行政院國家科學委員會專題研究計畫 成果報告

醫用迴旋加速器改善屏蔽後的中子輻射評估
研究成果報告(精簡版)

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執 行 期 間 ：100 年 08 月 01 日至 101 年 07 月 31 日
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計 畫 主 持 人：陳健懿
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報 告 附 件 ：出席國際會議研究心得報告及發表論文

公 開 資 訊 ：本計畫涉及專利或其他智慧財產權，2 年後可公開查詢

中 華 民 國 101 年 10 月 09 日

中文摘要： 為國內各醫學中心近年來加快裝設迴旋加速器，進行核醫製藥，但是，由運轉中的加速器會有巨量高能γ-ray 射線自靶區外釋。中子由 8O(p, n)18F 反應生成，造成迴旋加速器中心的環境輻射，大幅增加，並衍生放射性核種，對大眾或工作人員都具有直接或間接傷害。中山醫學大學附設醫院在配合原廠(CTI 公司 RDS-111)不改變靶體、靶材(polyethyleneketone, PEEK)、靶電流及照射時間情形下，提高 18F-FDG 產率由 2005 年的 4200 GBq 提升至 2011 年 10 月的 35900 GBq，需要將反應器主體屏蔽改進，以符合游離輻射防護法及正子放射同位素調製作業要點之要求，本研究以佈植 TLD-600 及 TLD-700 來偵測/估算迴旋加速器中心之機房、化學製藥室、辦公室之環境劑量，迴旋加速器中子偵測及最小可測輻射值 Minimum detectable limit (MDL) 估算雙 TLD 法，這可望推廣應用至各大醫學中心，而對日後加速器現場，提出必要的輻射防護建議。

中文關鍵詞： 醫用迴旋加速器、18F-FDG 產量、 二次中子劑量率(DR)、TLD-600、 L 型混凝土屏蔽

英文摘要： Of late, an increasing number of cyclotrons at medical centers in Taiwan have installed to produce nuclear medicine. However, as the operating cyclotron generates immense amounts of high energy neutrons from 18O(p, n)18F reactions, inducing gamma-ray which significantly magnifies high radiation from the cyclotron center, this intense radiation brings about health hazard to the medical personnel and the public whether through direct contact or indirect transmissions. In order to increase the yield of 18F-FDG products from 4000 GBq (2005) to 251000 GBq (2010) without changing the target PEEK (polyethyleneketone), target current and irradiation time, Chung Shan University Hospital (CSMCH) has to redesign self-shield CTI RDS-111 so as to meet the Guild requirements regarding the production of positron emission tomography. The design of self-shield CTI RDS-111 of Chung Shan Medical University Hospital (CSMCH) must have been developed to improve for meeting the Guild line of production of positron emission tomography. This two-year project is comprised of the first year scheme of calibrating and optimizing the conditions of TLD-600 and TLD-700, and the second year scheme of measurements taken at vault, hot laboratory and office of cyclotron center, evaluated neutron dose, and Minimum detectable limit (MDL) of pair-TLDs approach. The findings of this project can be adopted by medical centers to identify radioactive hot spots, developing precautionary measures for radiation protection.

英文關鍵詞： Medical cyclotron, 18F-FDG yield, Secondary neutron dose rates (DR), TLD-600, L-shaped concrete shield

醫用迴旋加速器改善屏蔽後的中子輻射評估

Evaluation of Neutron Radiation for Improving Shielded Design of Medical Cyclotron

計畫編號：100-2221-E-040-005
執行期限：100年8月1日至101年7月31日
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一、中文摘要

為國內各醫學中心近年來加快裝設迴旋加速器，進行核醫製藥，但是，由運轉中的加速器會有巨量高能 γ-ray 射線自靶區外釋。中子由 ^{8}O(p, n)^{18}F 反應生成，造成迴旋加速器中心的環境輻射，大幅增加，並衍生放射性核種，對大眾或工作人員都具有直接或間接傷害。中山醫學大學附設醫院在配合原廠(CTI 公司 RDS-111)不改變靶體、靶材(polyethyleneketone, PEEK)、靶電流及照射時間情形下，提高 ^{18}F-FDG 產率由 2005 年的 4200 GBq 提升至 2011 年 10 月的 35900 GBq，需要將反應器主體屏蔽改進，以符合游離輻射防護法及正子放射同位素調製作業要點之要求，本研究以佈植 TLD-600 及 TLD-700 來偵測/估算迴旋加速器中心之機房、化學製藥室、辦公室之環境劑量，迴旋加速器中子偵測及最小可測輻射值 Minimum detectable limit (MDL) 估算雙 TLD 法，這可望推廣應用至各大醫學中心，而對日後加速器現場，提出必要的輻射防護建議。

