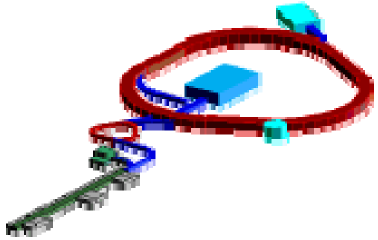


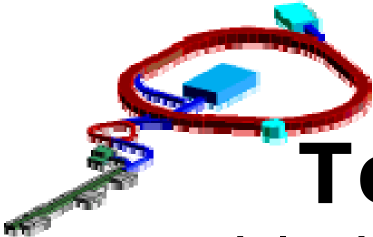
The Beam Collimator System of J-PARC Rapid Cycling Synchrotron

HB2008

presented by

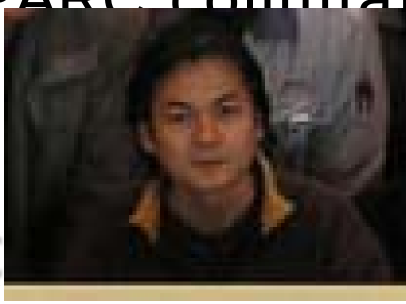
Kazami Yamamoto

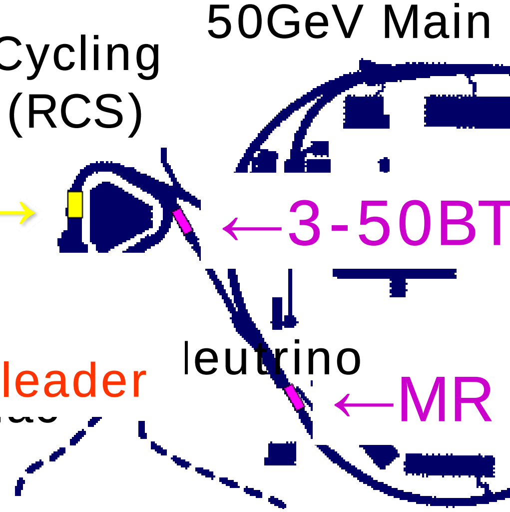
J-PARC Accelerator Physics Group



Topics in this presentation

- Title in the program is
  “J-PARC collimation system experience”





Dr. Ikegami

Linac commissioning leader

Dr. Koseki

MR commissioning leader

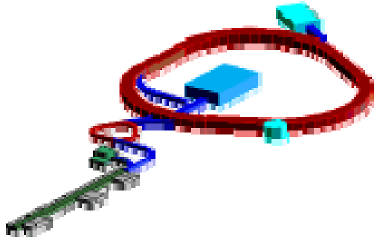
●L3BT scraper...Did not use since linac bea

● 3-50BT and MR collimator...Did not have commissioning have just started

Topic is RCS collimator

Outline of presentation

- Motivation
- Research and Development of RCS collimation system
- Results of first beam commissioning
- Summary



Motivation

The RCS ring is designed to deliver the 3GeV, 1MW pulsed proton beam to the spallation neutron target and the MR, hence our motivation is to achieve such high intense beam.

In order to achieve such high intense beam, the most important issue is to reduce and control(localize) the beam loss.

We have designed the beam collimator system for the purpose of the beam loss localization.

The design issues of the beam collimator system are:

1) High localization efficiency of the beam loss. (< 1W/m)

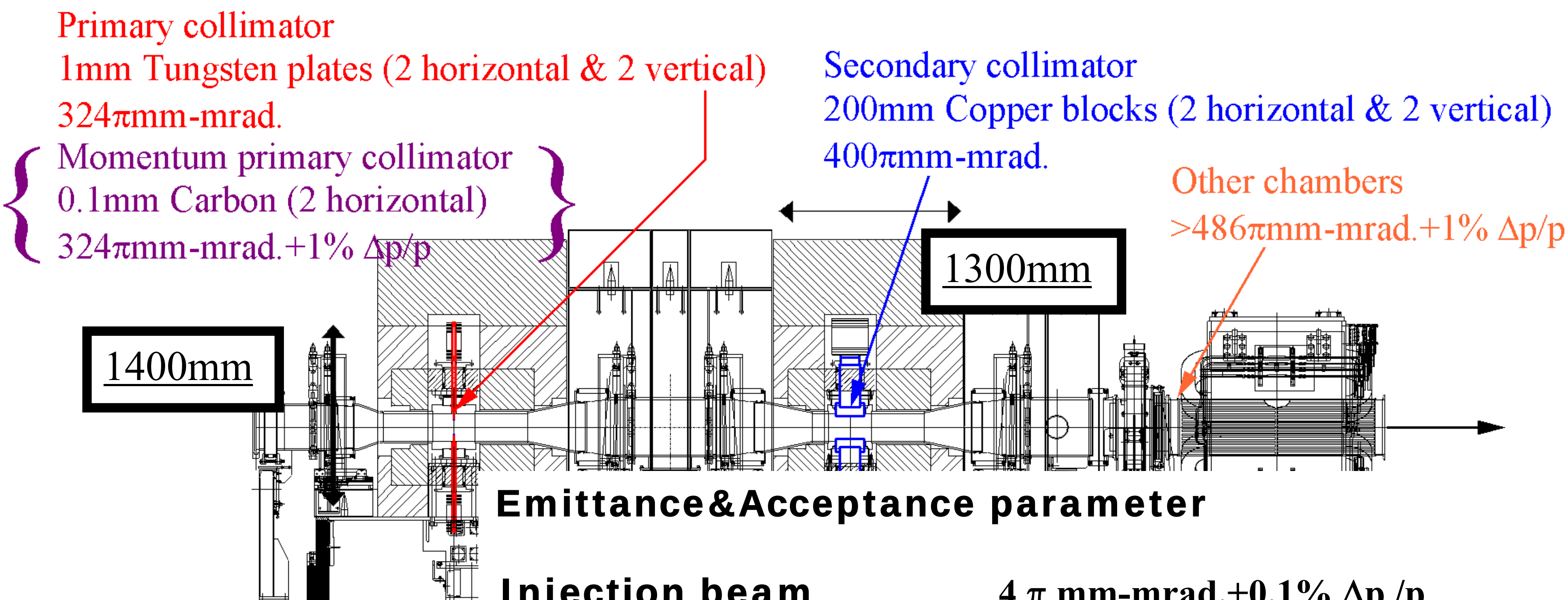
2) Enough shielding thickness to reduce the residual dose.

3) Easy maintenance system to save a labor close to the collimator.

4) Choice/development of the rad-hard components.

Construction of the RCS collimator

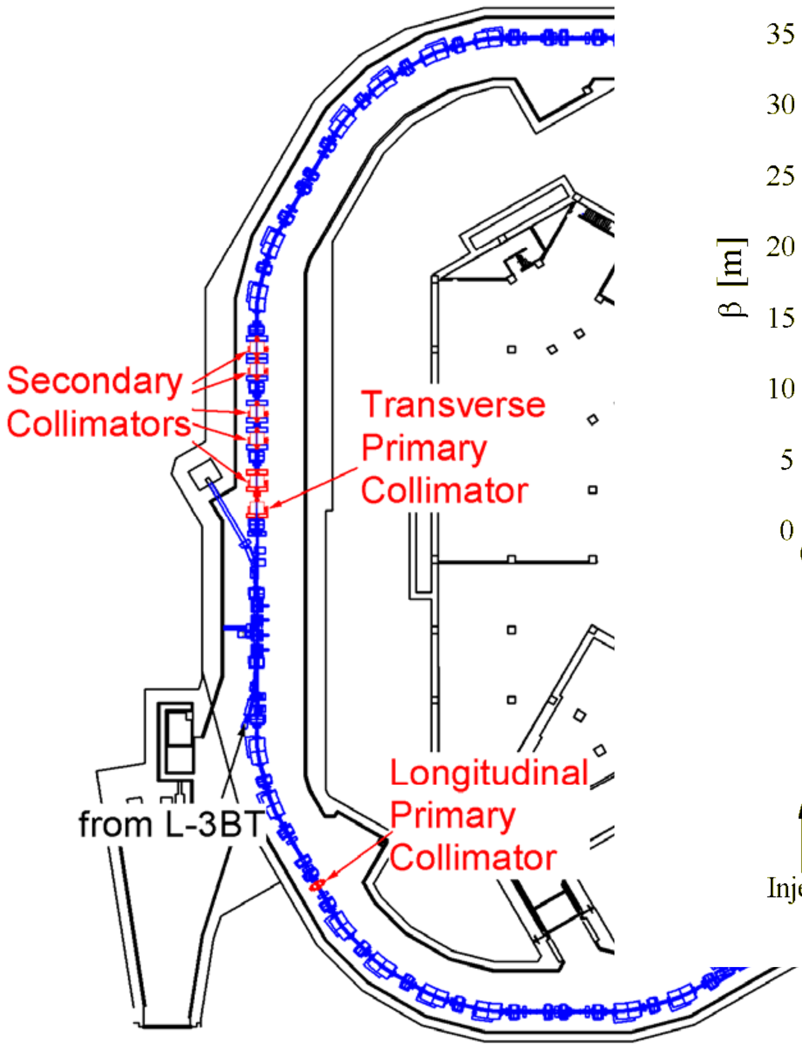
We use the two stage collimation system for the RCS collimator

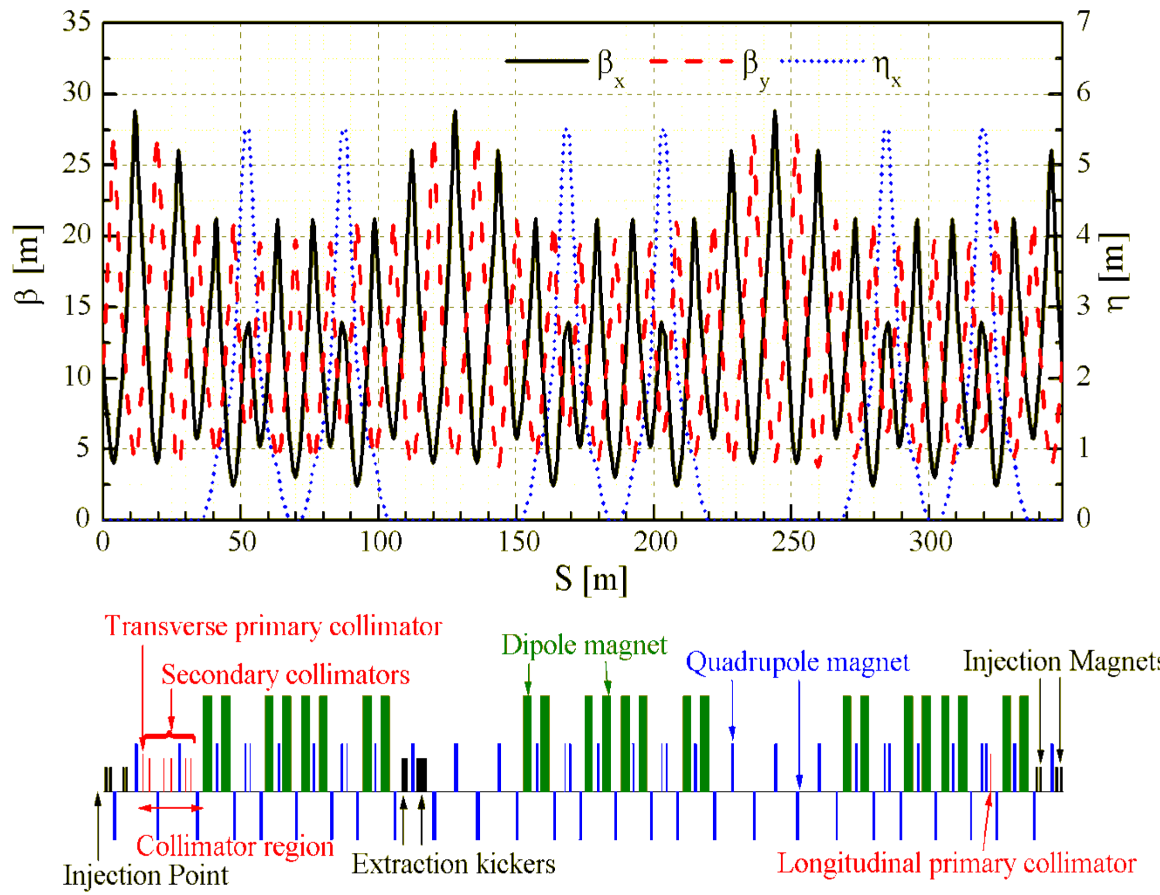


Emittance&Acceptance parameter

Injection beam	4 π mm-mrad.+0.1% Δp /p
Painting	216 π mm-mrad.
Pri. Collimator	324 π mm-mrad. +1% Δp /p
Sec. Collimator	400 π mm-mrad.
Physical acceptance	> 486 π mm-mrad. +1% Δp /p

RCS Parameters





3GeV RCS Twiss Parameter

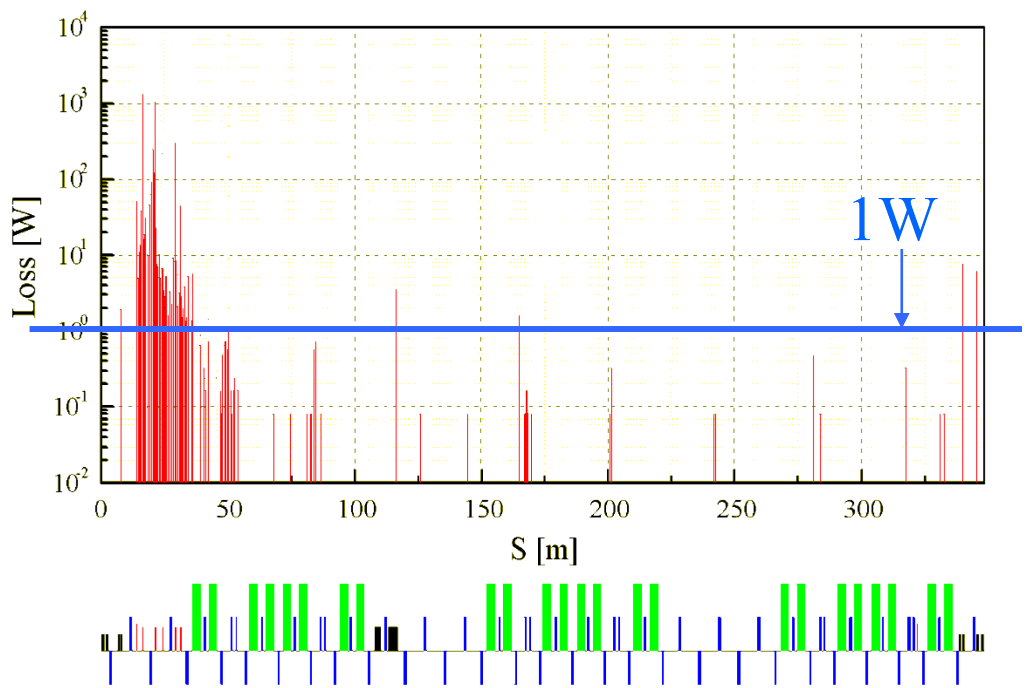
Beam loss distribution

●Calculated by STRUCT code (FNAL)
Linear transfer matrix
multiple scattering

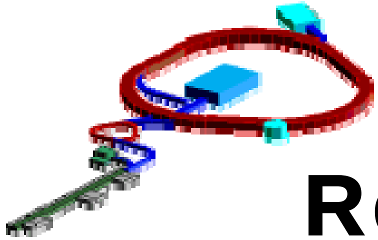
●Beam Halo Transverse:324 $<\varepsilon_{x,y}<$ 344 π mm-mrad. 4 kW were assumed

●Maximum loss point is first secondary collimator (1.2 kW).

