# A 10 MeV/40 kW L-band Linac for the Irradiation Applications in China

*G. Pei for the L-band linac group*


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# Content

- Design and Development
- Installation and commissioning
- Beam Test and Operation
- Summary

# Design and Development

- IHEP in China has very rich experience in the electron linac design and development. When requested to transfer the technology to industry, many S-band electron linacs have been developed for medical and irradiation applications.
- For the S-band irradiation linac, the beam power is limited to be ~20 kW because of the RF structure heating/cooling issues. L-band structure is usually adopted for the nature extending to much higher beam power up to ~100 kW level.
- For any high beam power machines the power efficiency is a concern.

$$\eta_{\max} = \frac{1}{2}\left[\frac{\left(1-e^{-2\tau}\right)^2}{\left(1-e^{-2\tau}\right)-2\tau e^{-2\tau}}\right]$$

Smaller τ is preferred !

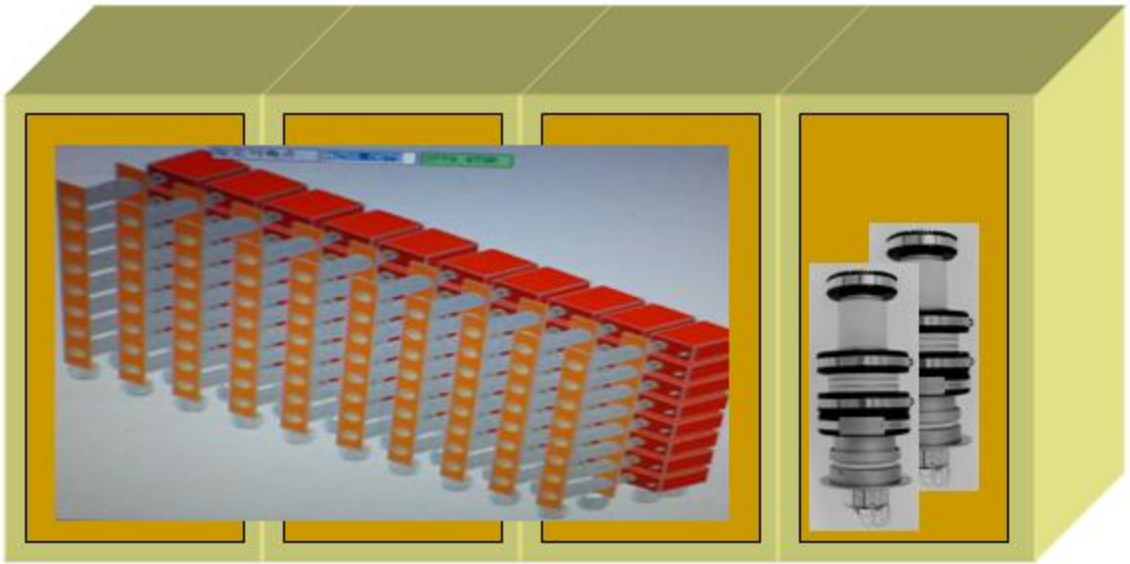
- The Thales TH2104U klystron, 2 A thermionic electron gun and 3 m long L-band disk-loaded constant impedance RF structure were adopted.
- The linac is a machine with very heavy beam loading; the beam energy range of 8 to 12 MeV can be easily controlled by simply adjusting the gun bias voltage (i.e. the gun emitting beam current), but above 10 MeV is not recommended for prevention of the neutron production.

# Main parameters

| | |
|---|---|
| Frequency | L-band（1.3GHz） |
| Beam energy | 10 MeV |
| Beam power | 40kW |
| Beam jitter (rms) | ≤±1% |
| Scan rep. rate | 5-200Hz |
| Scan width | 1.0m |
| Dose uniformity | ±5% |

# High power modulator

- PFN charging voltage 32kV max.
- Transformer ratio 1:12
- Beam voltage 168kV
- Beam current 136A
- Pulse width 29μs
- Average power: >300kW

