research Center (WERC), Japan. Three parts of the whole system (therapy beam line with accelarator, patients' positioning part with X-ray CT, and treatment planning part) are finished and now being verified.
The construction of the therapy beam line with two fixed irradiation ports has been completed, following to the completion of an accelarator complex with a 10MeV p tandem injector and a 200MeV p synchrotron. The synchrotron can now deliver 80, 90, 100, 120, 140, 160, 180 and 200MeV p with the maximum intensity of 7nA (at 200MeV). This accelarator system can produce the diameter of 100mm x 60mm SOBP
(Spread Out Bragg Peak) irradiation field with the flatness of 5% at the dose rate of 3Gy/min, using two wobbler magnets and scatterers. Some of obtained data are shown.
Two other parts of the system, which are positioning and treatment planning, are also being tested whether they are enough accurate for the medical use. The obtained data are shown. The first clinical trial is planned after some developments and more measurement opportunities are processed.

Treatment System in Hyogo Ion Beam Medical Center

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Accelerator managing section, Hyogo Ion Beam Medical Center

Hyogo Ion Beam Medical Center has been constructed for proton and carbon therapy. Clinical trial for proton therapy has started from the end of May. Beam delivery system and treatment planning system are introduced in this presentation.
We have four fixed beam lines and two gantry beam lines of six beam lines, and 5 treatment rooms. Wobbling beam delivery is adopted for spreading proton and carbon beam laterally, and stationary bar-ridge filter for SOBP. We prepare SOBP's between 30cm to 120cm in 1cm step. Uniformity of the radiation field is around +-2.5%. The uniformity was checked with dosimetry system. The system can measure three dimensional dose profile as well as absolute dose.
Treatment planning system has also been constructed. The TP system consists of information server, two planning terminals, and image fusion terminal. While MR image is good for drawing target outline, CT image is essential for planning. The image fusion makes drawing target on MR image possible by fusion CT and MR images. For dose engine, pencil beam code is adopted to consider the scattering effect in patient. The information server manages all data for treatment and communicate with HIS/RIS to accomplish smooth treatment.

Features of Hitachi Proton Therapy System

Kazuo Hiramoto, Kazumichi Suzuki and Kunio Moriyama
Hitachi, Ltd.

Hitachi has proposed and developed a proton therapy system which consists of a slow cycle synchrotron with maximum beam energy of 250MeV, beam tranport and rotating gantries with irradiation nozzles. The present system has several features needed in daily treatments, one of which is highly stable and reproducible proton beam with simple operation. For example, the beam position change in the irradiation nozzle is kept in 0.5mm without feedback control in daily treatments. This characteristic, which is especially important for irradiation due to double scattering or pencil beam scanning, is realized by Hitachi's new techniques of the RF driven slow extraction scheme, stable power supply and magnets, etc. Another feature is flexible operation for patient's respiration synchronized treatment, that is, the timing of synchrotron operation and beam extraction is varied according to patient's respiration signals. We consider that these features are essential and indispensable for reliable, precise and economical operation in proton therapy of cancer.

Operational experience of a medical ion accelerator HIMAC

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HIMAC has been providing carbon beams to medical treatment for seven years. Performance of beam delivery and irradiation systems will be presented. It will include stability and reproducibility of the accelerated beam, beam monitor, and alignment of the patient positioning system. Possible improvement will be discussed also.

Beam Optics for a Scanned Proton Beam at Loma Linda

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The next nozzle at Loma Linda will use two scanning magnets which will be installed on one of the three Loma Linda gantries. This will require a small beam at isocenter which can be swept across the tumor with the scanning magnets. The accelerator group has developed magnetic quadrupole solutions in the gantry beam lines which can deliver a small beam (less than 6 mm diameter) to isocenter. The strategy has been to find a solution for one energy, at one gantry angle, in one room and then find a general solution which can be used for all energies, all gantry angles and any gantry room. The simulation program TRANSPORT, first developed at Stanford Linear Accelerator Center, was used to find magnetic quadrupole strengths along the beam lines which must satisfy multiple constraints including a small beam at isocenter. Starting with the first gantry, we present a small beam solution for 155 MeV and compare TRANSPORT predictions with beam size measurements at nine positions along the beam line. Due to passive scattering systems in the nozzles, a small beam measurement at isocenter in the gantry rooms

is not possible at this time. However, the research room has been instrumented with scanning magnets and allows for small beam measurements at the appropriate distance to the patient. Small beam measurements and two dimensional patterns using the scanning magnets will be presented in this report.