●98 % lost particles were localized in the collimator region.
→1 W/m criteria was almost cleared!



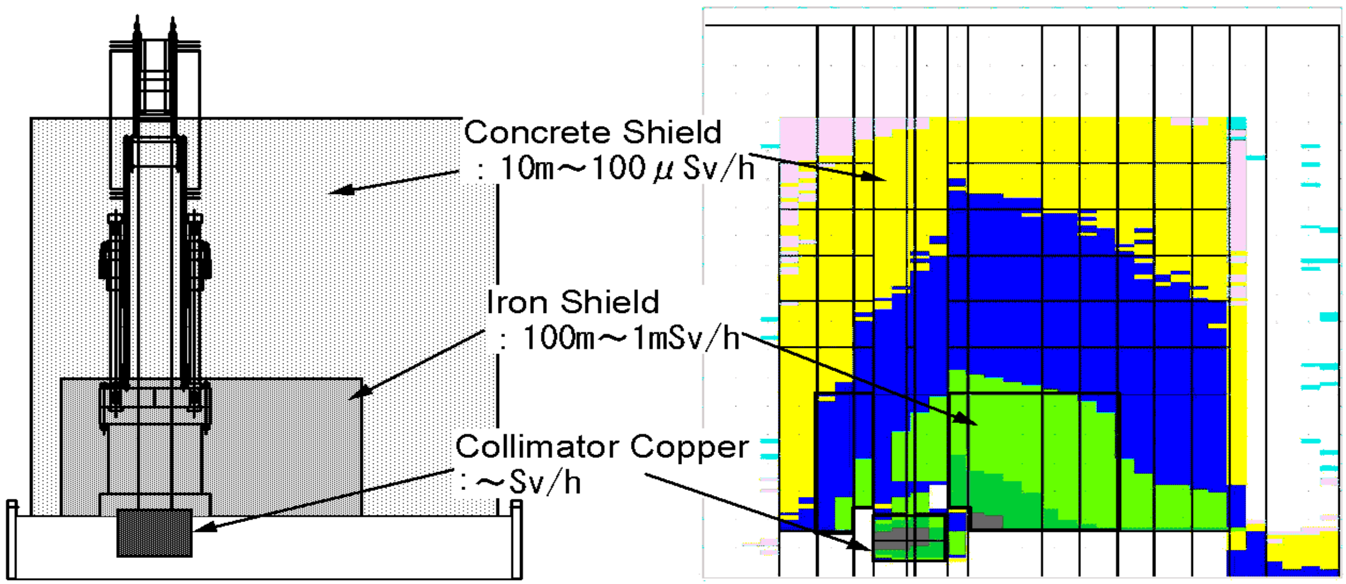
Results of Transverse Halo Collimation



Residual dose estimation

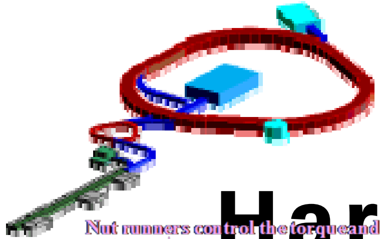
We designed the shielding wall for the sake of residual dose suppression less than 1W/m level (<1mSv/hr.)

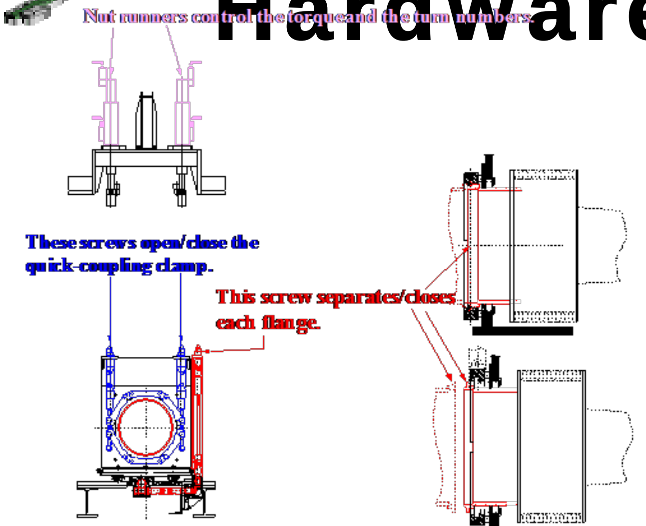
- ●Calculated by MARS code (FNAL)
- ●Covered with 300mm inner iron and 500mm outer concrete
- ●Assumed that 400MeV, 1.2kW loss is localized on the secondary collimator
- ●Residual dose rate after 1 month irradiation/1 day cooling

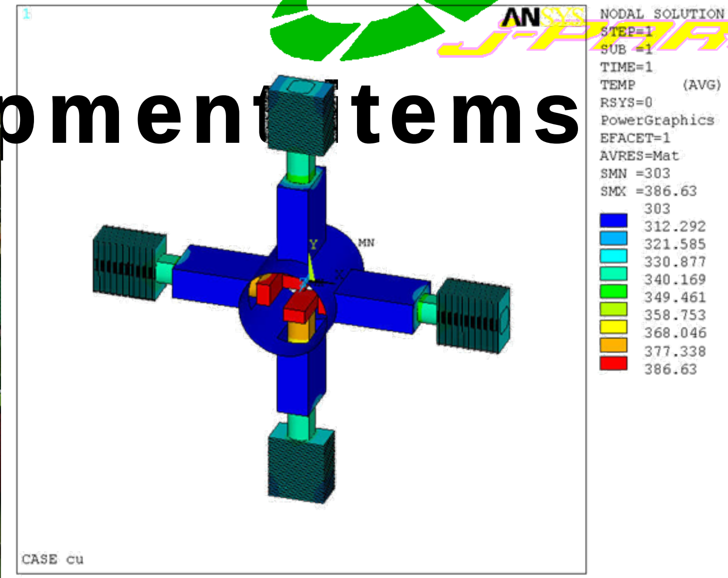


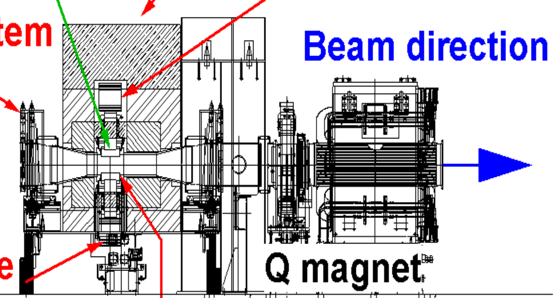
Outside of shield: ～handreds of μSv/h=1 W/m order

Hardware development items

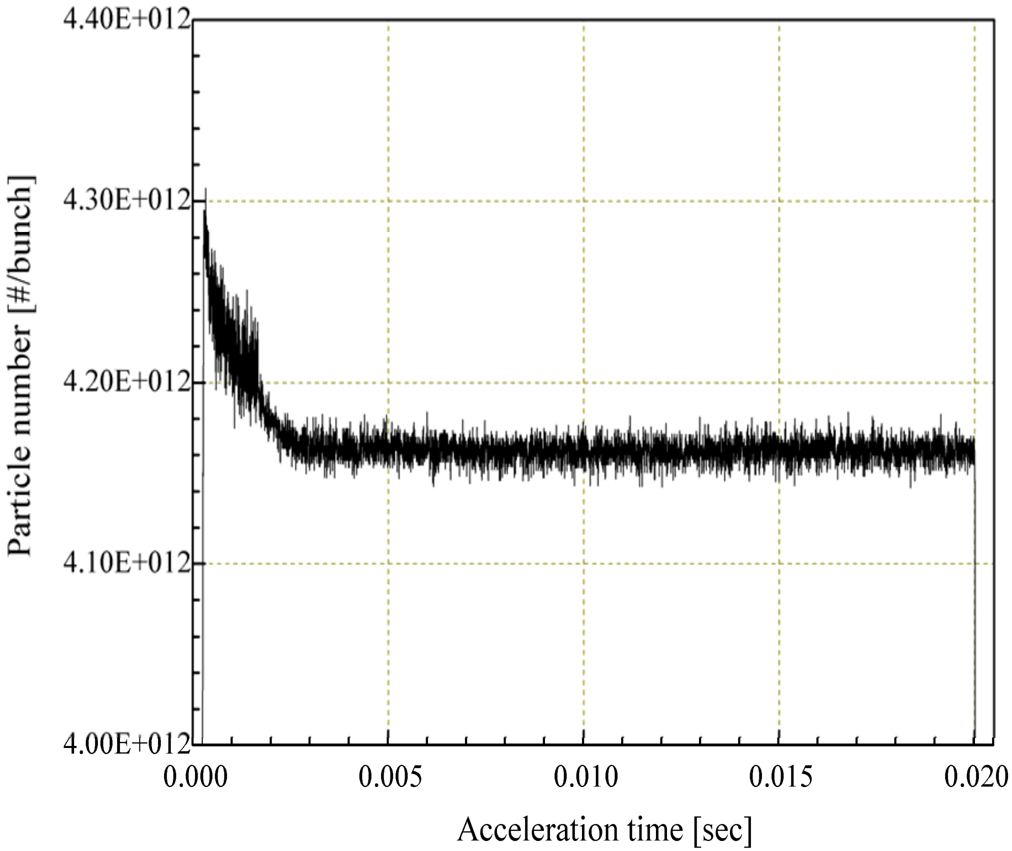






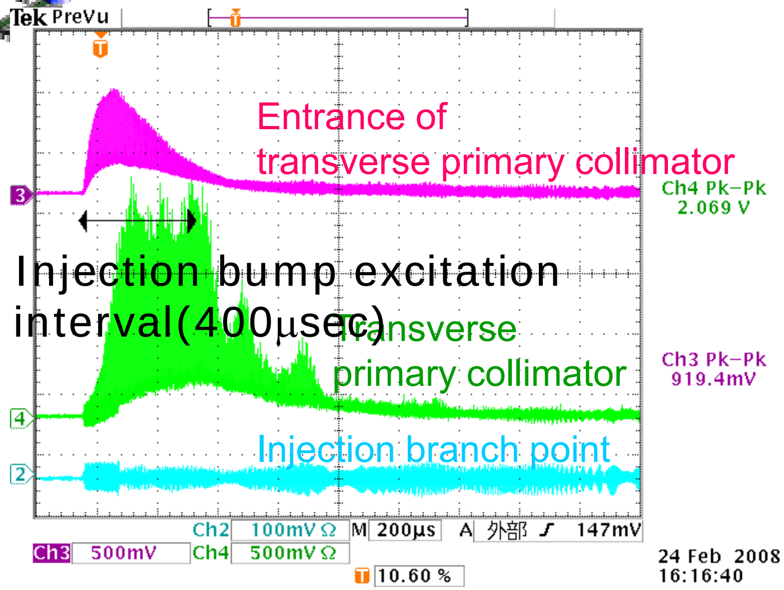


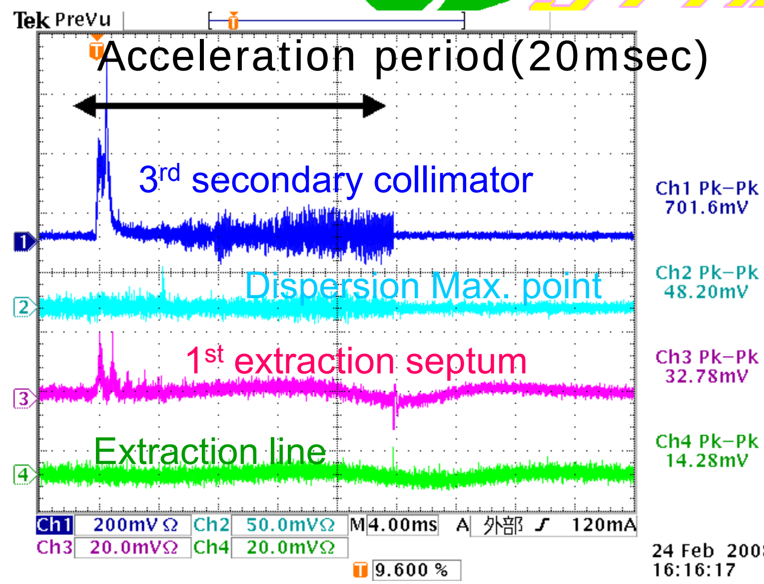
Results of first beam commissioning

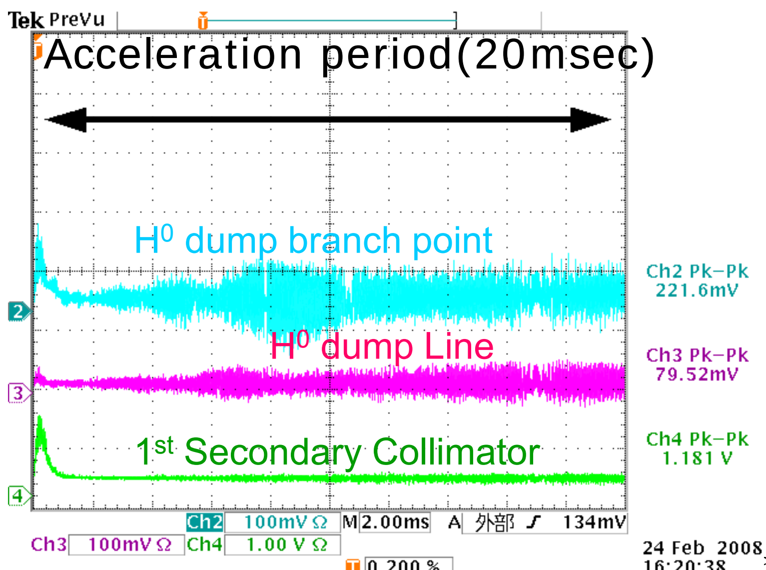


- The total beam power was restricted by the capacity of extraction dump(Capacity is an average of 4kW an hour).
- We usually use a few kW beam for continuous beam commissioning, but only few minutes we can accelerate high intensity beam (more than 100kW)
- In this case, the number of particles per bunch correspond to more than 50kW ($4.3x10^{12}$) was accelerated. The painting bump did not excited and all injection beam have entered into the ring center orbit in piles.
- The loss during the acceleration period was 3.4%.