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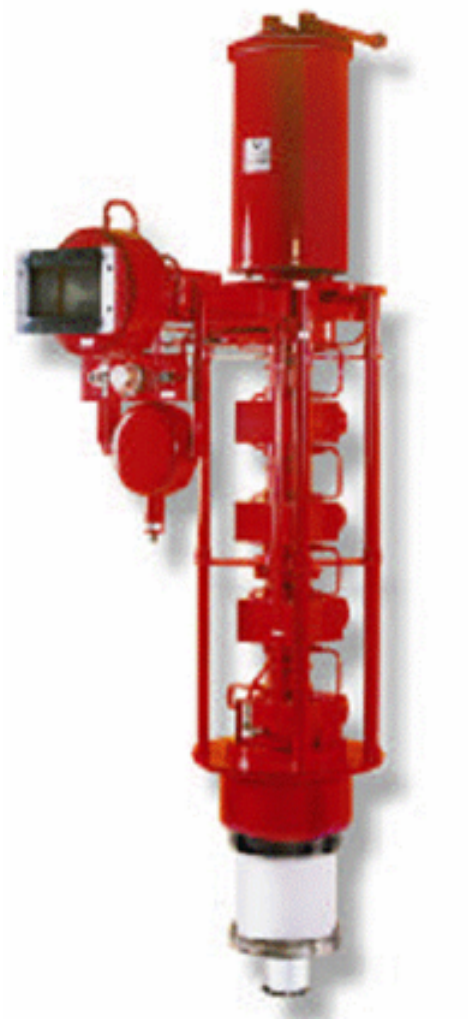
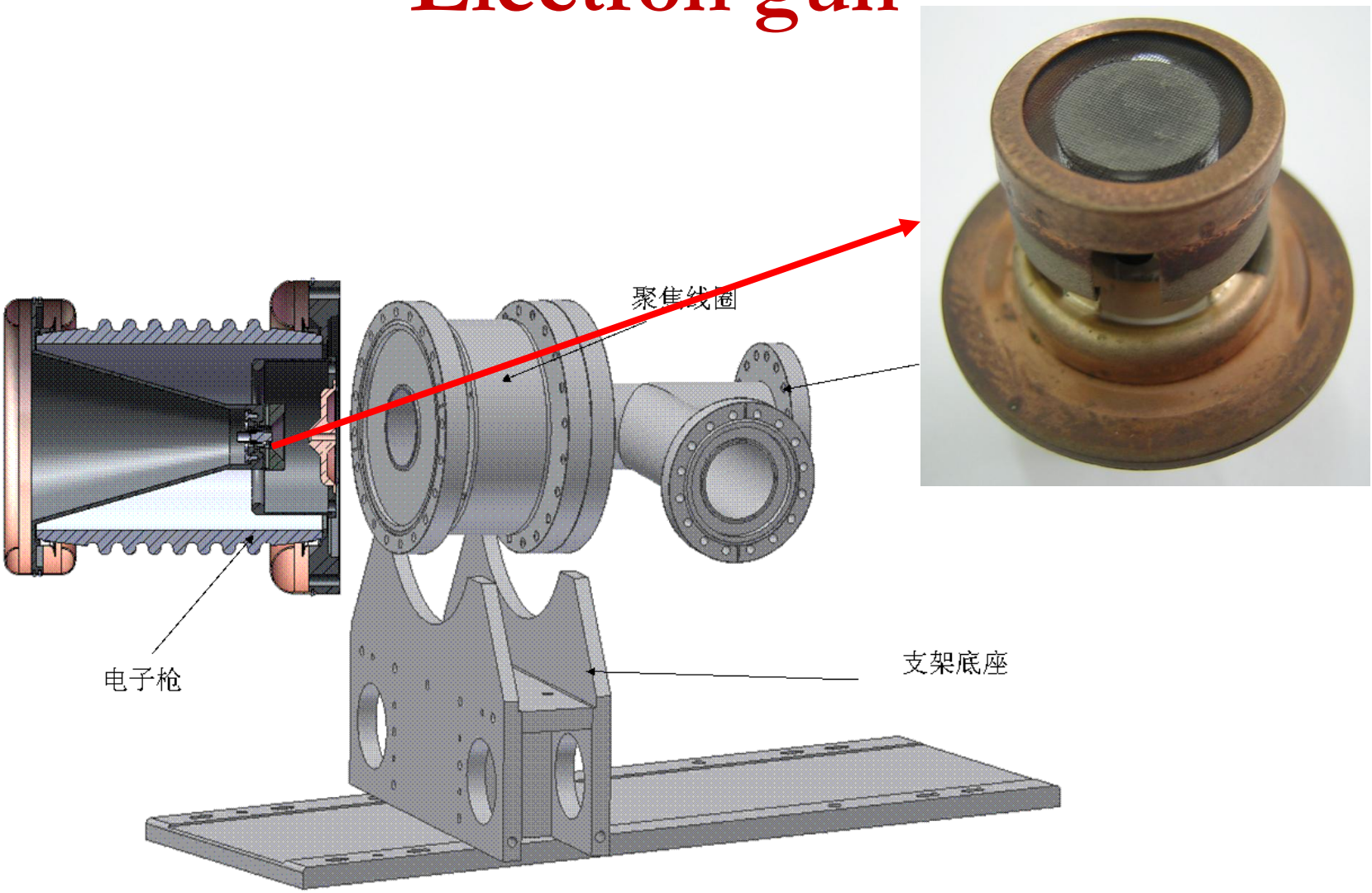
# L-band Thales TH2104U klystron