關鍵詞: 醫用迴旋加速器、^{18}F-FDG 產量、二次中子劑量率(DR)、 TLD-600、 L 型混凝土屏蔽

Abstract

Of late, an increasing number of cyclotrons at medical centers in Taiwan have installed to produce nuclear medicine. However, as the operating cyclotron generates immense amounts of high energy neutrons from ^{18}O(p, n)18F reactions, inducing gamma-ray which significantly magnifies high radiation from the cyclotron center, this intense radiation brings about health hazard to the medical personnel and the public whether through direct contact or indirect transmissions. In order to increase the yield of 18F-FDG products from 4000 GBq (2005) to 251000 GBq (2010) without changing the target PEEK (polyethyleneketone), target current and irradiation time, Chung Shan University Hospital (CSMCH) has to redesign self-shield CTI RDS-111 so as to meet the Guild requirements regarding the production of positron emission tomography. The design of self-shield CTI RDS-111 of Chung Shan Medical University Hospital (CSMCH) must have been developed to improve for meeting the Guild line of production of positron emission tomography. This two-year project is comprised of the first year scheme of calibrating and optimizing the conditions of TLD-600 and TLD-700, and the second year scheme of measurements taken at vault, hot laboratory and office of cyclotron center, evaluated neutron dose, and Minimum detectable limit (MDL) of pair-TLDs approach. The findings of this project can be adopted by medical centers to identify radioactive hot spots, developing precautionary measures for radiation protection.

Keywords: **Medical cyclotron, ^{18}F-FDG yield, Secondary neutron dose rates (DR), TLD-600, L-shaped concrete shield**

1. Introduction

1.1. Medical cyclotron

Rapid growth in the use of positron emission tomography (PET) as a clinical tool has led to a rapid increase in the number of cyclotrons worldwide that produce radiopharmaceuticals for PET (Lin *et al*., 2009; Lee and Chen, 2008; Herzog, 2007; Qaim, 2004). Unlike conventional cyclotrons used in physics research, medical cyclotrons are characterized by their compact size and operational ease in generating ^{18}F ($t_{1/2}$=109.4 min), ^{13}N ($t_{1/2}$=9.97 min) and ^{15}O ($t_{1/2}$=2.04 min), which are commonly utilized in PET studies (Reina *et al*., 2010; Herzog, 2007; Qaim, 2004). Chung Shan Medical University Hospital (CSMUH) is the only medical center in Taichung (that means central Taiwan) that produces these radiopharmaceuticals with short half-lives and is equipped with a self-shielded CTI (Knoxville, TN, USA) Radioisotope Delivery System (RDS-111) cyclotron (CTI, 1995). The RDS-111 cyclotron, installed in the basement of the CSMUH, was fully operational in September 1998. The cyclotron center shield was constructed based on the methodology and data provided in the National Council on Radiation Protection and Measurements (NCRP) 51 (Comsan, 1996; NCRP 51, 1977).

The room housing the RDS-111 cyclotron has 0.7-m-thick concrete walls. The vault room is located to the right of a hot laboratory, which is located to the right of the maze path. The vault room measures 6.7×8.2×4 m^3. The wall separating it from the hot laboratory is made of 0.5-m-thick concrete. The concrete floor and ceiling are 1 m and 1.5 m thick, respectively. The RDS-111 cyclotron is surrounded by a self-shielded system, comprising two interlocking shielded blocks. This system has an inside layer larger that is 30 cm in thickness and an outside layer that is 70 cm in thickness. The self-shielded system is a mixture of polyethylene (PE), boron carbon (B_4C), and concrete. The shield system is a primary radiation shield that surrounds the RDS-111 and has provided complete protection against radiation and has reduced the number of neutrons and γ-activity to safe levels since 1998 (Lin *et al*., 2009; Lee and Chen, 2008; CSMUH, 2007; Comsan, 1996; ICRP 60, 1991). Figure 1 plots the annual yields of ^{18}F-FDG in GBq during 1999-2011. The PET cyclotron generates accelerated protons with beams as high as 80 μA.