Beam loss point







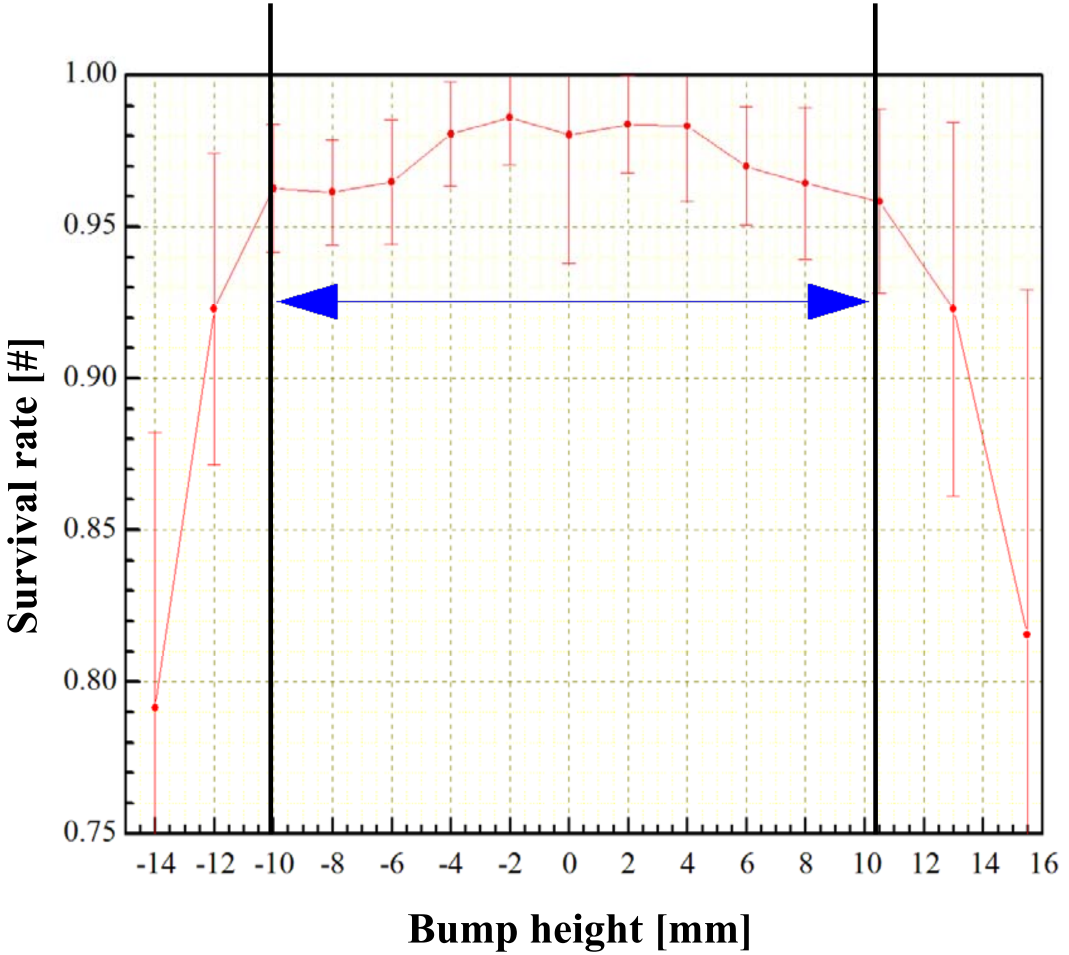
BLM signals appeared at

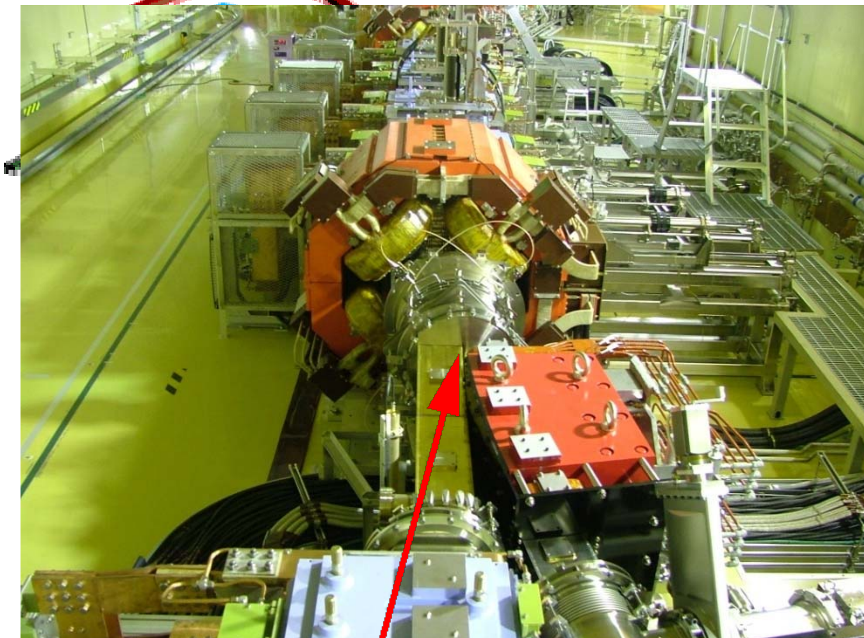
- Entrance of transverse primary collimator chamber
- H0 dump branch point
- Transverse collimators
- 1st extraction septum

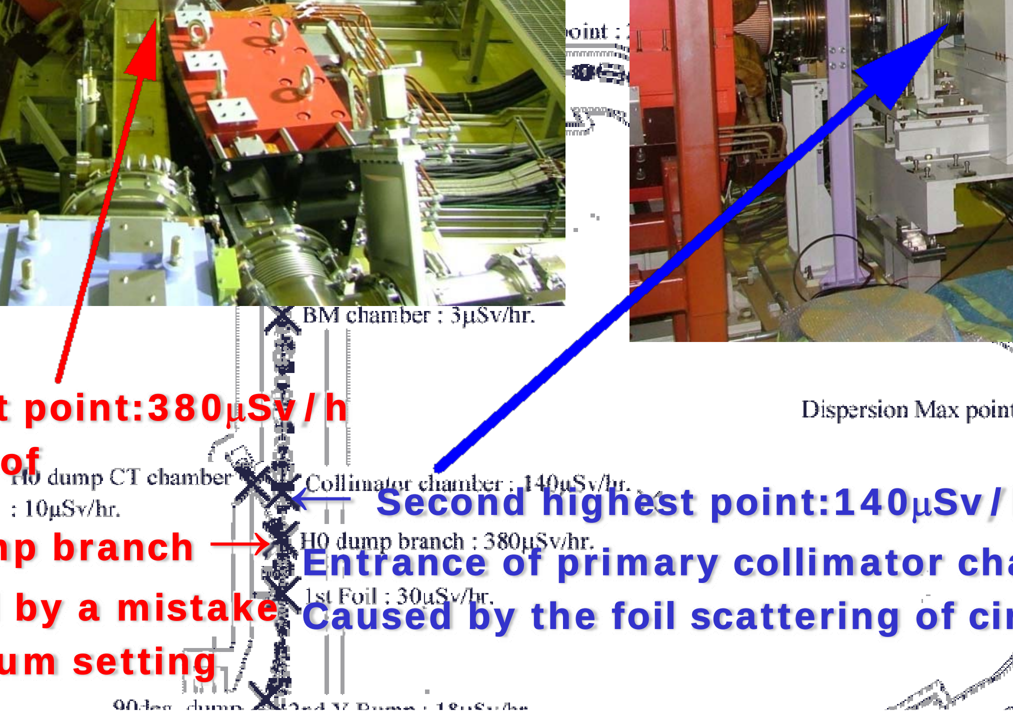
It is remarkable that the BLM of each collimator is put on the outside of shielding, those are further than the other BLMs, nevertheless signals were much larger !!

Actual collimator acceptance

- We investigated the actual transverse primary collimator acceptance.
- In this study, we shifted the injection bump height and the linac beam came into the outside of beam center.(Offset injection)
- Then, we measured the survival rate by the wall current monitor.
- The beam current suddenly decreased at 10mm bump height and it corresponded to about 324πmm-mrad.
- The position of the transverse primary collimator was approximately right.







Highest point:380μSv/h
Crotch of
H0 dump branch
Caused by a mistake
of septum setting

Second highest point:140μSv/
Entrance of primary collimator cha
Caused by the foil scattering of cir

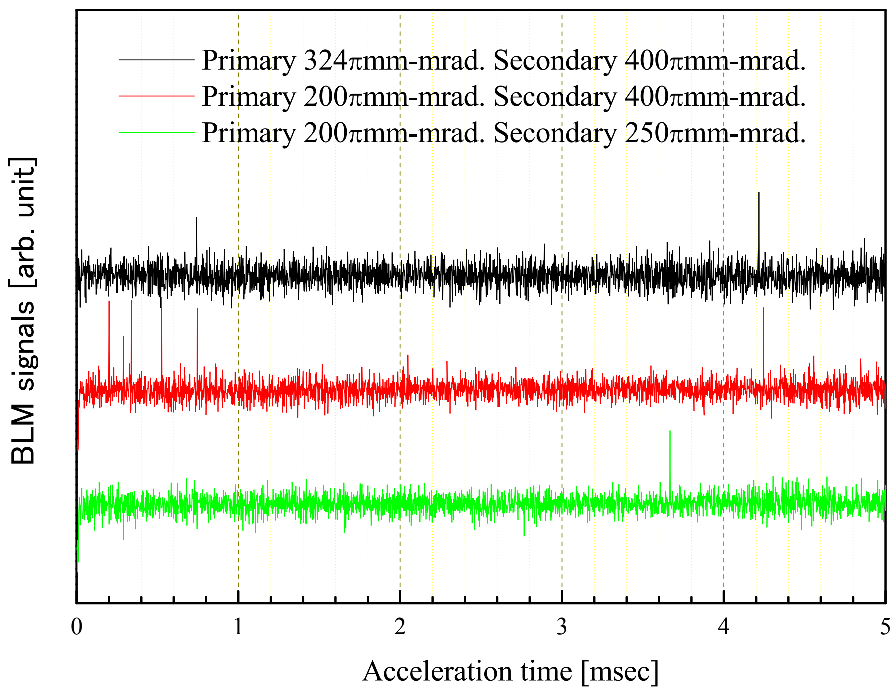
Practically, each collimator would have much larger residual dose. but we could not measure the inside of collimator shielding. We could detect only the residual dose on the outside of shielding and It is a background level.

Beam collimator system has good performance!!

Does the system perform as expected? Did the simulations/calculations performed during the design stage accurately predict the actual performance?

→For the moment, We think our collimation system has enough performance according to above reason.

Acceptance ratio of primary and secondary



BLM signals of dispersion maximum point after collimator region

Black
:Designed acceptance
Pri. 324π : Sec. 400π ≒ 4:5

Red
:"Unbalanced" acceptance ratio
Pri. 200π : Sec. 400π = 1:2

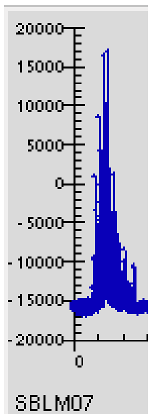
Green
:Design acceptance ratio
Pri. 200π : Sec. 250π = 4:5

→Unbalanced acceptance ratio caused leakage loss from collimator region

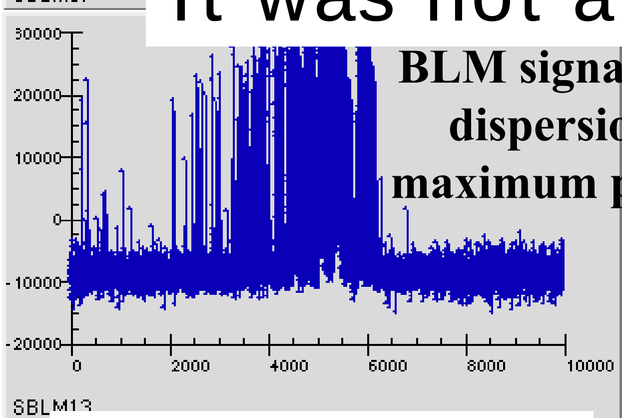
Designed acceptance has enough performance

Longitudinal collimation

- However, the collimation system did not work as our expectation in some respects.

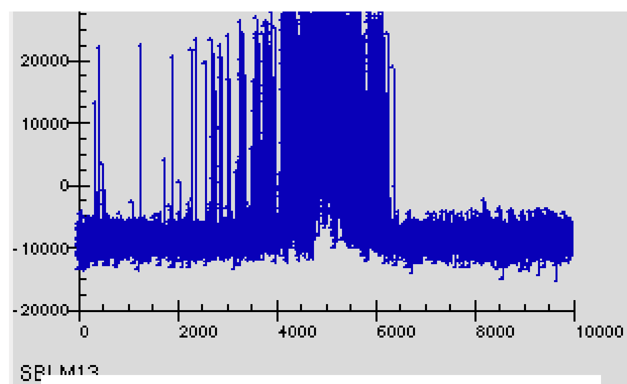


●Fortunately, at present there was no longitudinal halo in usual operation because of good performance of the ring RF system and the Linac chopper.
It was not a problem for the moment.



BLM signals of dispersion maximum point

Not insert the longitudinal collimator



Insert the longitudinal collimator

were lead on the transverse secondary collimators, but BLM signal of the dispersion maximum point was scarcely reduced.

What are the major limitations in performance? Were they known in the design stage?

- We did not reach the technical limitation because now limitation is caused by the dump capacity.
- High power(more than 100kW) test will be carried out next December and major limitation will become clear.

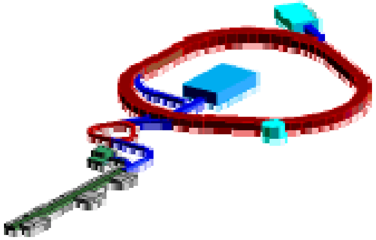
If someone were to begin now designing the same type of system for a similar machine, what is the one piece of advice that you would give them?

- The most important issue is measures for high radiation.

(Easy maintenance system and choice/development of high durability component)

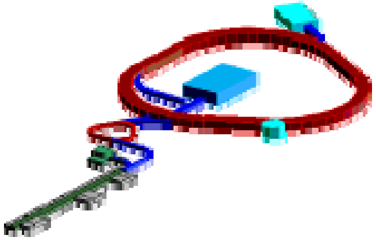
- you should make effort to reduce the source of longitudinal halo.

(Longitudinal collimation is difficult. Reinforce not the longitudinal collimator but the ring RF system or linac chopper system)



Summary

- We optimized the collimation system for J-PARC RCS and developed the collimator components as the requirements.
- Our collimation system had enough performance during the first commissioning period.



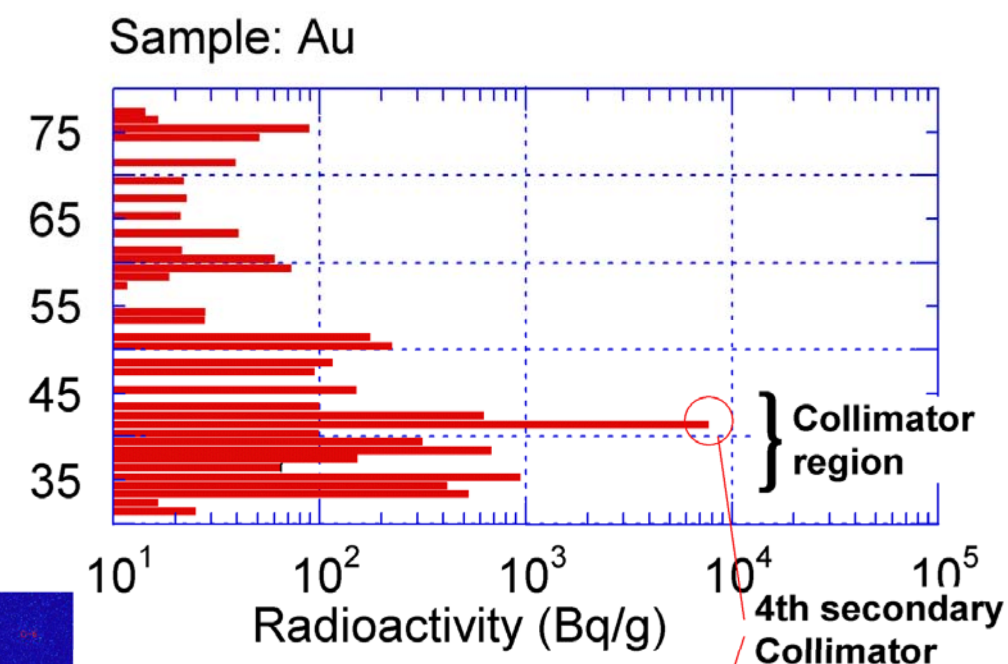
Thank you for your attention

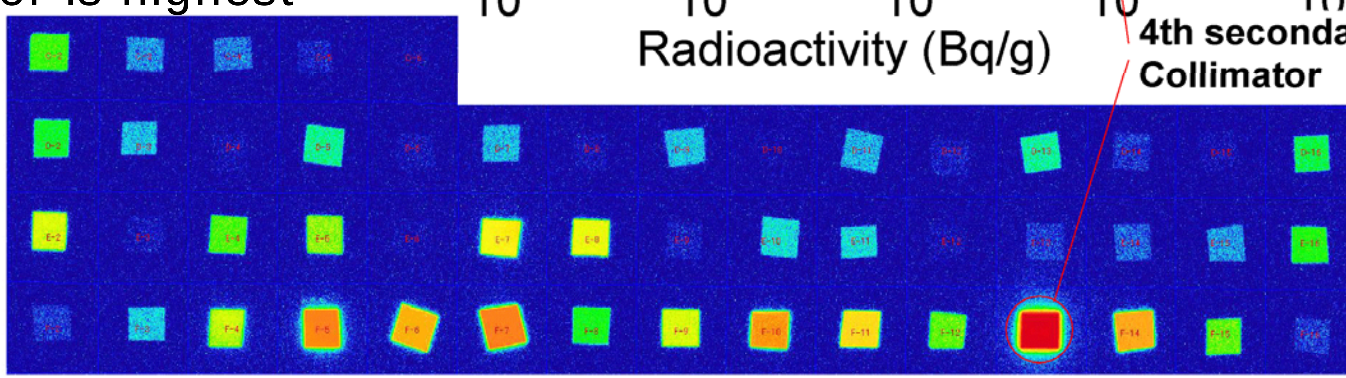
Radio-activation sample

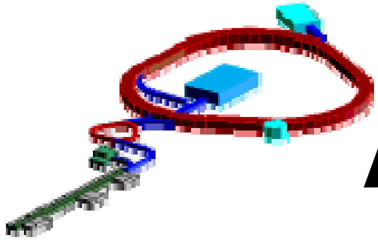
We put many gold samples on the vacuum chamber, in the shielding walls of collimators, or on the tunnel wall.