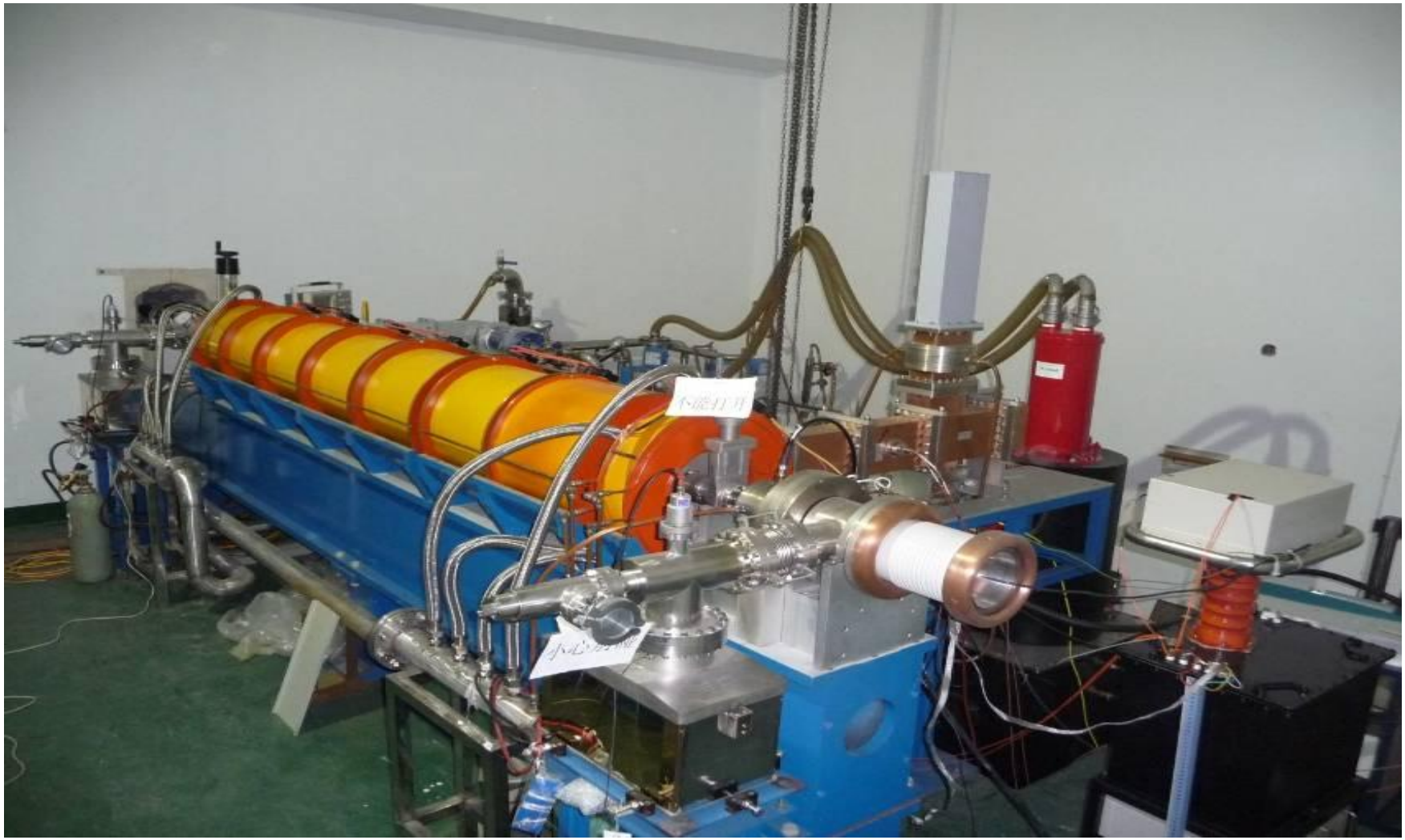


| | | |
|---|---|---|
| Frequency | 1300 | MHz |
| Output power | 10 | MW |
| Gain | > 47 | % |
| Pulse width | > 55 | μs |
| Duty cycle | > 1.1 | % |
| Output average power | > 130 | kW |
| Efficiency | 45 | % |
| Beam voltage | 167 | kV |
| Beam current | 136 | A |

# Electron gun



# The main 10/40 L-band linac



# Installation and commissioning

| Date | Activity |
|---|---|
| October, 2007 | Proposal and design |
| Auguest, 2008 | Manufacture, purchase |
| September, 2009 | Assembly at EL PONT |
| November 3, 2010 | First beam |
| November 6, 2010 | Beam at 5 Hz |
| March 31, 2011 | 30 kW |
| April 24, 2011 | 40 kW |