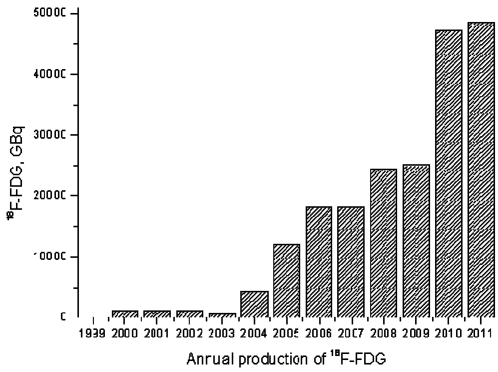

Fig. 1. Annual production of ^{18}F-FDG at the cyclotron center of the CSMUH

In this study, a refined shielded design was generated by changing the slide door (d_2) installed across the maze entrance and adding an L-shaped concrete shield to comply with the stringent dose limit of 100 mSv 5yr^{-1} for workers and 1 mSv yr^{-1} for the public set by International Commission on Radiological Protection (ICRP) and ROC-AEC (ROC-AEC, 2005; ICRP 60, 1991).

1.2. Redesigned RDS-111

Instead of the 0.5m-thick concrete wall, which is an insufficient thickness, shielding was improved by adding an L-shape concrete shield. Figure 2b shows that shielding was improved by a biological Pb shield, measuring 120×120×3.2 cm^3, placed at location F in front of a maintenance table. One accesses the vault by moving along the maze path and then directly through two motor-driven sliding doors (*i.e.*, d_1 and d_2), which are made of 1-cm-thick Pb and 5-cm-thick PE.

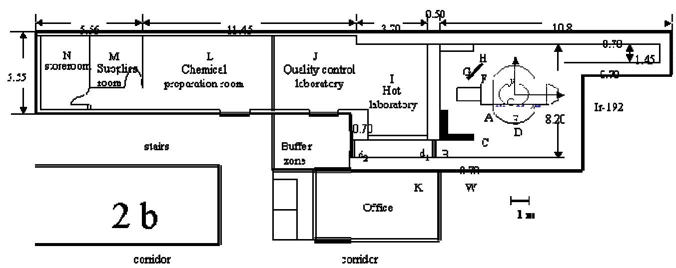

Fig.2b. Refined shielded design and layout of the cyclotron center at CSMUH, showing the geometric correlations between the vault room, maze path, and hot laboratory. The L-shaped

concrete shield, measuring 1.4×0.4×2.2 m^3, was placed in 2005 next to the hot laboratory to reduce secondary neutrons and γ-rays.

Figure 2b shows the current layout of the cyclotron center. To improve the radiations of the cyclotron vault room, because the maze is too short, the most effective method is to suppress neutron DRs along the maze by installing a shielded sliding door (d_2) across the maze entrance and an L-shaped concrete shield measuring 1.4×0.4×2.2 m^3. However, the DRs from secondary neutrons remain the dominant radiation risk to the public, center staff, and maintenance workers (Lin *et al*., 2009; Lee and Chen, 2008).

Early in 2003, our laboratory started monitoring secondary neutron DRs with the BF_3 neutron counting system near the cyclotron and linear accelerator (linac) at the CSMUH (Liu *et al*., 2010, Lin *et al*., 2009; Lee and Chen, 2008; Chen and Chung, 1997). Furthermore, gross counts recorded with the TLD provide more precise and accurate data for analytical processes than the high purity germanium detector, which performs an analysis partly based on a γ-spectrum when assessing environmental radiation (Changlai *et al*., 2012; Lin *et al*., 2009; Lee and Chen, 2008; Katona *et al*., 2007). Precise measurement by the TLD-600 is critical when evaluating neutron DRs because the process for quantifying a small number of neutrons (~10^4 n cm^{-2} s^{-1}) is difficult practically and the neutron distribution in the vault room fluctuates markedly (Lin *et al*., 2009).