The most radio-activated point is 4^{th} secondary collimator.

On the other hand, the calculation indicated 1st secondary collimator is highest loss point.







Acceptance optimize

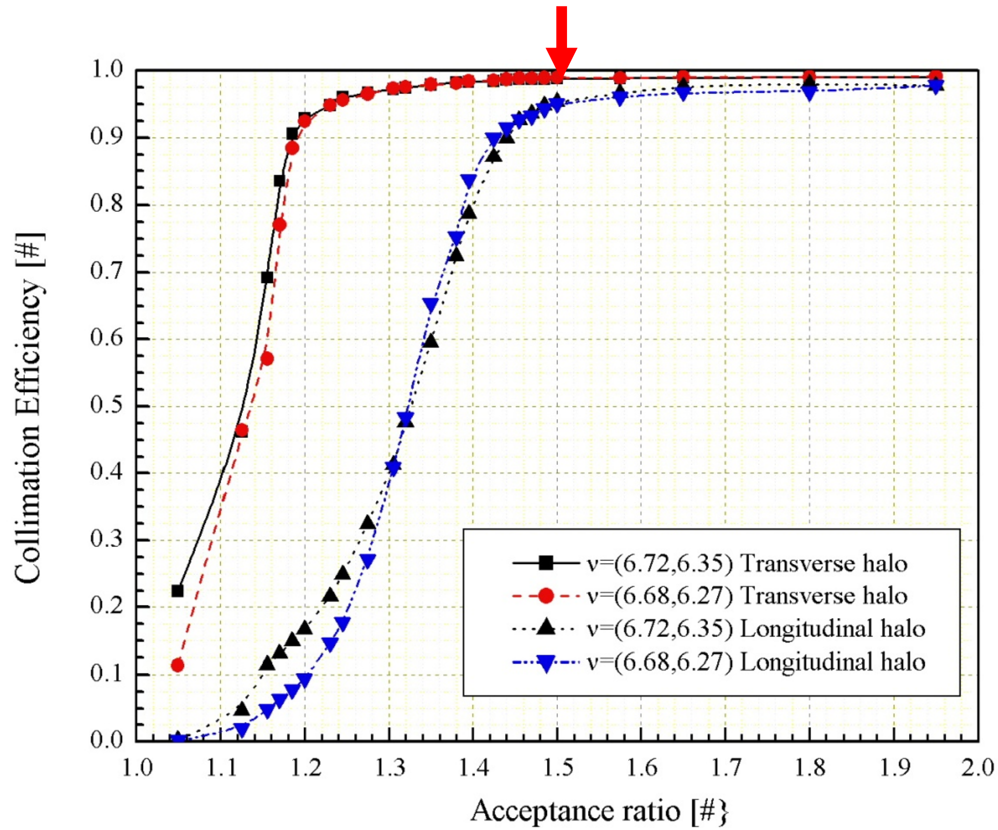
●Collimation efficiency

$$\frac{\text{Lost particles in the collimator region}}{\text{All lost particles}}$$

●Acceptance ratio

$$\frac{\text{Physical acceptance } [\pi\text{mm-mrad.}]}{\text{Collimator acceptance } [\pi\text{mm-mrad.}]}$$

Design Value

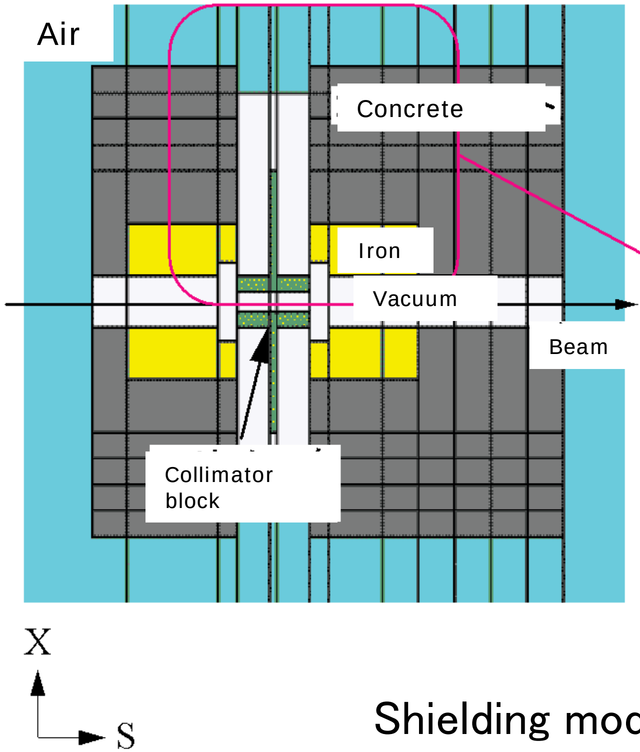


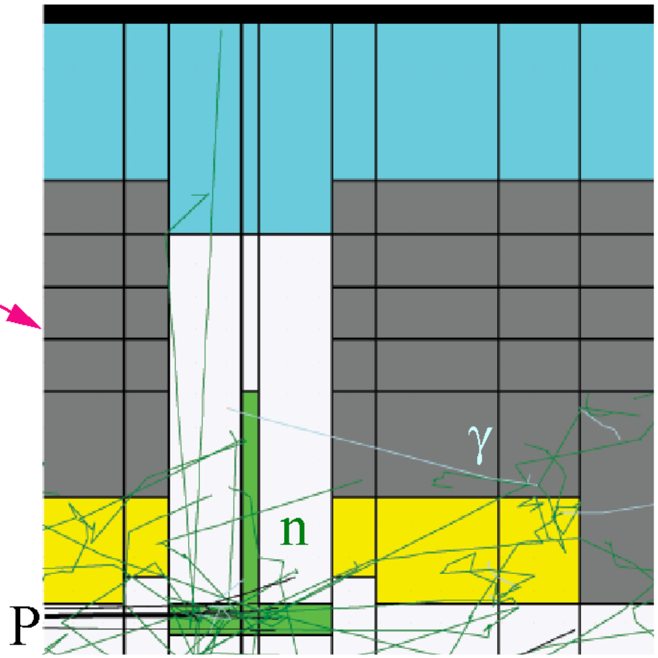
Collimation efficiency dependence on the collimator acceptance

Residual dose estimation

Shielding design for the sake of residual dose suppression under 1W/m level (<1mSv/hr.)

- Calculated by MARS code (FNAL)
- Covered with 300mm inner iron and 500mm outer concrete
- Assumed that 400MeV, 1.2kW loss is localized on the secondary collimator



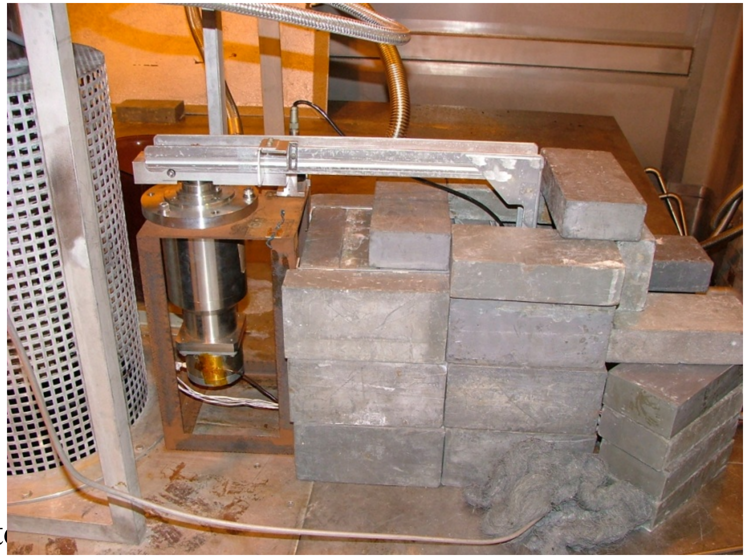


Shielding model and particle trajectories

Development of Rad-Hard Components

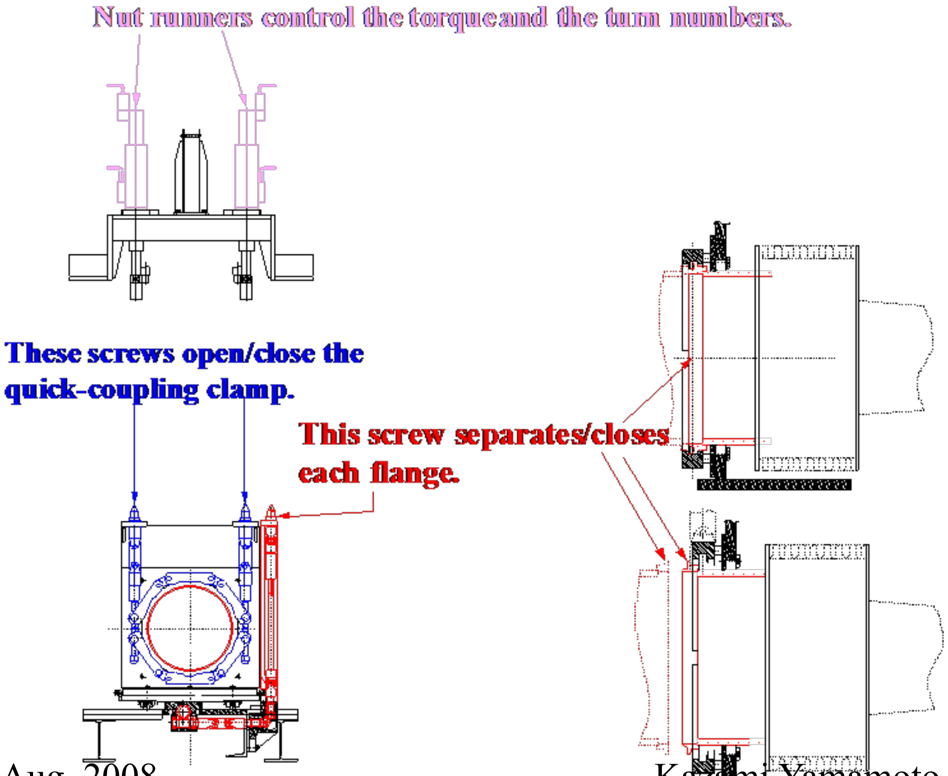
Gamma-ray irradiation experiment of the collimator components (motors, cables, connectors) were performed by a Co-60 gamma-ray irradiation facility.

Established high rad-hard components, especially the stepper motor had high durability over 100MGy gamma-ray irradiation.



Remote clamp system

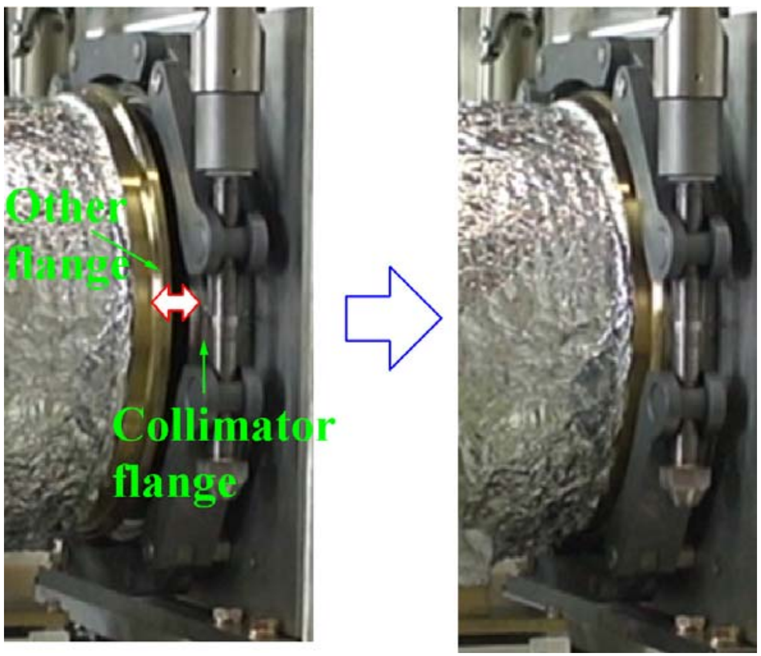
- We developed the remote clamp handling system to reduce the radiation exposure during the maintenance procedure.
- We can maintain several meter away from the collimator chamber by using the nutrunners and the remote clamp handling system.
- First we connect the nutrunners on the screws which move its frange and clamp.



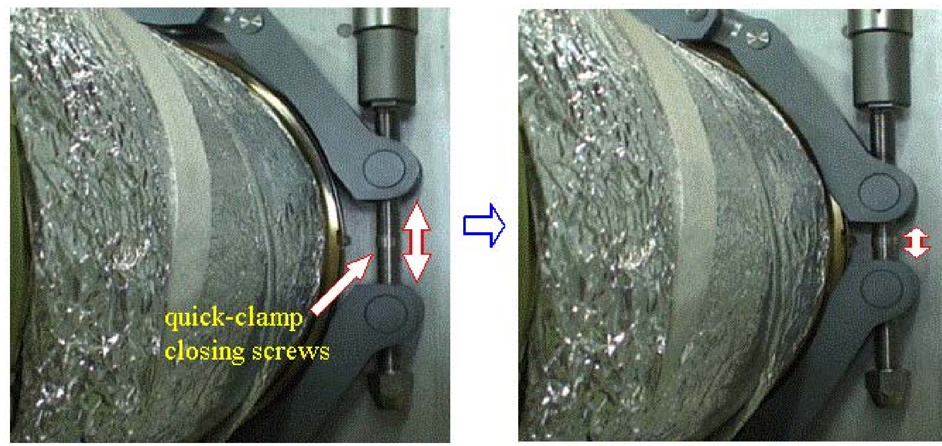
Remote clamp system

● The nutrunners control the separation of each flange and closing torque of quick-coupling clamp.