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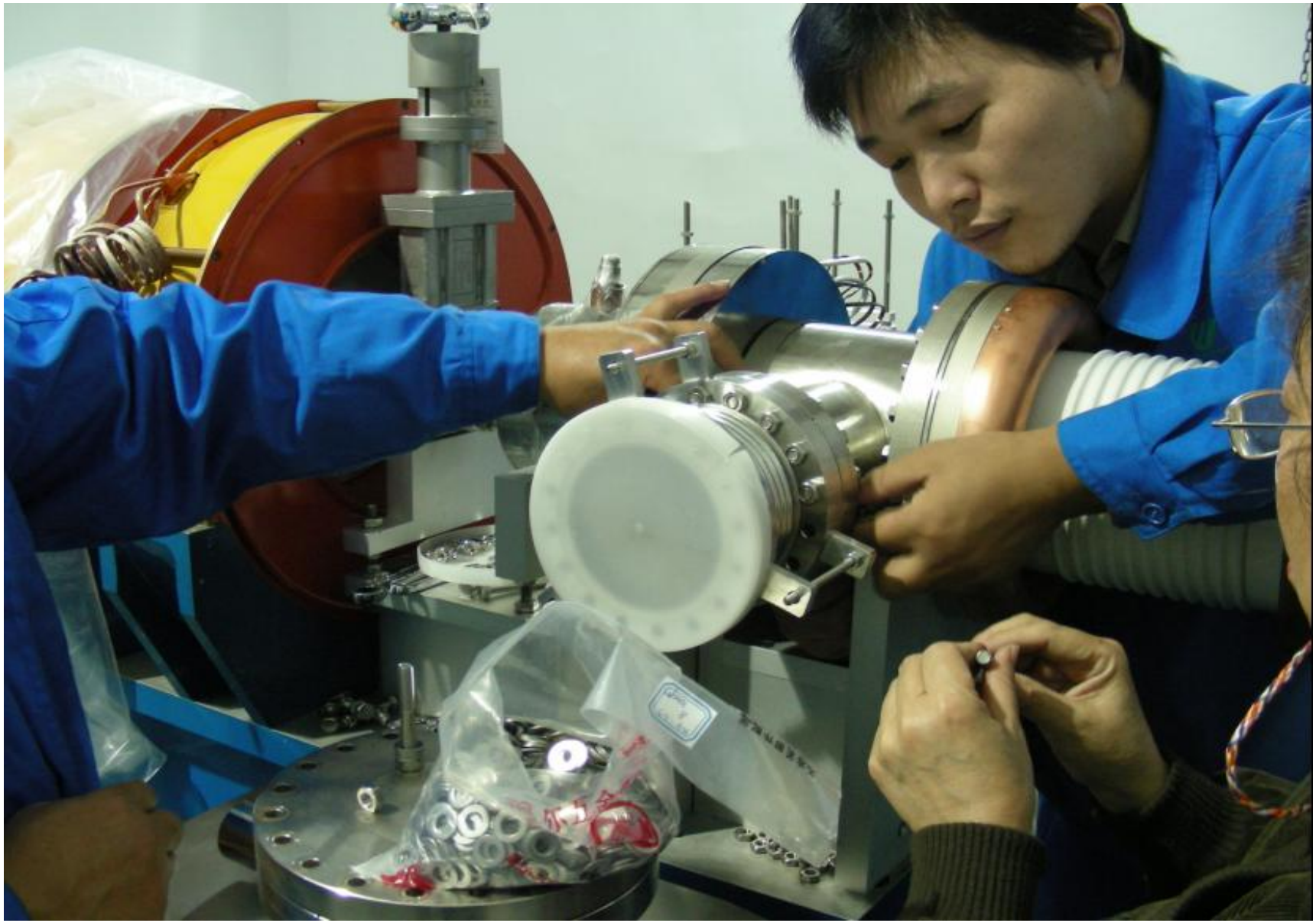