1.3. Radiation weighting factor (W_R) of neutron

According to the (ICRP) 60, the radiation weighting factor (W_R) for neutrons in the range of 5-20 MeV is quite high, likely generating a large effective dose to the public (ICRP 60, 1991). Different techniques, such as TLD-600 (Hsu *et al*., 2008), activation detectors (Liu *et al*., 2010; Lin *et al*., 2009), bubble dosimeters, Bonner sphere spectrometers and Monte Carlo simulation, have been employed to measure neutron DRs in mixed neutron γ-radiation fields of medical cyclotrons.

2. Method and materials

2.1. Thermoluminescent dosimeters (the TLD-600)

Because it indicates long-term dose accumulation, the TLD-600 has been used widely over the last 30 years to assess mixed neutron γ-radiation fields for neutron DRs of cyclotrons and linacs (Hsu *et al*., 2008; Ranogajec-Komor *et al*., 2003). To compare the fluctuation of the TLD-600, two TLDs were combined in one bag, such that the 88 TLDs represented 44 measurement locations in the CSMUH and TLDs were detected as neutron DRs during a one-month survey. Additionally, five bags were utilized to measure the fluctuation of Harshaw 3500 readers in the lab, which has low background levels of radiations (Changlai *et al*., 2012). All measurements were conducted in triplicate and carried out with a batch of highly sensitive 3.2×3.2×0.89 mm^3 TLD-600 dosimeters. The TLD-600 is composed of 95.6% ^{6}Li and 4.4% ^{7}Li. The TLDs' lithium isotopic concentrations provide a different response to neutrons, which is mainly associated with the $^6Li(n,\alpha)^3H$ nuclear reaction (Hsu *et al*., 2008). Before irradiation, the TLD-600 was heated to 400°C for 1 h and 200°C for 2 h in a furnace 47900 and then allowed to cool to ambient temperature before use. After the one-month survey, the TLDs were analyzed with a fully automated Harshaw 3500 reader (Bicron NE Solon, OH, USA). The readout uses a two-step procedure: first, TLD is heated to 50°C for 1 s, and then heated to 300°C at a rate of 10 °C sec^{-1}, and held at 300°C for another 1 s (Hsu *et al*., 2008; Ranogajec-Komor *et al*., 2003). The TLD-600s were then counted and analyzed to map the distributions of secondary neutron DRs in the vault room.

2.2. Surveying neutron DRs in the cyclotron room

For all locations where neutron DRs were measured, two TLD-600s were irradiated with the averaged signal. To map neutron DR distributions, the TLDs were suspended at a height of 1 m above floor to represent the neutron DR of a standing person (Changlai *et al*., 2012; Lee and Chen, 2008). Other TLD-600s were suspended anywhere inside the cyclotron center during experiments. The TLD-600s randomly measured throughout the cyclotron center. The center of the RDS-111, location O (0, 0), was defined as the geometric origin, and all dimensions are in meters (cf. Fig. 2b). Further, two pairs of TLD-600s were placed at locations D (0, -1.70) and E (0, -1.40) at a height of 1.80 m inside and outside layer of the self-shielded system to evaluate the effectiveness in protecting against secondary neutrons. Measurements were made at 44 locations using reusable TLDs in two consecutive operating cycles per day during the one-month survey. The first cyclotron operation was run from 02:30 to 04:40 AM in the NMD to yield ^{18}F-FDG for use by hospitals located in either northern or southern Taiwan. The cyclotron was then run a second time from 05:20 to 07:30 AM from Monday through Friday since 2005 to yield ^{18}F-FDG products for use by other nearby hospitals. Notably, compared with the original design, operation time was increased 3.25 times that in 1998 for the same two operational cycles. All measurements were made using a 35-μA proton current. These neutron DRs were taken as a function of distance from the geometric origin of the vault room and were interpolated between measurement locations at each distance. When neutron DRs were measured at several locations the same distance from location O during triplicate measurements, averaged neutron DRs at that distance are used.