○Flange movement



○clamp closing



● 1mm positioning error of flange can be corrected by the inner guide.

● Finally we connected all remote clamps less than $5*10^{-11}$ Pa·m³/sec He leak rate.

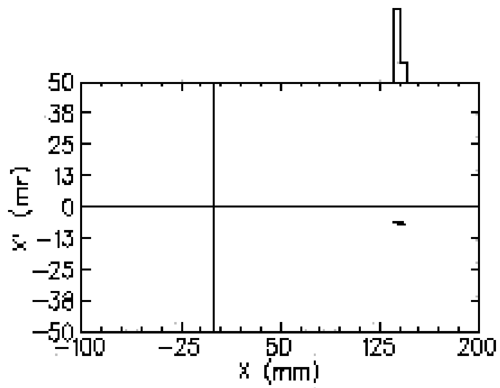
Results of first beam commissioning

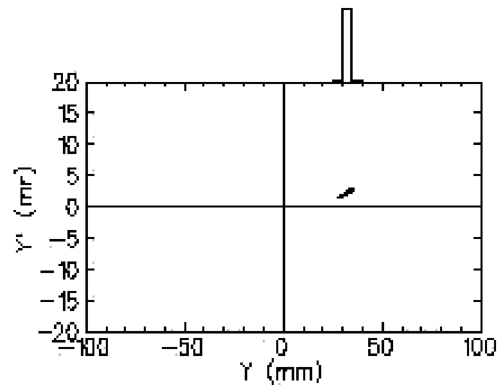
- During the first commissioning, we set the all collimators as designed acceptance.

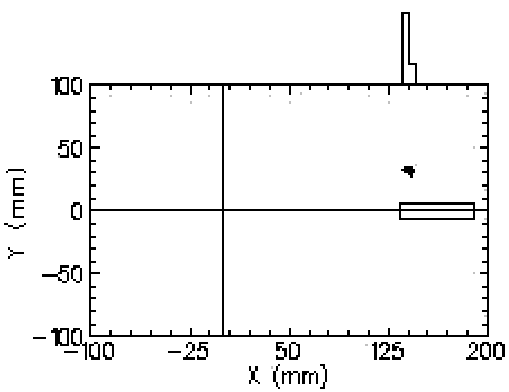
(**Pri. Collimator** 324 π mm-mrad. +1% $\Delta p/p$, **Sec. Collimator** 400 π mm-mrad.)

- In this condition, the beam loss monitor signals appeared at next point:

Beam Tracking with Space Charge

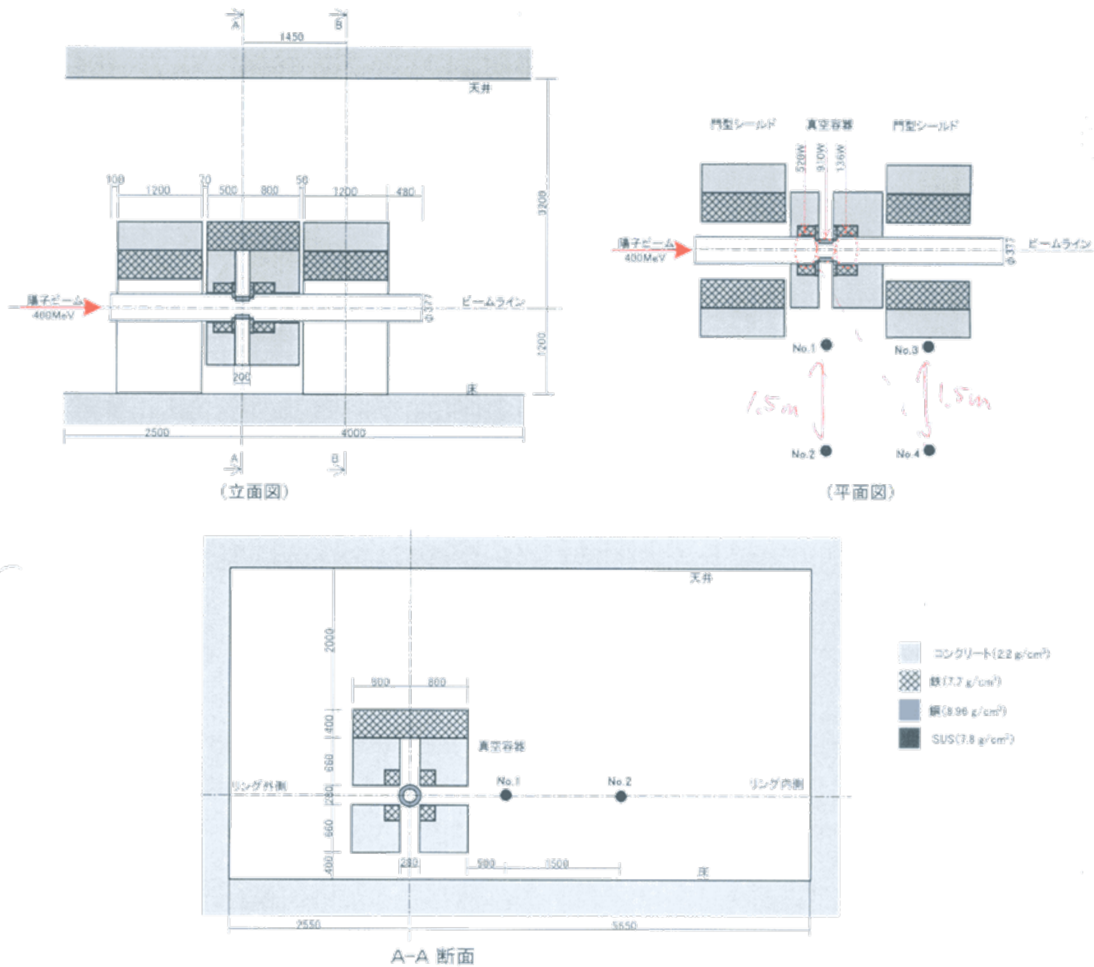






- Calculated by ACCSIM code (TRIUMF)
- Particle number corresponded to 1MW beam power.
- Include painting injection process.

Residual dose estimation



·Calculation result of *PHITS,DCHAIN-SP and QAD-CGGP2 codes*

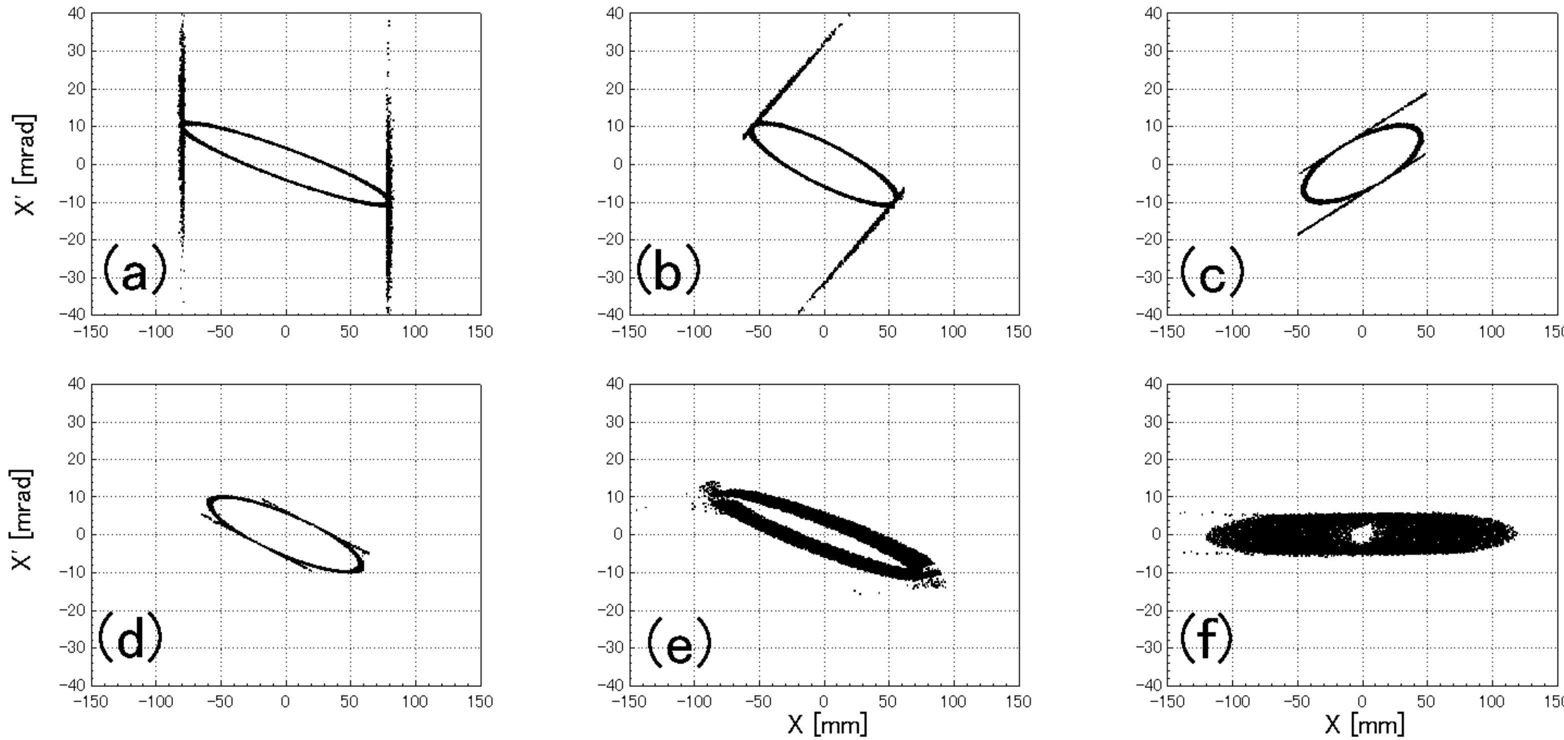
·400MeV,1.2kW loss at first secondary collimator

· Calculation include the effect of all activated materials (Collimators, shields,chambers and tunnel walls)

· Residual dose rate after 1 year irradiation/1 week cooling

at point No.1 : 15.9mSv/hr.
at point No.2 : 2.78mSv/hr.
at point No.3 : 36.5mSv/hr.
at point No.4 : 189mSv/hr.

位相空間内での粒子の運動

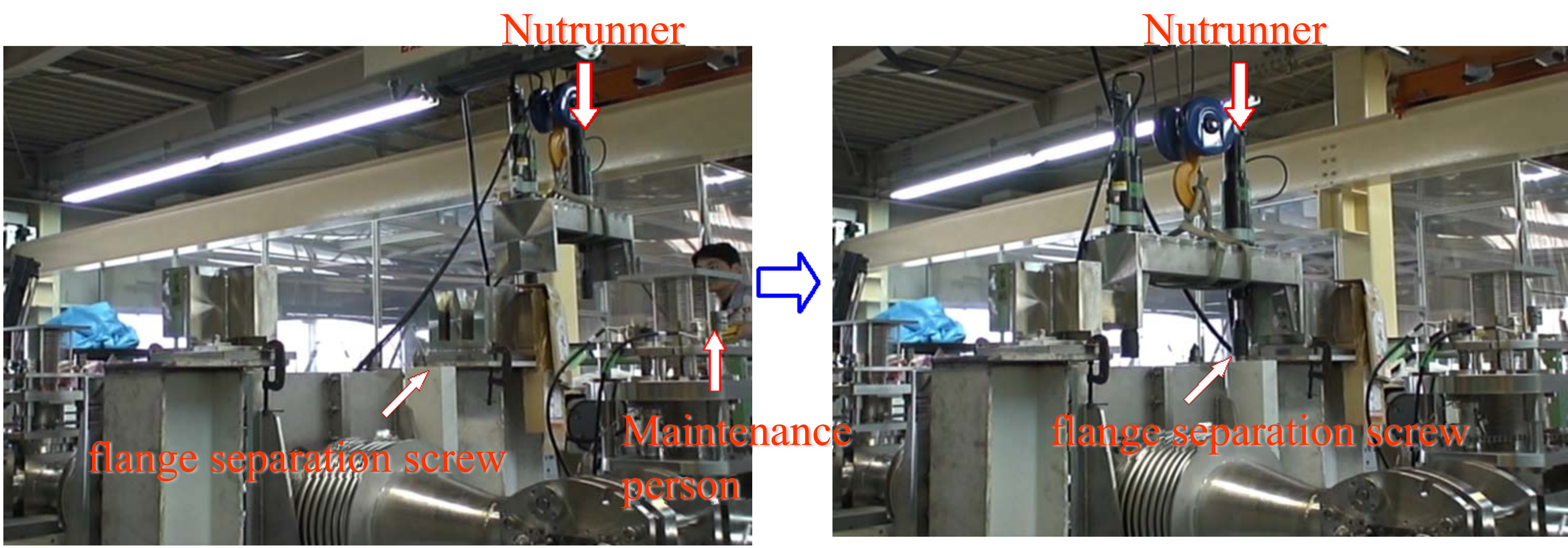


(a) プライマリーコリメータ直後　(b)(c)(d)一台目、三台目、五台目のセカンダリーコリメータ直後
(e) コリメータ直後の偏向電磁石二台通過後　(f) コリメータ後最初のディスパージョン最大位置

ディスパージョンのある領域で、プライマリーコリメータで受けた散乱角が小さいがモメンタムは大きく失った粒子がロス→コリメーション効率が100 %にならない

Remote clamp system ②

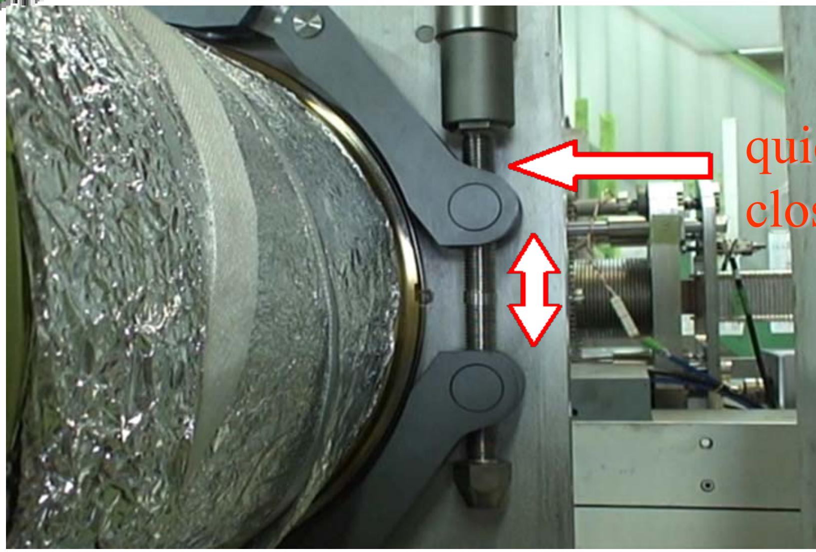
First step : We set the nutrunner on the flange separation screw from several meter away from the collimator chamber.