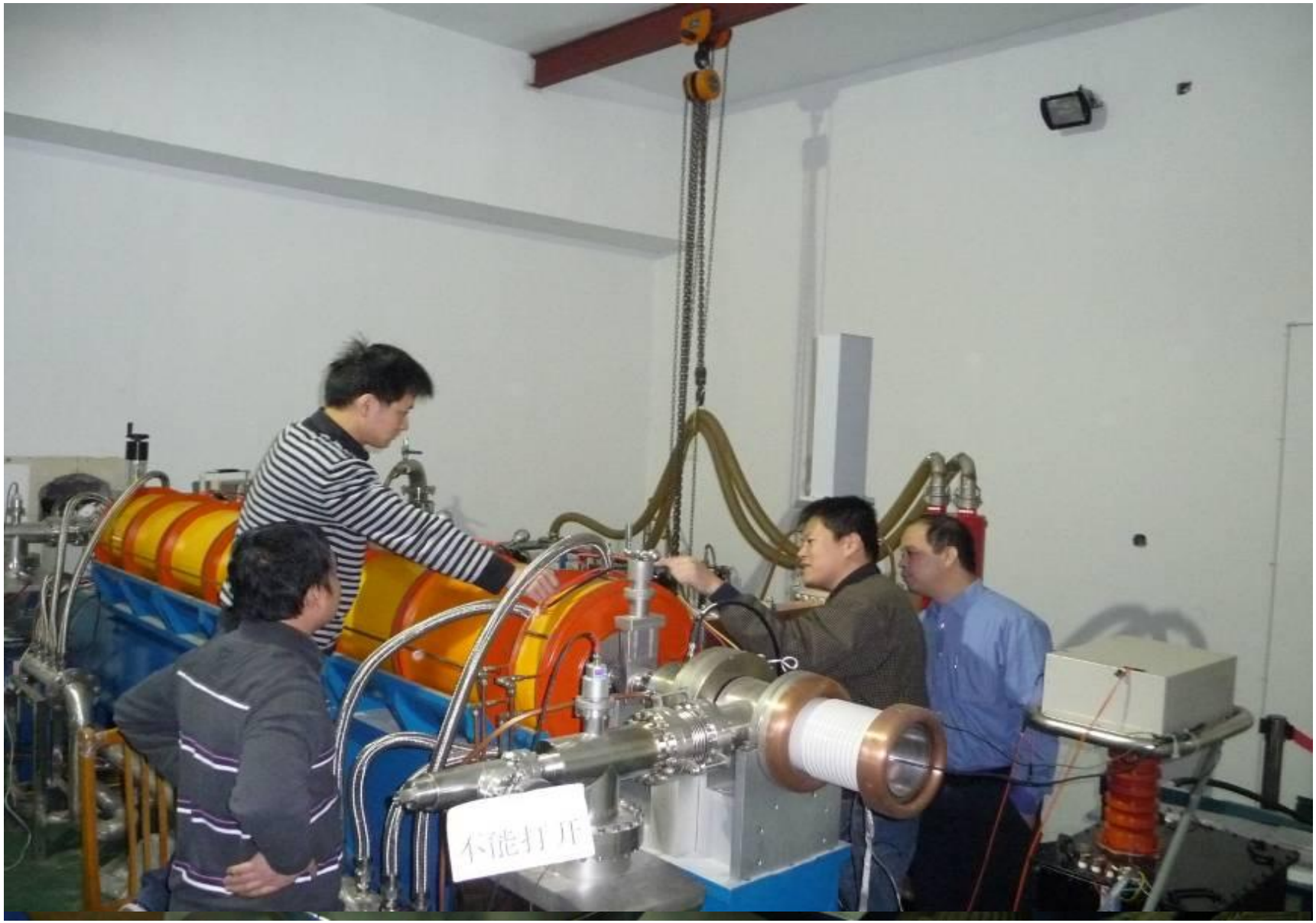
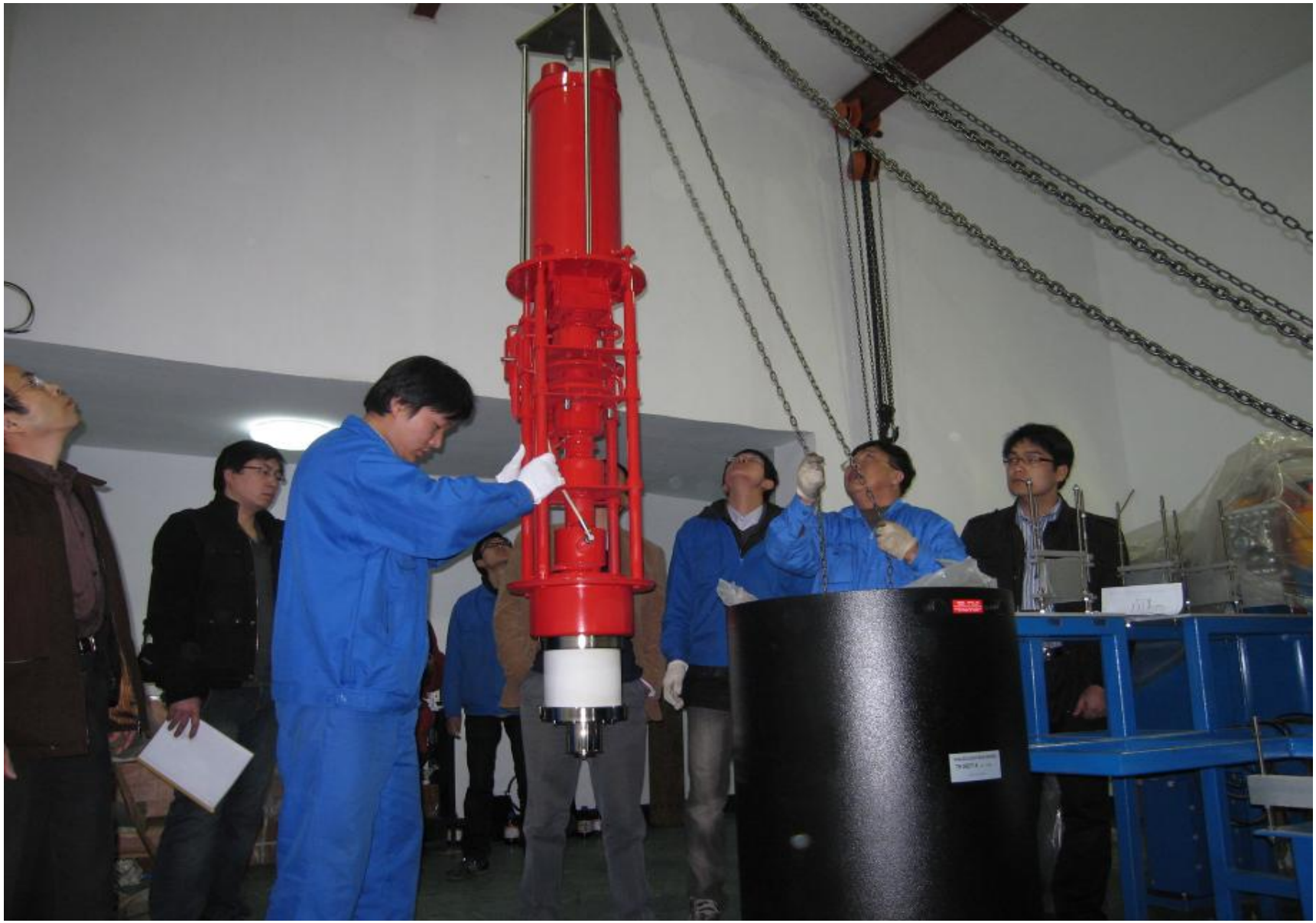