3. Results and discussion

3.1. TLD-600 calibration

The relative sensitivity of these TLD-600s was determined as the element correction coefficient to correct variation in individual sensitivities (Hsu *et al.*, 2008). The neutron DR calibration of TLDs in terms of exposure was performed using BNCT beams at NTHU (Hsu *et al.*, 2008). Energy response was tested at 6 MV X-ray, and calibration of individual TLDs was performed with a sensitivity correction applied to each TLD at the CSMUH. The TLDs were arranged in methylacrylate boxes 10 cm in diameter. Each box contained 10 lines, and each line contained 9 TLD-600s arranged alternately. A pencil-shaped ionization chamber (Wellhofer IC-69; CT Probes Model 350407', Nuclear Associates, Victoreen, Inc., New York) with a volume of 0.6 cm^3 was also used to determine X-ray exposure. The chamber was connected to a signal digitizing preamplifier via a 0.9-m low-noise cable. The system's readout meter was an innovation therapy dosimeter exposure meter.

3.2. Neutron DRs among the vault room

Figures 3 plots the contour maps of neutron DRs. Two-dimensional distributions in the vault room can be mapped using colored profiles that reflect various neutron DRs. All measurement data were obtained at 1 m above the floor, except for those at locations D and E, which were 1.8 m above the floor, and used to determine shielding efficiency of the self-shielded system. The red color in Fig. 3 indicates that neutron DRs exceeded 10^3 μSv mo^{-1}, and the other colored zones represent varying intensity of the smoothed neutron DRs in the vault room. Table 1 shows the neutron DR at detection locations for these TLDs. This finding is due to distributions of secondary neutrons generated from the ^{18}O(p,n)^{18}F target went through self-shielded blocks and through the L-shaped concrete shield (Lee and Chen, 2008; Herzog, 2007).

Table 1

Table 1 lists neutron DRs at the RDS-111 cyclotron center (μSv mo^{-1})

Location	Neutron dose rate
Controlled area	
A (-1, -0.65) [a]	12.5±0.68
B (-3.8, -4.0)	2.17±0.15
C (-2.0, -2.8)	11.9±0.3
D (0, -1.70) [a,b]	90.6±11.3
E (0, -1.79) [b]	8.01±0.96
F (-1.9, 1.25)	42.3±5.2
G (-2.0, 1.45)	13.6±1.6
H (-3.0, 3.60)	4.14±0.56
d_1	2.17±0.54
d_2	0.61±0.18
Public area	
I (Hot lab)	0.43±0.14
J (QC lab)	0.53±0.17
L (Chem room)	0.49±0.16
K (Office)	0.58±0.17
M (Supplies room)	0.62±0.22
P (Above O)	0.51±0.16
Q (Below O)	0.63±0.21
W (Waiting room)	0.48±0.15

[a]unit: mSv mo^{-1}

[b]measured at 1.80 meters high for evaluating self-shielded efficiency

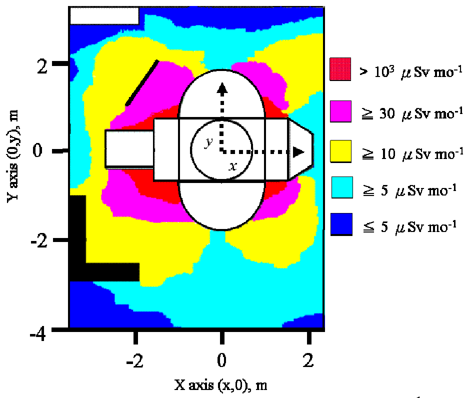

Fig. 3. Neutron DRs (μSv mo^{-1}) inside the RDS-111 vault room.

Figure 2b shows the hot spots that are closest to medical personnel working in the hot laboratory. One can reasonably assume that leaking neutrons can penetrate far through the 50-cm-thick concrete wall and maze, and then disperse into the cyclotron center. Over a total three-month survey, neutron DR at location W (waiting room) closed to Varian 2100 linac of the CSMUH was 0.48±0.15 μSv mo^{-1}. This value roughly equals 0.67±0.04 nSv h^{-1} and 0.66±0.04 nSv h^{-1} measured in Taichung (Lee and Chen, 2008; Chen and Chung, 1997), indicating that NO significant amounts of neutrons existed in the public area, office (K), and hot laboratory (I), which is just opposing the RDS-111 target, the quality control laboratory (J) in the controlled area, and the office (K). In the public area, NO significant differences in neutron DRs existed among these locations. Furthermore, on the upper floor just above location O (P), and on the lower floor just below location O (Q), neutron DR was 0.51±0.16 and 0.63±0.21 μSv mo^{-1}, respectively. These values during cyclotron operation are far below the limits recommended in the ICRP 60 (ICRP 60, 1991).