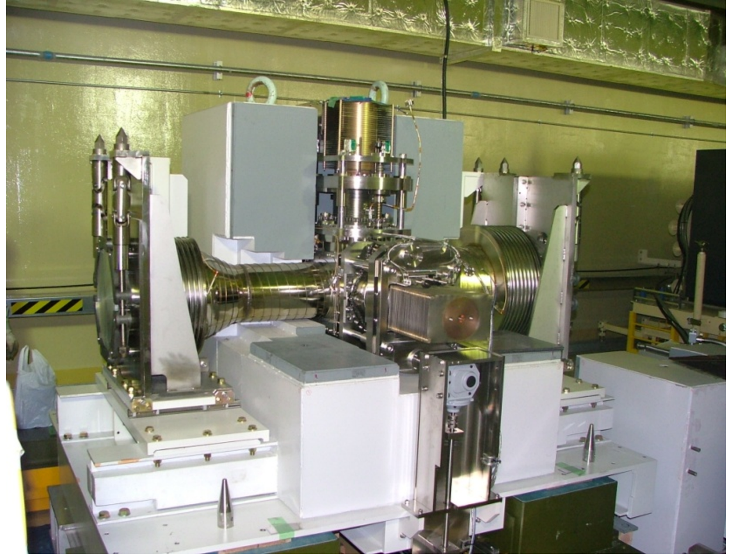
Remote clamp system ③

Second step : The nutrunner close the separation of each flange.

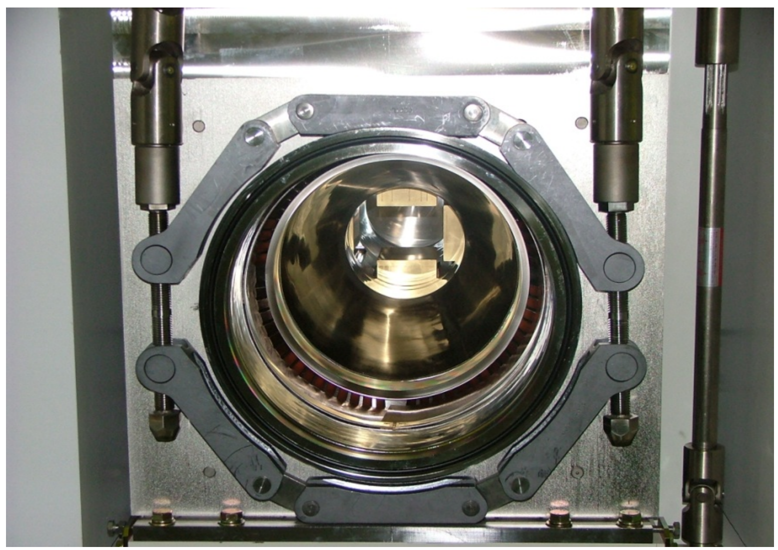
Remote clamp system ⑤



Fourth step : The nutrunner control the closing torque of quick-coupling clamp.



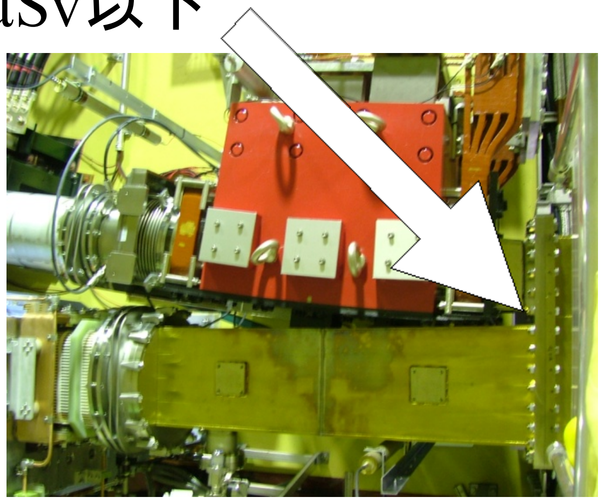
Inside of the beam collimator shielding.



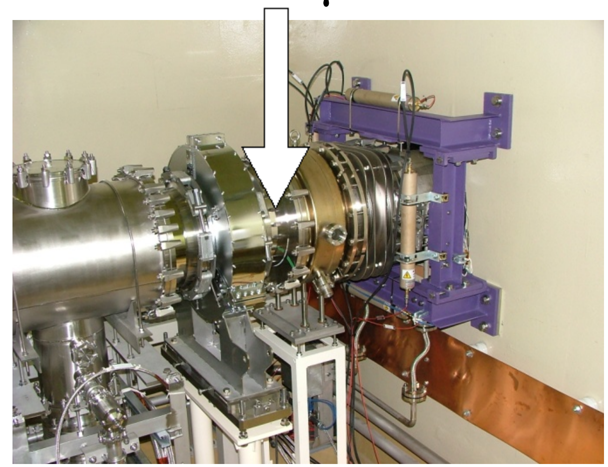
Inside of the collimator chamber.
4 absorbers were coated with TiN.

12/7　再測定①

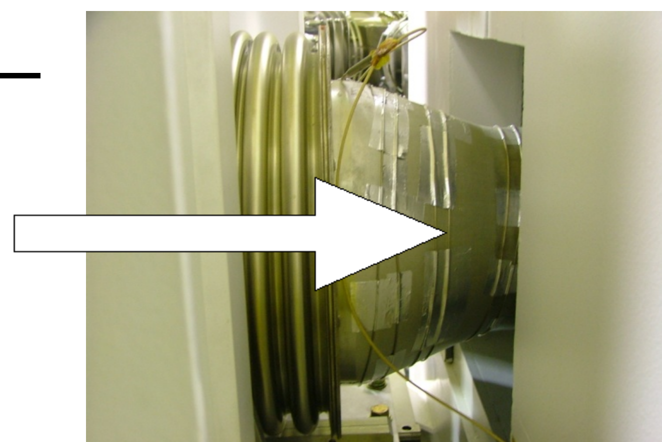
入射合流ダクト股部分
10μSv以下



PPS-CT下流側
25～30μSv（上下左右）

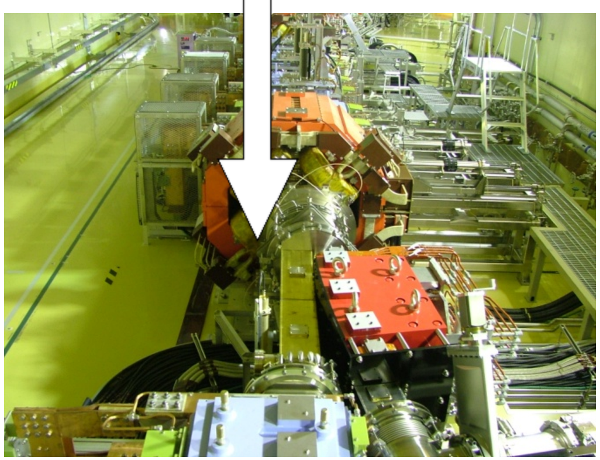


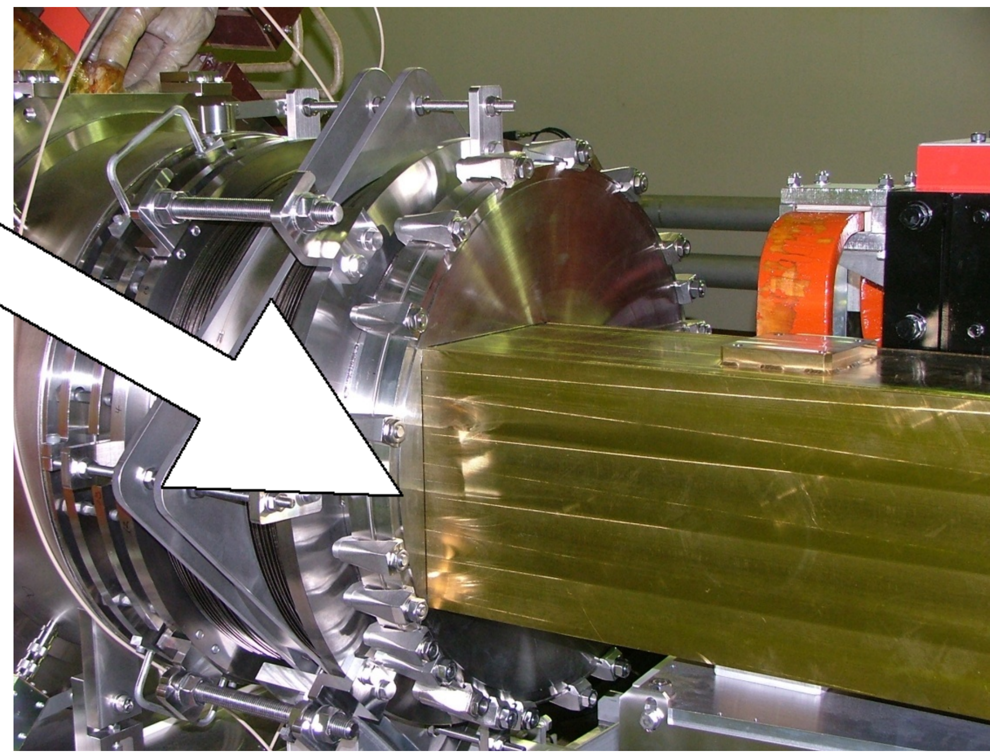
コリメータ先頭チャンバー
内周：30μSv
外周：100μSv
上下：～15μSv



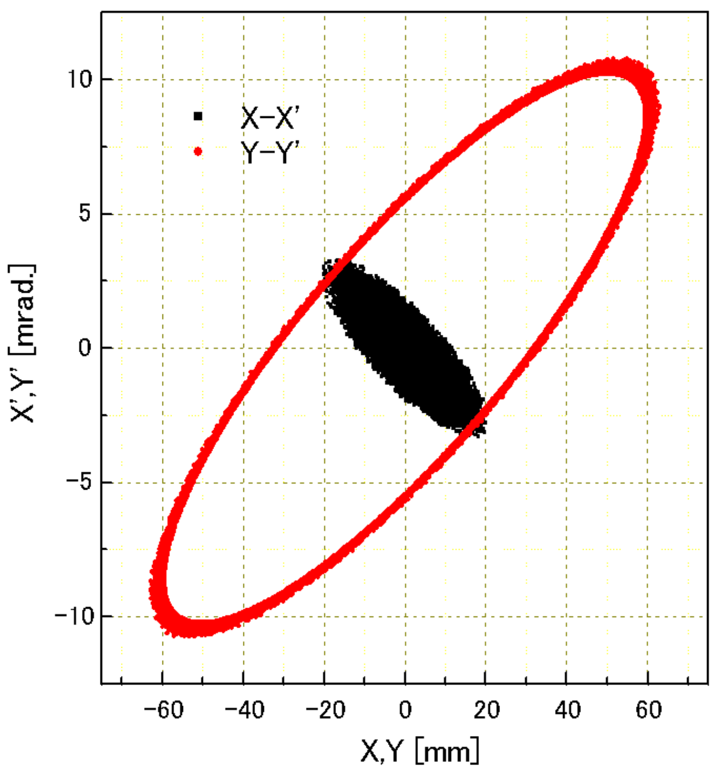
12/7　再測定②

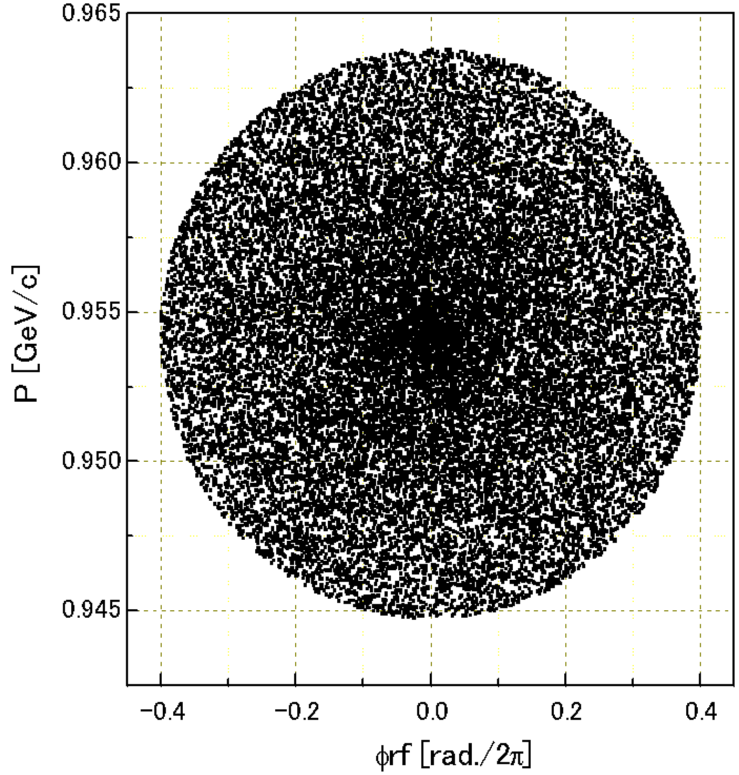
HOダンプ分岐チャンバー
内周：20μSv
上下外周
：～10μSv





トラッキング初期条件



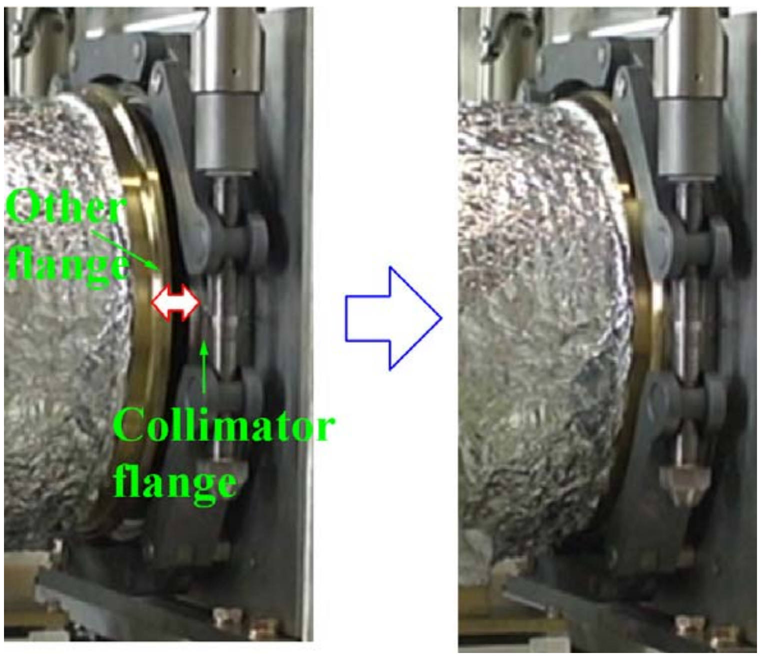


●ビームハロー

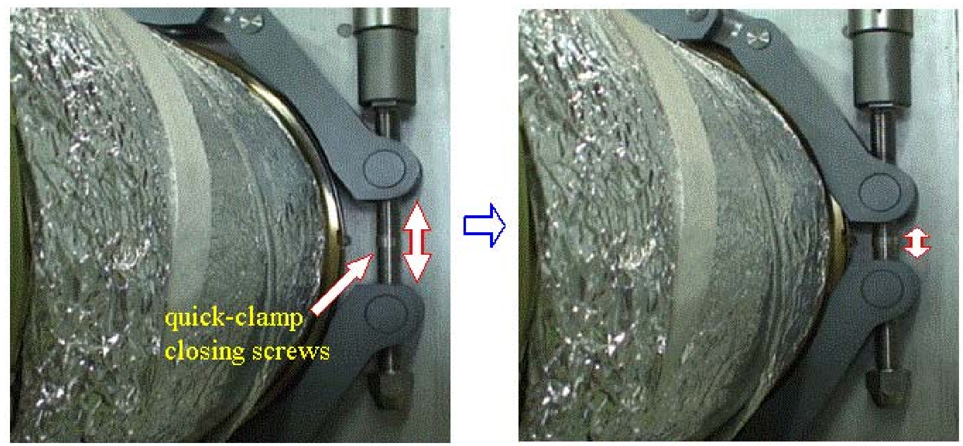
Transverse:344 > $\varepsilon_{x,y}$ > 324 π mm-mrad. 4 k Wを仮定