不能打开



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# November 3, 2010 the first beam


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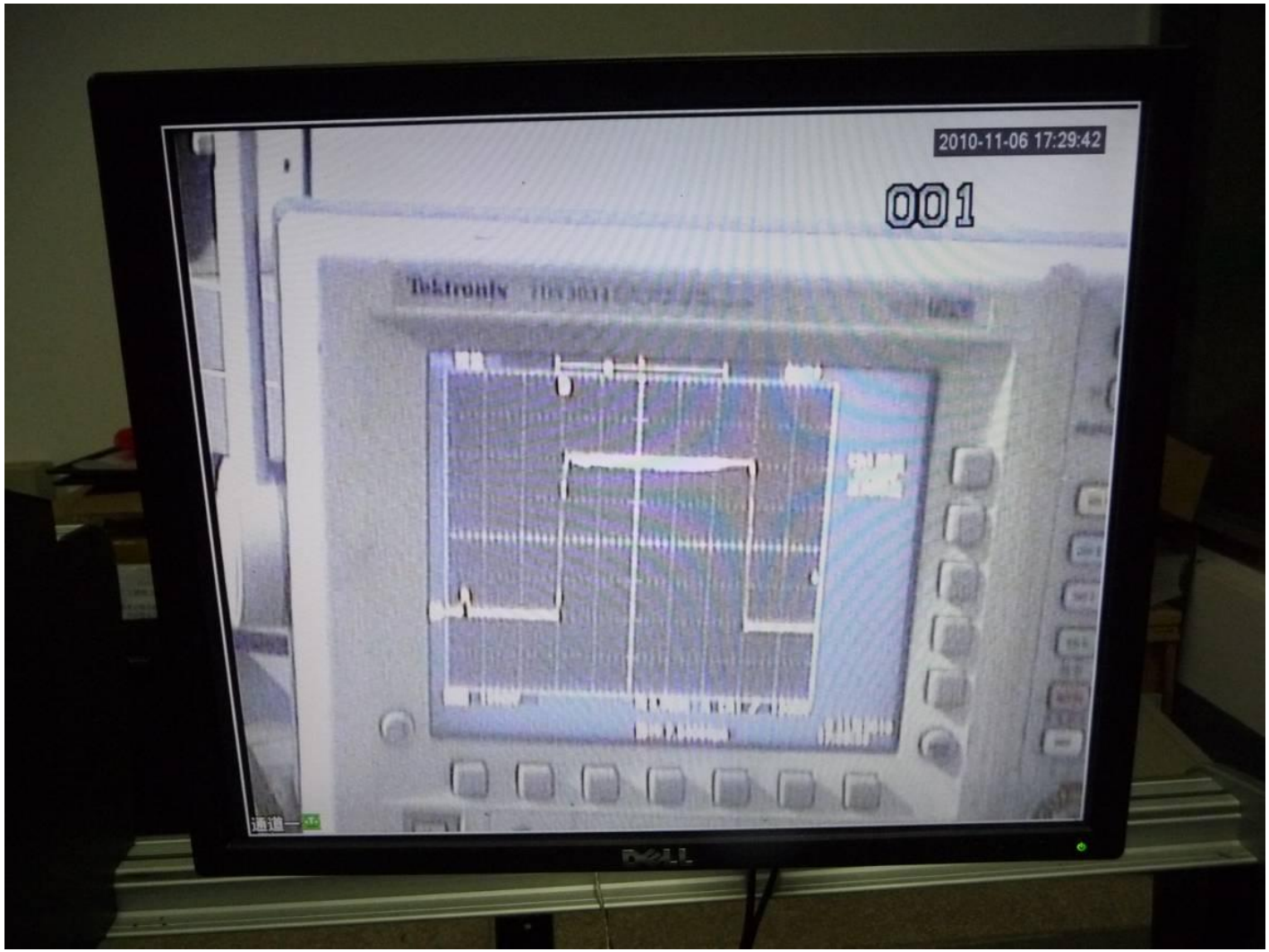
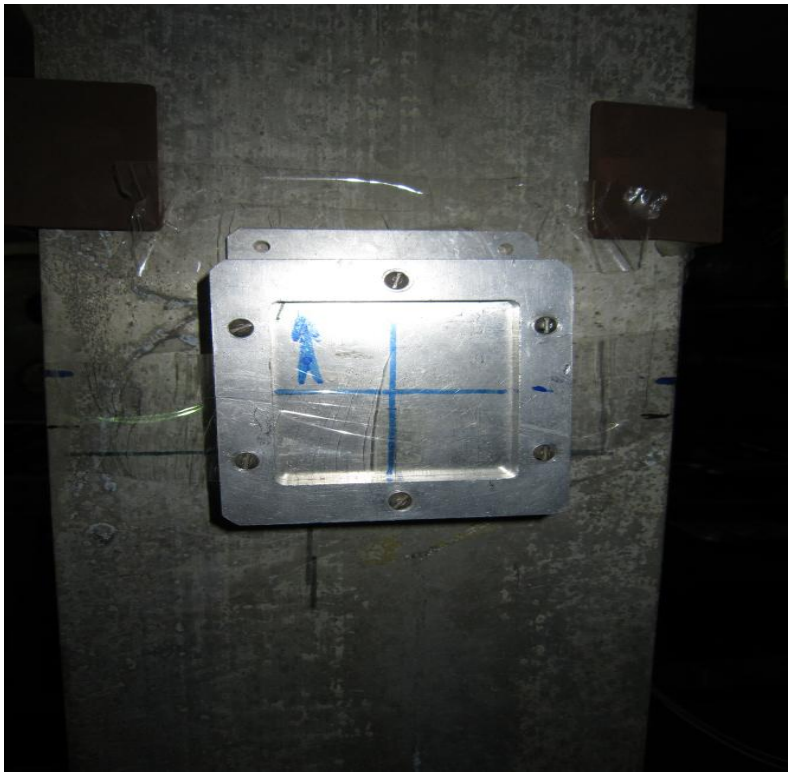
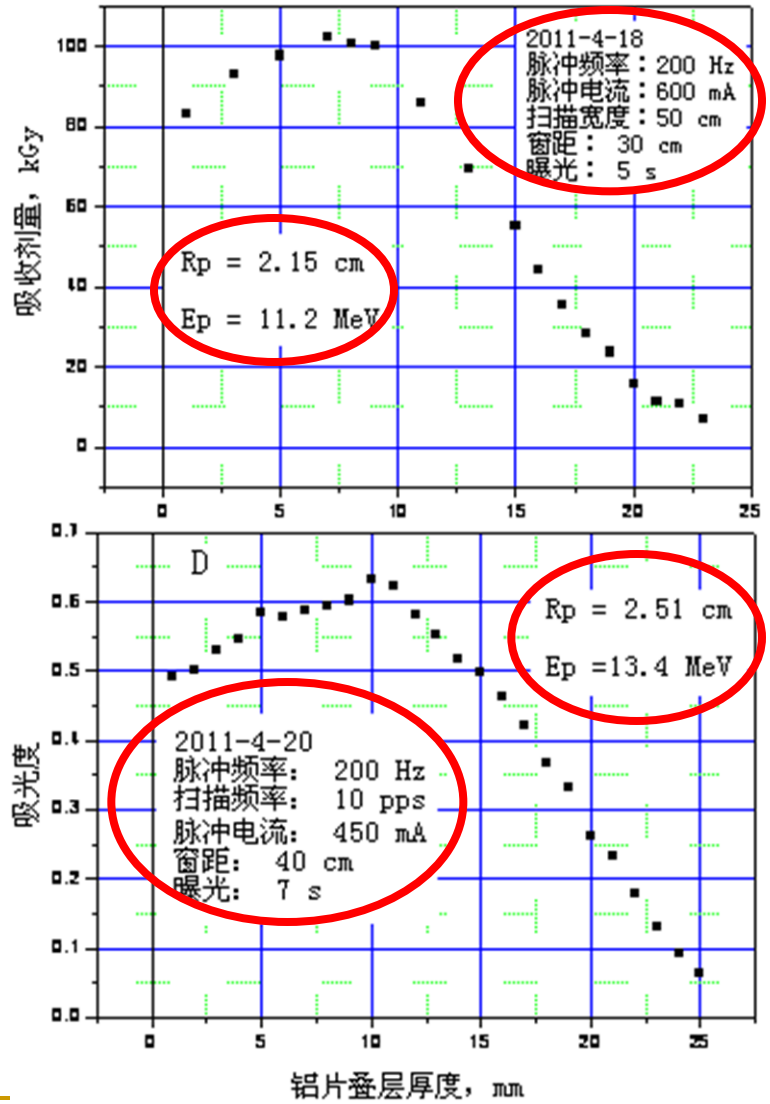
# November 6, 2010 5Hz beam