The Accelerator and Beam Transport System of PMRC, Univ. of Tsukuba

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The proton therapy system of PMRC employs a synchrotron with a maximum energy of 250MeV and two rotating gantries. The proton beam was successfully accelerated to 10 energy levels and transported to the irradiation nozzles through the gantries. Each gantry can be rotated ±190 degrees. Since each rotating gantry has sufficient stiffness, the measured mechanical iso-center precision was found to be inside a cube of 1mm sides for all rotating angles. The position of the beam extracted from the synchrotron and transported to the irradiation nozzles was confirmed to be very stable and reproducible, which is sufficient for formation of a flat irradiation area by using the dual ring double scattering method developed at University of Tsukuba. The present system is being applied to clinical trials with satisfactory reproducibility and stability.

Specific design peculiarities of proton synchrotrons for hadron therapy

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Proton synchrotrons for hadron therapy can be divided into two groups according to an operation mode. The first group is a low-cycling accelerator and the second one is a rapid-cycling machine. The first group combines machines with the repetition rate less or equal to 1 Hz. The second group presents synchrotrons with the fast repetition rate. The repetition rate of the medical proton accelerator defines main parameters of the beam, which should meet first of all the medical requirements to treat different kind of cancer tumours. From the other side a compact design is the common feature of the medical machines. The presented report is devoted to study of specific design peculiarities of the low-cycling proton synchrotron, in particular the effects of the space-charge of the low-energy high-intensity proton beam and non-linear magnetic field distribution near the edge of the quadrupole and dipole magnets of the synchrotron. In the case of the proton synchrotron the high-intensity beam itself without any magnetic field imperfections can excite the high-order resonances, that could lead to increasing of the beam emittances. To avoid the blow-up of the transverse emittances during the multi-turn injection process the parameters of the machines should be optimized, particularly the working point position on the betatron tune diagram and the parameters of the RF system. Moreover, the non-linear effects of the fringe fields can increase the chromatic tune shift and reduce the dynamic aperture of the compact synchrotron significantly. Combination of these effects can limit the beam intensity of the medical machine. To avoid it the proper choice of main machine parameters should be based on detail analysis of these effects. The report presents the simulation results for the low-cycling proton synchrotron of PMRC (University of Tsukuba).
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Implementation of a Voxel-Based Monte Carlo Code for Direct Dose Planning in Proton Therapy, Including Inelastic Scattering

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For simulation of proton transport we introduce a voxel based Monte Carlo algorithm which includes inelastic scattering in detail. The aim of this work is threefold: obtaining pencil beam kernels for a semi-analytical planning algorithm
(s. paper in addition); direct Monte Carlo dose planning, and also for quality control of the semi-analytical model; tackling questions concerning real proton fluence, boundaries, inhomogeneous media, and secondary particle transport.
Our algorithm is based on PTRAN. Unlike to it we calculate the non-elastic interactions with the atomic nuclei on event by event. Together with the condensed random walk the procedure yields a more realistic outcome in respect to the dose distribution for protons. In addition the algorithm is real 3D and voxel-based.

Light CT ---- 3D Proton Dose Distribution Measurement ---

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The Light CT was designed and developed in order to make the measurement of the proton 3-d dose distribution easy and reliable. It is composed of a scintillation part that emits light according to the proton dose distribution and a CCD camera that can detect the emitted light from arbitrary direction. The principle of Light-CT is basically similar to that of X-ray CT. The proton 3-d dose distribution was reconstructed by the filtered back projection method. The evaluation of its performance was made using the proton radiation field that has four different residual ranges. This demonstrated that Light-CT could measure the proton 3-d dose distribution in use of the principle of the Light CT. However, it also showed some problems such as reduction of resolutions due to the light scattering in the scintillation part. We plan to investigate its effect using the numerical phantom.