Conclusions

A newly designed vault room, comprising the L-shaped concrete shield and the added d_2 door reduced possible neutron DRs and γ-ray radiation in the cyclotron center at a medical university. Thus, the L-shaped concrete shield and the d_2 door suppresses neutron DRs, which meet PET requirements, and increased ^{18}F-FDG products by 11.5 times that in 2005. Those shield and door effectively reduced the neutron DR by a factor of 55500, and the effectiveness of the self-shielded system was 11300. These analytical results demonstrate that the self-shielded system and L-shaped concrete shield can protect the public from radiation exposure. Data in this work reveal that NO significant amounts of neutrons were detected in the public area. The annual "extra" neutron DR is far less than 50 mSv 5yr^{-1} for workers and 1 mSv yr^{-1} for the public during a one-year operational period, far below the levels recommended by the ICRP 60. The TLD-600 was a useful and reliable tool for evaluating DRs resulting from secondary neutrons in the cyclotron center.

Acknowledgments

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<tr><td rowspan="2">會議名稱</td><td>中文：CEN-S 2012春季化學工程國際會議國際化學與環境會議</td><td rowspan="2">會議地點</td><td>國家：中國大陸</td></tr>
<tr><td>英文：CEN-S 2012 Spring International Conference on Chemical Engineering</td><td>城市：西安</td></tr>
<tr><td rowspan="2">發表論文題目</td><td colspan="3">中文：醫用迴旋加速器改善屏蔽後的中子輻射評估</td></tr>
<tr><td colspan="3">英文： Evaluation of Neutron Radiation for Improving Shielded Design of Medical Cyclotron</td></tr>
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心得報告

一.參加會議經過

今年春季化學工程國際會議/國際化學與環境會議於5月27日至5月30日在中國西安舉行舉行，與會人士分別來自世界各國家，約500 餘人參與盛會。

CEN-S 2012春季化學工程國際會議國際化學與環境會議 (CEN-S 2012, Spring International Conference on Chemical Engineering) 會議針對天然環境、化學工程、化學應用之發展趨勢、化學災害評估等相關領域，之最新狀況與技術進行論文發表與技術交流。主辦單位為武漢大學、天津大學、西安理工大學、西安交通大學及IEEE Xi‘an Section,等14所大學。

本人於5月25日(星期五)下午13:20從桃園機場搭乘華航直飛中國大陸，約18:00 到達西安近郊咸陽機場，再搭乘其公車(約60分鐘)至西安大會現場(建國飯店)，大會於25及26日舉行了簡單之接待宴會(Welcome party)，讓與會者作初步之接觸與認識。

大會於5月27日(星期日)上午8:00-15:00進行開幕/報到儀式，5月28日(星期一)上午8:00由大會主席Yi Zhao 教授致詞表達歡迎後，再由韓國國立材料科學研究所(Korea Institute of Material Science, KIMS) Sung Cheal Moon教授進行開幕演講，介紹化學工程與研究的現況與未來(Advances in Chemical Engineering and Science)。接著的課程(08:00-12:00)分成三個演講廳進行為口頭論文發表(Oral Presentation)。

本人參加此次會議，並發表"醫用迴旋加速器改善屏蔽後的中子輻射評估(Evaluation of Neutron Radiation for Improving Shielded Design of Medical Cyclotron)"。

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二.與會心得

參加本次會議，得以了解世界各國相關輻射劑量評估技術、各種輻射應用發展趨勢及環境保護、永續發展。由會議所發表之論文了解，近年來因日本福島核事故後所引起的游離輻射恐慌，更需要學者對醫用加速器實驗實做的查訪。

三.建議

此次大會是CEN-S 2012 全球舉辦的2012年會，大會中對主題，各項安排，都有長期策劃，並有論文增訂成書。如何教育下一代得知/強調游離輻射在環境保護及能源上永續發展，本人深深體會到需要由醫院內的輻射安全與防護，認知現今游離輻射及輻射安全問題， 這次大會，得到很多，實在是不可得的機會，應該鼓勵，多多參加。