# Beam test and operation

## Energy measurement with Al stack method



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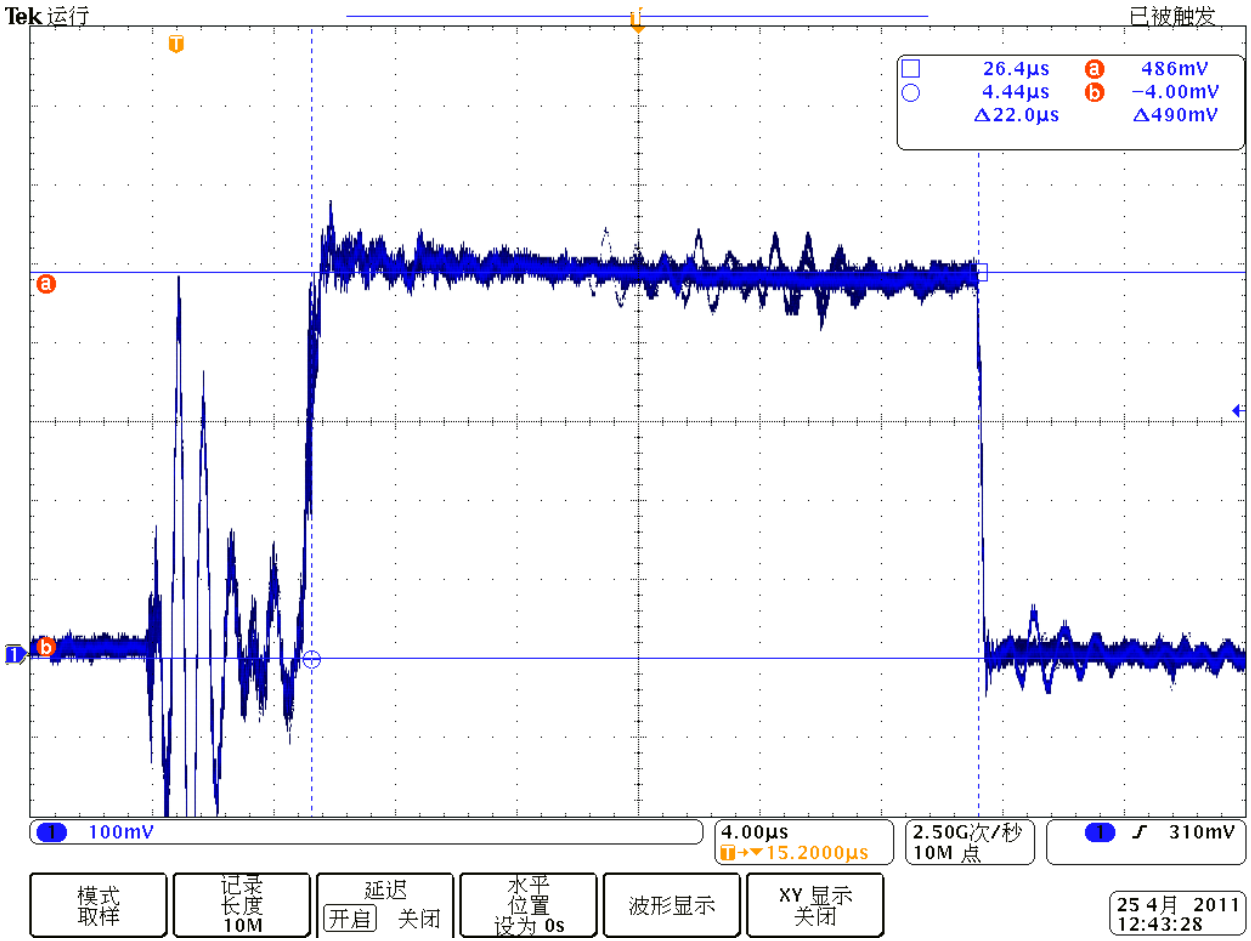
# April 25~26, 2011
# 40kW beam 24h operation

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# Formal test report

中国计量科学研究院

校 准 证 书

证书编号 DYjl2011-3077

| | |
|---|---|
| 客户名称 | 无锡爱邦辐射技术有限公司 |
| 器具名称 | 电子直线加速器辐照装置 |
| 型号/规格 | L40 |
| 出厂编号 | / |
| 生产厂商 | 无锡爱邦辐射技术有限公司<br>中科院高能物理研究所 |
| 客户地址 | 江苏省无锡市钱桥工业园区伟业路 8 号 |
| 校准日期 | 2011 年 12 月 26 日 |

批准人：

中国计量科学研究院 2 校准专用章

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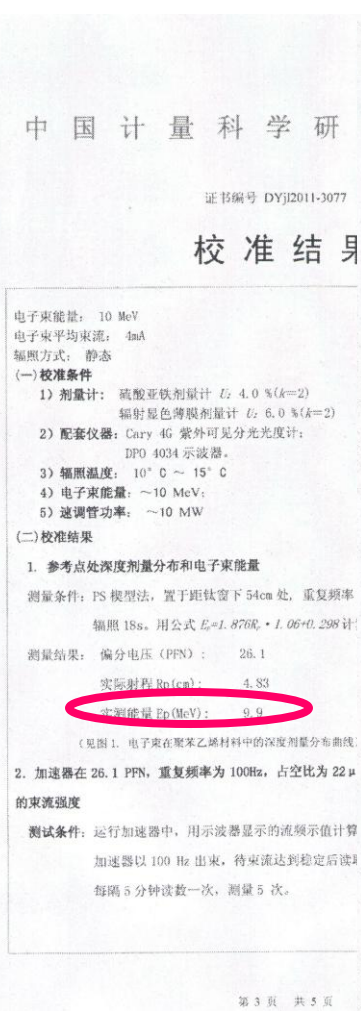

中国计量科学研

证书编号 DYjl2011-3077

校准结果

电子束能量： 10 MeV

电子束平均束流： 4mA

辐照方式： 静态

(一)校准条件

1) 剂量计： 硫酸亚铁剂量计 $U_r$ 4.0 %($k$=2)

辐射显色薄膜剂量计 $U_r$ 6.0 %($k$=2)