Dosimetry of pulsed clinical proton beams by a small ionization chamber

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Response of a micro volume (0.01 ml) ionization chamber has been studied with pulsed proton beams which are used for clinical purposes and has been compared with those of some JARP ionization chambers (0.6 ml). All chambers used had been calibrated by

standard 60Co beams at the Electrotechnical Laboratory (ETL) and exposure calibration factors, Nx, were obtained on advance. Two methods are used to compensate the general recombination which occurs during pulsed beam irradiations : theoretical correction by a Boag's formulation and a modified two-voltage technique. An evaluation of absolute absorbed dose-to-water is performed on the basis of the protocol provided by ICRU report 59. The results imply that, to a first approximation, both chambers indicate the almost same result within 2% when unknown chamber-dependent parameters of the micro chamber are tentatively assumed to be identical to those of the JARP chamber for the calibration with 60Co beams. The about 1.5 % discrepancy observed in the response of both chambers is not discussible due to presumably 1-2 % uncertainty of the protocol of ICRU report 59 which does not include any chamber-dependent corrections for the perturbation effects in proton beams.

Beam quality measurements of the gantry beam at new PMRC, Tsukuba

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Dose distributions of the gantry beam at the new Proton Medical Research Center (PMRC), University of Tsukuba have been extensively measured using a silicon semi-conductor sensor scanned in a water vessel. A uniform fluence distribution is formed by a double scattering method using a uniform first scatterer and a dual-ring second scatterer. Depth-dose distributions of the broad beam have been measured for beam with ten different energies. Based on the measured Bragg curves, we designed ridge filters. We prepared two series of ridge filters. Whereas the one series are optimized for 200-MeV protons, the other series are optimized for 155-MeV protons. Depth-dose distributions of the range-modulated beam are measured and compared with calculations. Basic quantities such as lateral penumbras and distal falloffs are measured and compared with calculations. We found that measurement results agreed well with the calculations. As expected from calculations, dose distributions of beam with lower incident energy were found to be largely affected by insertion of a ridge filter and a range shifter.□ Dose distribution measurements using a water vessel with a movable cross-type
array of parallel-plate ionization chambers

Dose distribution measurements using a water vessel with a movable cross-type array of parallel-plate ionization chambers

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A detector has been fabricated to measure proton dose distributions in water efficiently. It is a cross-type array of forty parallel-plate ionization chambers (twenty chambers in each direction) movable in a water vessel. A reference chamber is prepared to compensate time variation of beam intensity. Since the assembly can be rotated manually around an axis of

rotation, dose distributions can be measured for many rotational angles of the gantry. The pitch of the ionization chambers is 10 mm and the effective volume of individual chambers is about 0.1 cc (5.6 mm□ x 4 mm).. Calibration of sensitivities of ionization chambers was made by locating each chamber at the center of beam field and by measuring the electric charge in the chamber. A transmission ionization chamber along the beam line is used for compensating the beam-intensity variation during the measurements. Since the device enables us to measure lateral dose distribution in x- and y-axes simultaneously, it serves to reduce the measurement time of dose distributions. Depth-dose distributions of forty lateral positions can be obtained at once by moving the array remotely.

Experimental Evaluation of Proton Dose Calculations in Heterogeneities

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We have developed a method of dose calculation based on the pencil beam algorithm (PBA) and the simplified Monte Carlo (SMC) dose calculation method with the new concept. In order to verify the accuracy of calculations by the PBA and the SMC, we manufactured heterogeneous phantoms which were made of Tough Water and Tough Lung, and dose distributions in heterogeneities were measured. The results of the measured dose distributions agreed with the measured ones within several percent since the PBA could not predict the edge scattering effect. On the other hand, the calculated results by the SMC agreed considerably with the measured ones. In conclusion, Care must be taken to apply the PBA to dose calculations in heterogeneities and the dose-calculation method by the SMC will be applicable to actual treatment planning of the proton therapy.

Development of a Multi-layered Ionization Chamber for Heavy Ion Therapeutic Beam

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In heavy ion radiotherapy, it is strongly desired to measure dose distributions for individual patients, and to compare them with the results of calculated dose distributions. So we are developing a multi-layered ionization chamber(MLIC) for the measurements of the dose distributions. It can take the data of depth dose distributions at once.

Measurements of charge-changing cross sections for carbon and neon beams

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High-energy ion beams exhibit a flat depth-dose distribution near the end of their range, where there is a marked increase in dose, called the Bragg peak. In cancer therapy using high energy ion beams, energy absorbers are usually set in front of a patient in order to

superimpose the Bragg peak over the whole target volume. These absorbers cause attenuation of the beams through nuclear fragmentation and may possibly change the beam fluence which is planned for patient irradiation. Nuclear fragmentation cross sections are therefore of particular interest in heavy ion radiotherapy.
Although fragmentation reactions have been studied for many years from the viewpoint of nuclear physics, there is still a lack of experimental data, especially for light ions such as are used in therapy, and there are in some cases large differences between data and model calculations. We have measured the survival of 400 MeV/u carbon and neon beams as a function of the absorber thickness with dE-type plastic scintillators. The total charge-changing cross sections of several materials for those beams were deduced from the measured survival data. We will show comparisons between our data, theoretical predictions and other experiments.