リモートクランプシステムの開発②

〇フランジ接続動作



〇クランプ締結動作



作業精度を考慮して、フランジ面間が1mmずらした状態での取り付け
→フランジ内部に取り付けられたガイドによって接続時に修正。5.0×10^{-11}Pa・m^3/sec以下のリーク量 **で締結可能**

ガンマ線照射試験

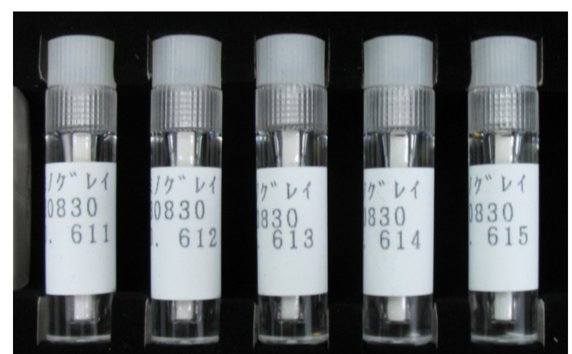
日本原子力研究開発機構　高崎量子応用研究所のガンマ線照射施設　第1照射棟Co60線源を用いたγ線照射試験

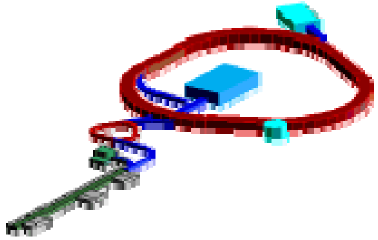
コリメータで使用する機器の耐放射線量

MARSでの評価→100MSv以上

γ線換算で100MGy以上を目標

照射線量は、アラニン線量計中のラジカル量を電子スピン共鳴(ESR)スペクトルで測定することで求められる。





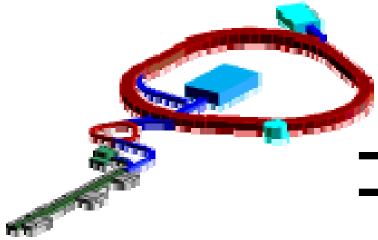
コリメータの真空処理

加速器での真空の必要性

・残留ガスとの衝突を繰り返すことによるビームロス
・それらビームロスやイオン化した残留ガスが真空容器表面に衝突し、 壁面からガスが放出されさらなる真空度の悪化
・真空度が悪いと真空機器の寿命を縮めメンテナンスの頻度が上昇
・残留ガスのイオン化によって発生した電子が増幅し不安定性が発生

↓

コリメータブロックの高温真空脱ガス処理
表面へのTiNコーティングとその特性試験



コリメータ銅ブロックのプリベーク

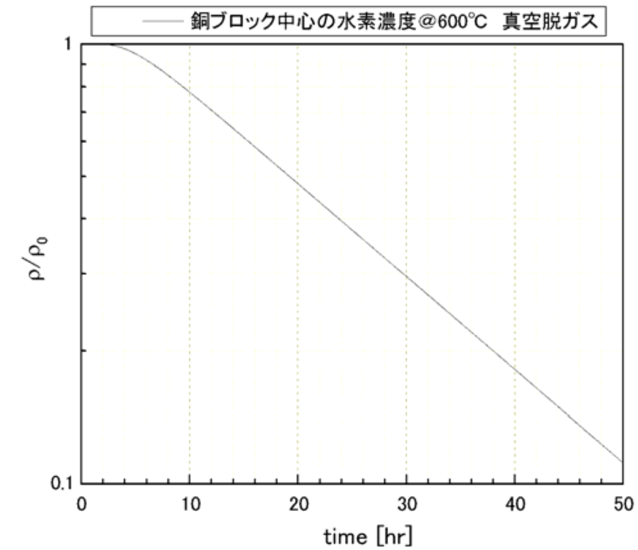
バルク中のガス成分の除去を行い、ビーム衝撃による真空度悪化を抑制

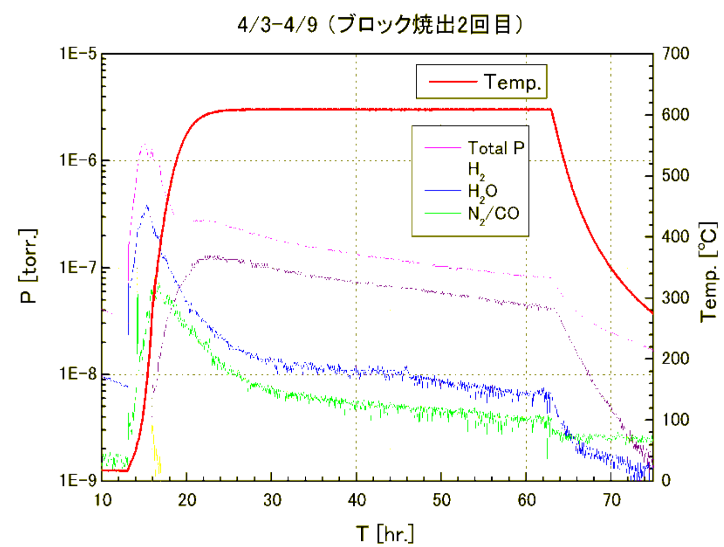
↓

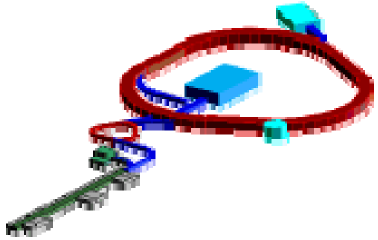
目標：バルク中の水素濃度を1/10以下に低減

焼き出し条件

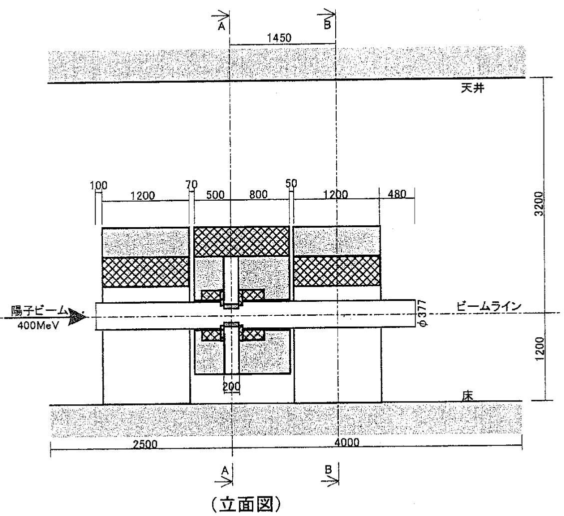
：600℃　40時間キープ

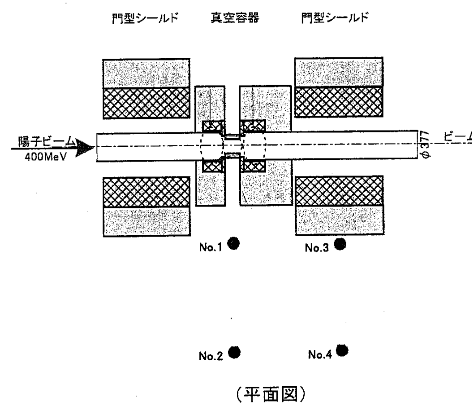


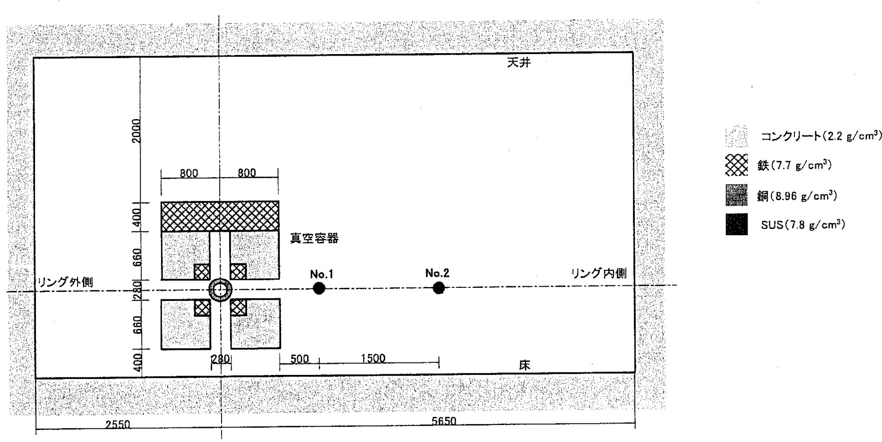




残留線量②







●メンテナンス作業時の被曝線量の詳細検討 ***(PHITS,DCHAIN-SP,QAD-CGGP2 codes)***

●**400MeV,1.2kW loss @**
一台目のセカンダリーコリメータ

● １年ビーム照射/１週間冷却後の結果

No.1 : 15.9mSv/hr.
No.2 : 2.78mSv/hr.
No.3 : 36.5μSv/hr.
No.4 : 189μSv/hr.

遮蔽体の影であれば
Hands-on maintenance可能

インピーダンス測定

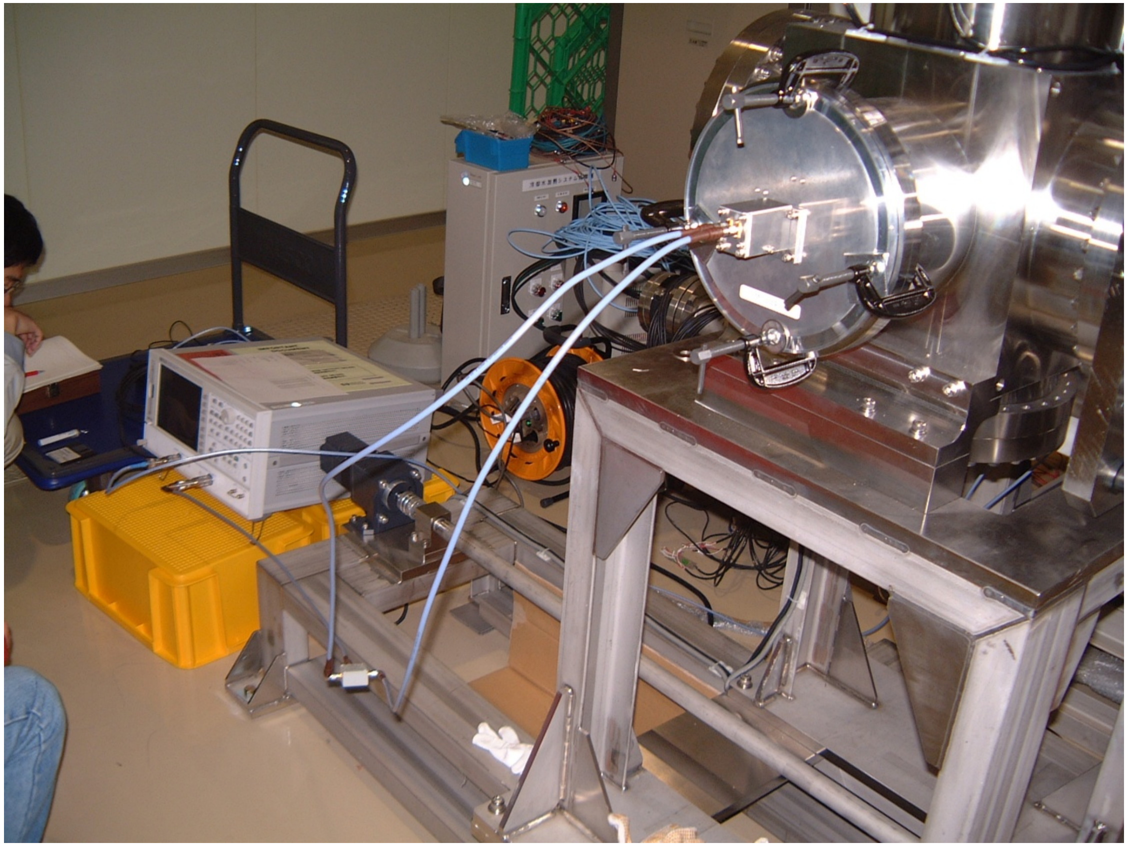
●試作コリメータにて、縦方向インピーダンスをワイヤー法にて測定

$$\frac{Z_L}{n} \approx 0.20 \quad \Omega @ Injection$$

$$\approx 0.28 \quad \Omega @ Extraction$$

$$\Downarrow$$

Criteria　1071Ω@Injection
40Ω@Extraction
はクリアーする事を確認



PBI

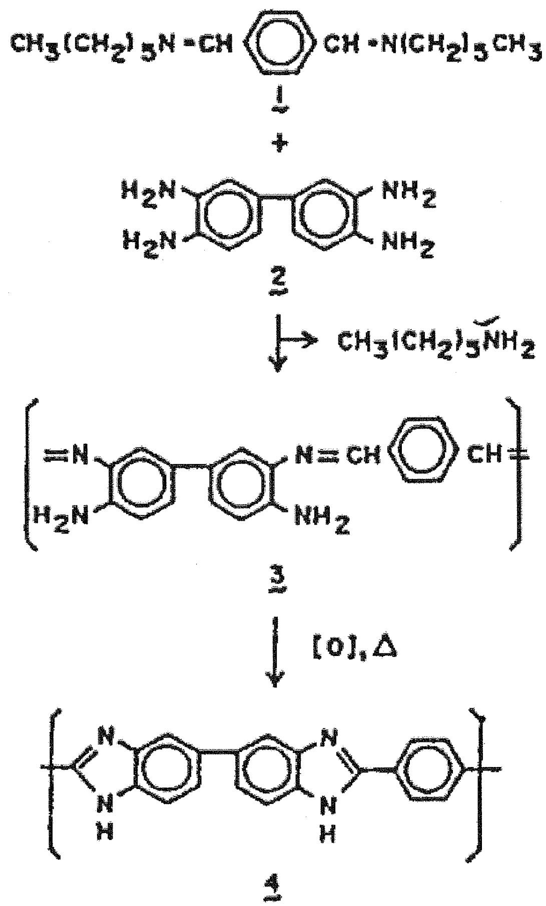
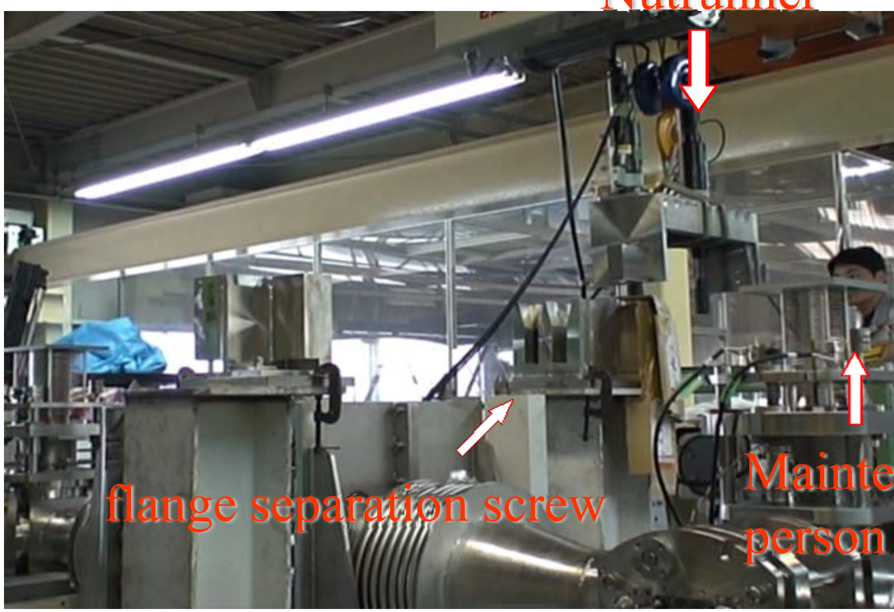
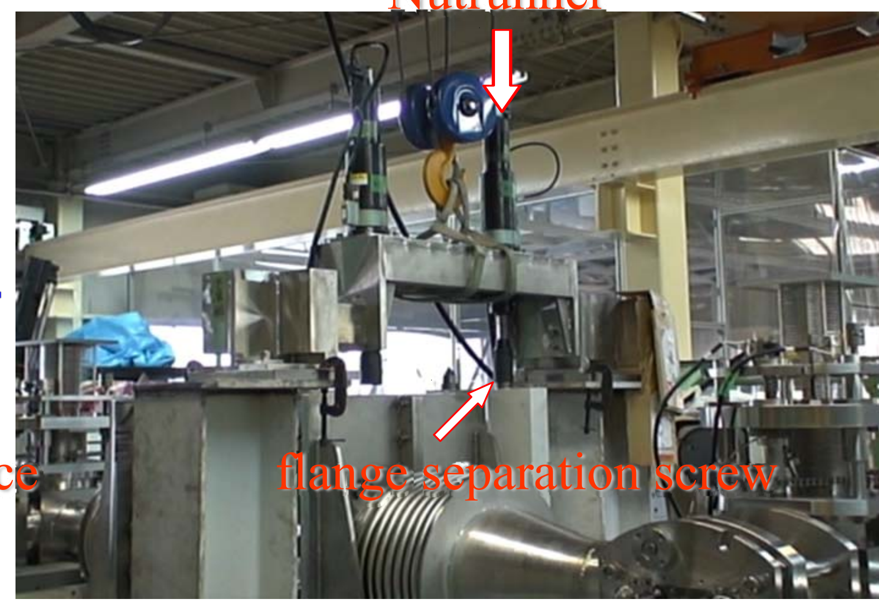


Fig.2.Synthesis of aromatic polybenzimidazole(PBI).