2) 配套仪器： Cary 4G 紫外可见分光光度计；

DPO 4034 示波器。

3) 辐照温度： 10° C ～ 15° C

4) 电子束能量： ～10 MeV；

5) 速调管功率： ～10 MW

(二)校准结果

1. 参考点处深度剂量分布和电子束能量

测量条件：PS 模型法，置于距钛窗下 54cm 处，重复频率

辐照 18s。用公式 $E_p=1.876R_p+1.06\pm0.298$ 计

测量结果： 偏分电压（PFN）： 26.1

实际射程 Rp(cm)： 4.83

实测能量 Ep(MeV)： 9.9

（见图 1. 电子束在聚苯乙烯材料中的深度剂量分布曲线）

2. 加速器在 26.1 PFN，重复频率为 100Hz，占空比为 22 μ

的束流强度

测试条件：运行加速器中，用示波器显示的流频示值计算

加速器以 100 Hz 出束，待束流达到稳定后读

每隔 5 分钟读数一次，测量 5 次。

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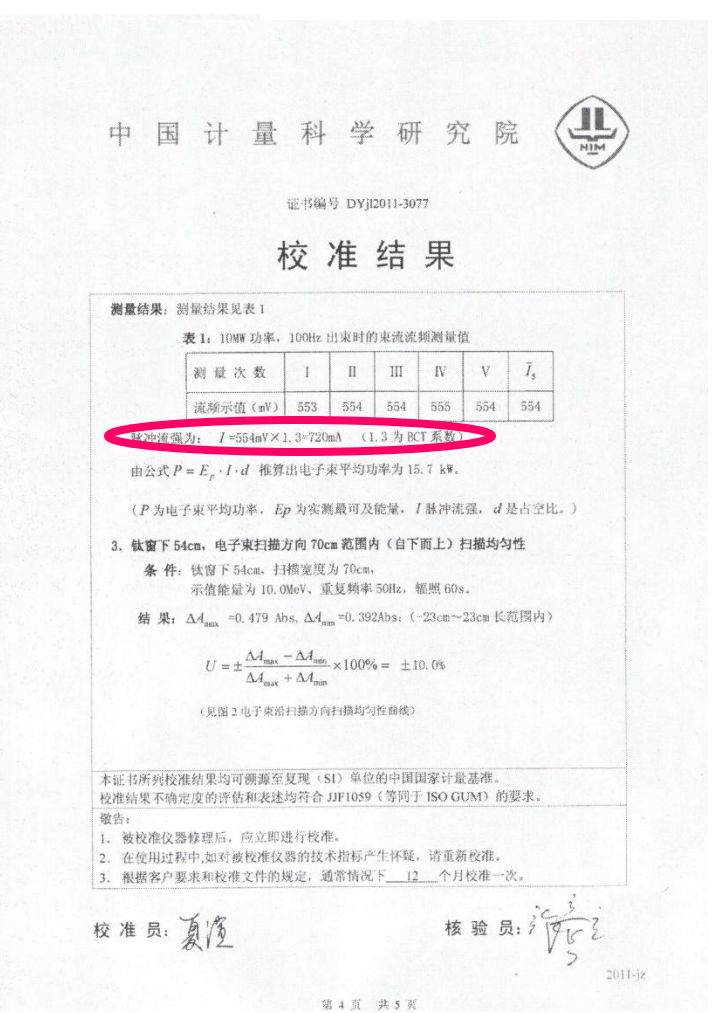

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校准结果

测量结果：测量结果见表 1

表 1：10MW 功率，100Hz 出束时的束流流频测量值

| 测量次数 | I | II | III | IV | V | $\bar{I}_5$ |
|---|---|---|---|---|---|---|
| 流频示值（mV） | 553 | 554 | 554 | 555 | 554 | 554 |

脉冲流强为： $I$=554mV×1.3=720mA （1.3 为 BCT 系数）

由公式 $P=E_p\cdot I\cdot d$ 推算出电子束平均功率为 15.7 kW。

（$P$ 为电子束平均功率，$Ep$ 为实测最可及能量，$I$ 脉冲流强，$d$ 是占空比。）

3. 钛窗下 54cm，电子束扫描方向 70cm 范围内（自下而上）扫描均匀性

条 件：钛窗下 54cm，扫描宽度为 70cm，

示值能量为 10.0MeV、重复频率 50Hz，辐照 60s。

结 果：$\Delta A_{max}$ =0.479 Abs, $\Delta A_{min}$ =0.392Abs;（-23cm～23cm 长范围内）

$$U=\pm\frac{\Delta A_{max}-\Delta A_{min}}{\Delta A_{max}+\Delta A_{min}}\times 100\%=\pm 10.0\%$$

（见图 2 电子束沿扫描方向扫描均匀性曲线）

本证书所列校准结果均可溯源至复现（SI）单位的中国国家计量基准。

校准结果不确定度的评估和表述均符合 JJF1059（等同于 ISO GUM）的要求。

敬告：

1. 被校准仪器修理后，应立即进行校准。
2. 在使用过程中,如对被校准仪器的技术指标产生怀疑，请重新校准。
3. 根据客户要求和校准文件的规定，通常情况下 12 个月校准一次。

校准员：　　核验员：

2011-jz

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# Summary

The high power 10MeV L-band electron linac is the first 40 kW irradiation linac developed and constructed in China. The formal beam testing was conducted by the National Institute of Metrology on December 26th, 2011, and the testing beam current is 720 mA with energy of 9.9MeV. If the machine works at a duty cycle of 0.7% as already processed, the beam power can reach 50 kW. The conversion efficiency $\eta$ from the RF power to the beam power is ~72%, a little bit lower than the theoretical prediction, which is partially because the RF power into the accelerating structure is lower than 10 MW, and/or the beam loss.

Now the machine has been put into operation at Wuxi EL PONT Company.

*Thanks for your attention,*
*any comments or suggestions,*
*please come to my post.*