Study of acoustic signals generated by pulsed proton beam irradiation

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In proton therapy, a location of the high-dose volume must be controlled very accurately. However only few studies have been tried to measure a dose distribution inside a patient's body. All radiation beams, especially a pulsed proton beam, generate an acoustic wave inside a medium. This phenomenon may have a possibility of being used to verify dose distributions during treatment, since shapes of acoustic signals have a 3-D dose information. Based on dose measurements with 1.6mm resolution using imaging plates, we calculated expected acoustic signals at different locations in water with 1 □sec resolution. In the calculating model we made two assumptions. Firstly, for each point of dose distribution the micro pressure was generated by the adiabatic expansion and the amplitude of pressure is proportional to the dose. Secondly, the pressure signal travels to the detector with a delay proportional to the distance (r) and with an attenuation proportional to 1/r. Results of the calculations agreed well with the measurement results detected by the hydrophone in a water tank.

Microdosimetric Characteristics of the JINR, Dubna Clinical Proton Beams

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Proton clinical beams contains particles with high linear energy transfer (LET). Secondary heavy charged particles and degraded protons at the Bragg peak region are particles with high LET. The contribution of the high LET particles to the dosimetric and microdosimetric characteristics of proton beams was experimentally studied by track etched detectors.
The method of the LET spectra measurement with track etched detectors allows one to determine the contribution of high LET particles to the dosimetric characteristics of proton

clinical beams, absorbed dose, equivalent dose and the value of the Relative Biological Effectiveness (RBE). For the RBE calculation from the measured LET spectra the Biological Weighting Function r(y) proposed by T.Loncol was used.
Track detectors were irradiated in the various depth of proton clinical beams with the primary energies of 155 and 200 MeV at the JINR (Dubna) phasotron. The LET spectra between 10 and 700 keV/μm were measured by means of the CR-39 track etch detectors and automatic optical image analyzer LUCIA at the NPI (Prague). Due to the increased fraction of high LET particles with a depth of proton beam penetration, radiobiological characteristics of the clinical proton beam changed with the depth as well.
The relative contribution of the high LET particles to absorbed dose increases from several percent at the beam entrance to several tens of percent at the Bragg peak region. The value of the RBE increased from about 1.0 at the beam entrance to about 1.25 at the Bragg peak. These values undoubtedly must be taken into account during beam production and using.
In future it will be interesting to make the same measurements of RBE values at the Bragg peak region of the modified proton and heavy ions clinical beams, where this effect is more significant.

Progress on DICOM Standard for Ion Beam Therapy

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The increasing number of different beam delivery and planning systems that are now or soon to be on line for proton therapy will require a large effort in developing communications protocols. These protocols are necessary not only to pass beam information from the planning system to the delivery system but also to compare treatments within inter-institutional trials. A sub-committee of the DICOM-RT working group has been formed to propose a communication standard for ion beam therapy. A progress report on the activities towards this standard will be presented.

RBE values of 180 MeV proton beams at the Wakasa-Wan Energy Research Center (an interim report)

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Prior to the start of clinical use, we are investigating the relative biologicaleffectiveness (RBE) of 180 MeV therapeutic proton beams for the following objectives; 1) to confirm RBE for the medical course of synchrotron installed in the Wakasa-Wan Energy Research Center, 2) to accumulate data of RBE values for protonbeams, 3) to check the apparatuses such as dose monitors by comparing with RBE which was measured in another facility with an accelerator. The biological systems used were HSG cell (human salivary glands) for in vitro experiment and mouseintestinal crypt cells for in vivo experiment. The dose responses by irradiationat the entrance plateau and a middle portion of a Spread-Out-Bragg-Peak (SOBP) of 6-cm width were compared with those by X-ray irradiation of a linac at 4 MV. RBE values of in vitro experiments were 1.14

and 1.08 at entrance plateau and SOBP, respectively. RBE values of in vivo experiments were 1.00 and 1.12at entranceplateau and SOBP, respectively, showing similar RBE values previously reported.We are currently repeating measuring those RBE values of the beams for more reliable values.