四.攜回資料名稱及內容（附件：與會手冊封面、論文暨海報發表時程等影本）

一、大會議程手冊(2012 Spring World Congress on Engineering and Technology (SCET 2012) 。

二、大會論文磁片(International Conference on Applied Mathematics and Sustainable Development -Special track within SCET 2012) 。

國科會補助計畫衍生研發成果推廣資料表

日期:2012/09/26

國科會補助計畫	計畫名稱: 醫用迴旋加速器改善屏蔽後的中子輻射評估
	計畫主持人: 陳健懿
	計畫編號: 100-2221-E-040-005- 學門領域: 醫用電子

無研發成果推廣資料

100 年度專題研究計畫研究成果彙整表

計畫主持人：陳健懿	計畫編號：100-2221-E-040-005-
計畫名稱：醫用迴旋加速器改善屏蔽後的中子輻射評估	

成果項目			量化：實際已達成數（被接受或已發表）	量化：預期總達成數(含實際已達成數)	量化：本計畫實際貢獻百分比	單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
國內	論文著作	期刊論文	0	1	100%	篇	
		研究報告/技術報告	0	1	100%		
		研討會論文	2	2	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	1	1	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	2	2	100%		
國外	論文著作	期刊論文	0	1	100%	篇	
		研究報告/技術報告	1	1	100%		
		研討會論文	2	2	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	1	1	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	2	2	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	1.預計投稿到 Journal of Radioanalytical and Nuclear Chemistry, 291 No. 3 (2012) 859-863. (ISSN 0236-5731, impact factor: 1.520, 514/35= 17.14%, refer to SCI '11 report Cat: Nuclear science and technology) 或 Radiation Physics and Chemistry 80 (2011) 917–922, (ISSN 0969-806X, impact factor: 1.227, 10/35= 28.57%, refer to SCI '11 report Cat: Nuclear science and technology) 2.已發表研討會 Yi-Chiao Teng1, Ssu-Chia Tsai1, Teng-San Hsieh2,3, Pan-Fu Kao4, Jye-Bin Lin 1,5, Chien-Yi Chen1* , 'Evaluations of Environmental Neutron Radiations at Medical Cyclotron' 4th Conference of Chung Shan Medical Imaging and Radiological Sciences, RS-16 p.20, 2012, May 30. Ching Wang1, Ling Kao1, Pai-jung Chang 1,3, Jong-Kang Lee2,3, Chien-Yi Chen1, Jye-Bin Lin 1,4, Jih-Dar Shy4* ,' Environmental radiation detected at Nuclear Medicine Department of Chung Shan University Hospital' The 7th Conference of International Medical Imaging and Radiological Science. CO-C1, 2012, May 26.

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：□已發表 □未發表之文稿 ■撰寫中 □無

專利：□已獲得 □申請中 ■無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

Of late, an increasing number of cyclotrons at medical centers in Taiwan have installed to produce nuclear medicine. However, as the operating cyclotron generates immense amounts of high energy neutrons from 18O(p, n)18F reactions, inducing gamma-ray which significantly magnifies high radiation from the cyclotron center, this intense radiation brings about health hazard to the medical personnel and the public whether through direct contact or indirect transmissions. In order to increase the yield of 18F-FDG products from 4000 GBq (2005) to 251000 GBq (2010) without changing the target PEEK (polyethyleneketone), target current and irradiation time, Chung Shan University Hospital (CSMCH) has to redesign self-shield CTI RDS-111 so as to meet the Guild requirements regarding the production of positron emission tomography. The design of self-shield CTI RDS-111 of Chung Shan Medical University Hospital (CSMCH) must have been developed to improve for meeting the Guild line of production of positron emission tomography. This two-year project is comprised of the first year scheme of calibrating and optimizing the conditions of TLD-600 and TLD-700, and the second year scheme of measurements taken at vault, hot laboratory and office of cyclotron center, evaluated neutron dose, and Minimum detectable limit (MDL) of pair-TLDs approach. The findings of this project can be adopted by medical centers to identify radioactive hot spots, developing precautionary measures for radiation protection.