Remote clamp system ②

First step : We set the nutrunner on the flange separation screw from several meter away from the collimator chamber.



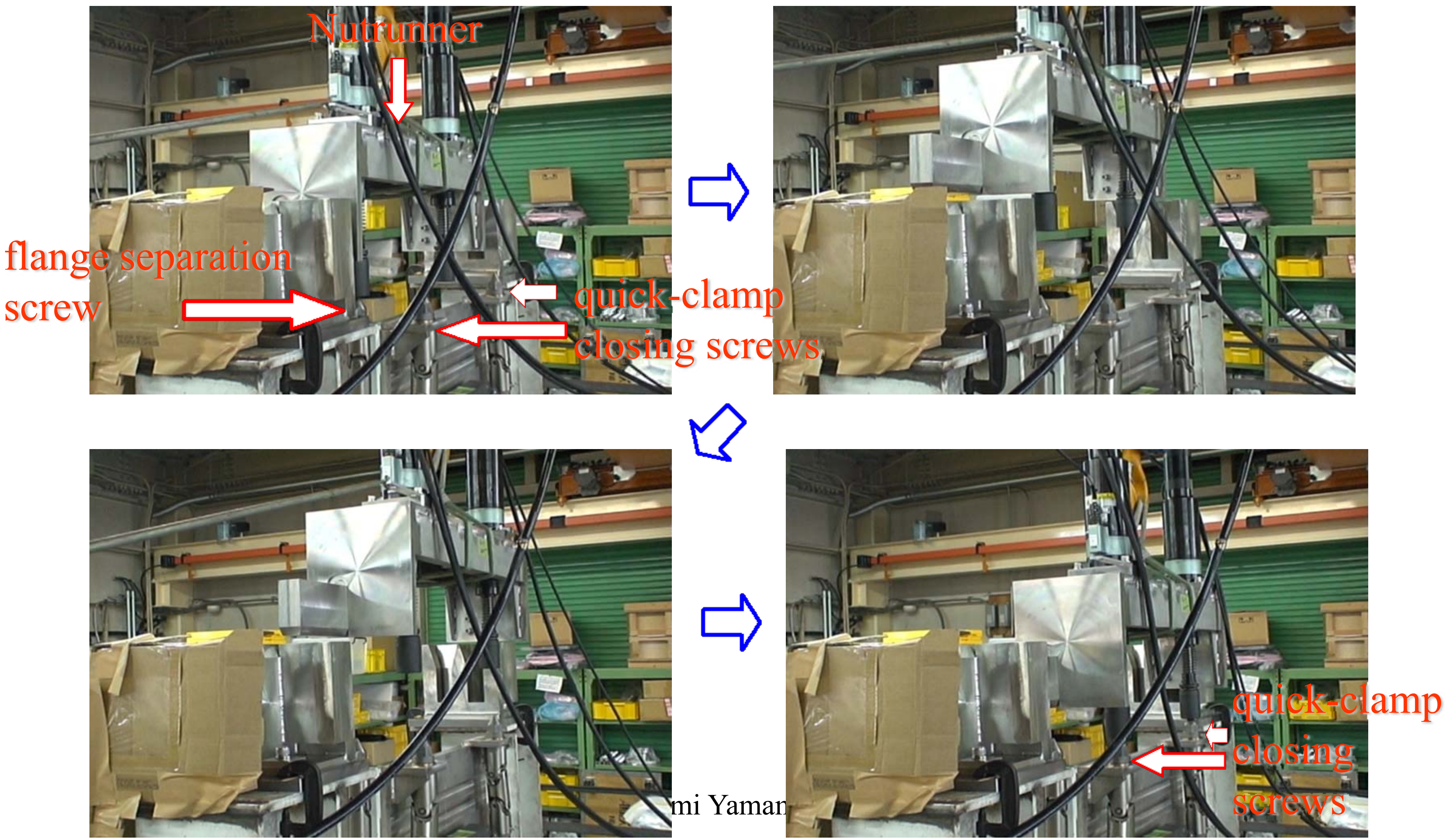


Remote clamp system ③

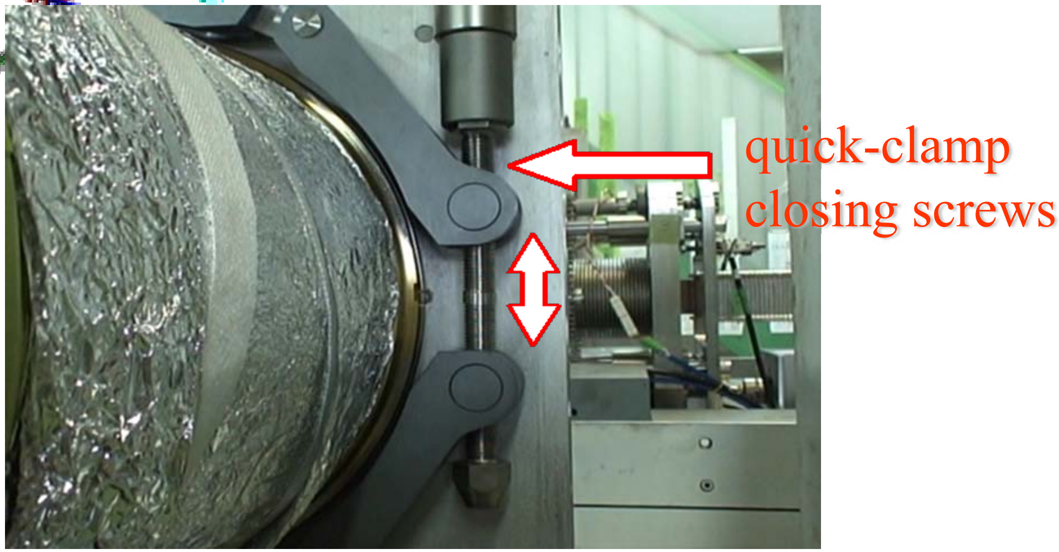
Second step : The nutrunner close the separation of each flange.

Remote clamp system ④

Third step : The nutrunner is remounted from the flange separation screw to the quick-clamp closing screws.

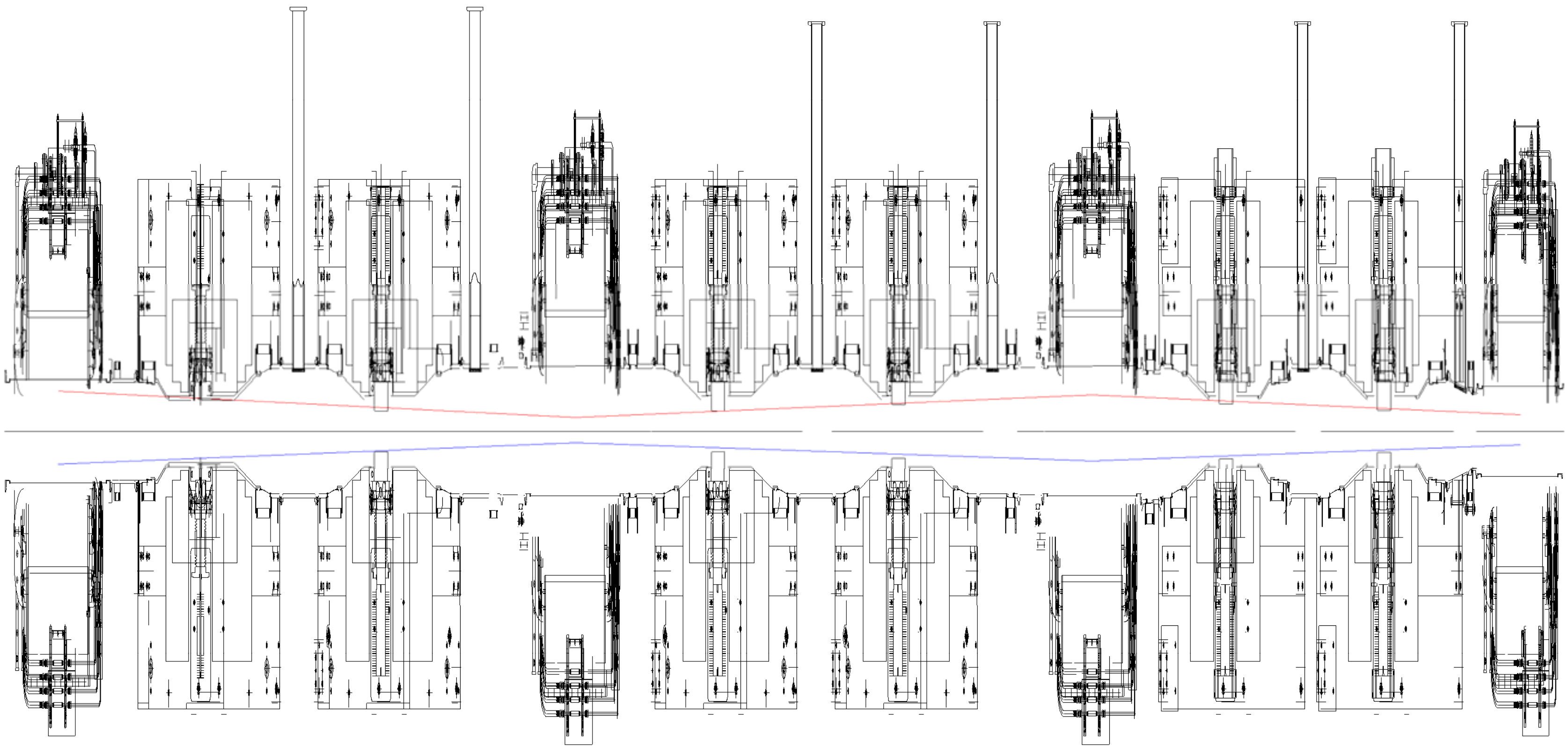


Remote clamp system ⑤

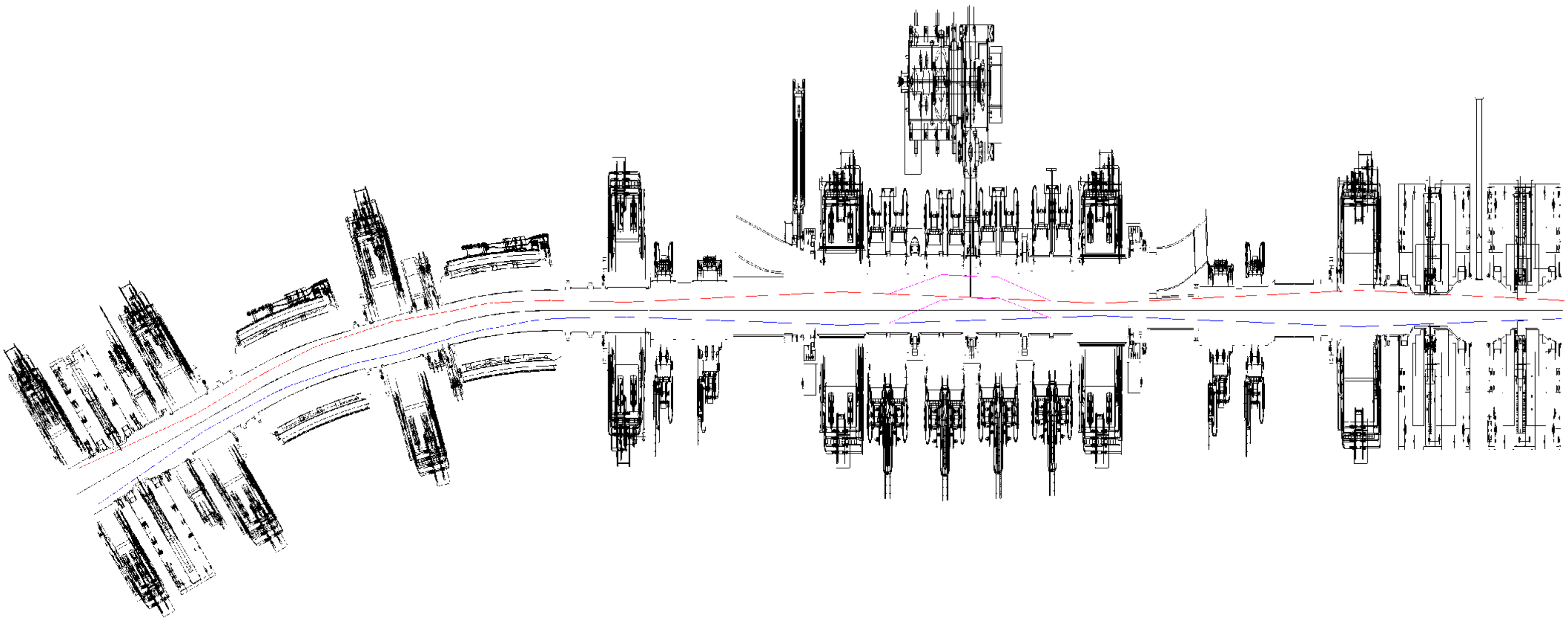


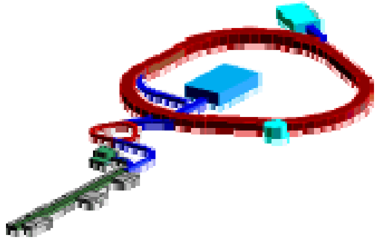
Fourth step : The nutrunner control the closing torque of quick-coupling clamp.

ビームエンベロープ①



ビームエンベロープ②



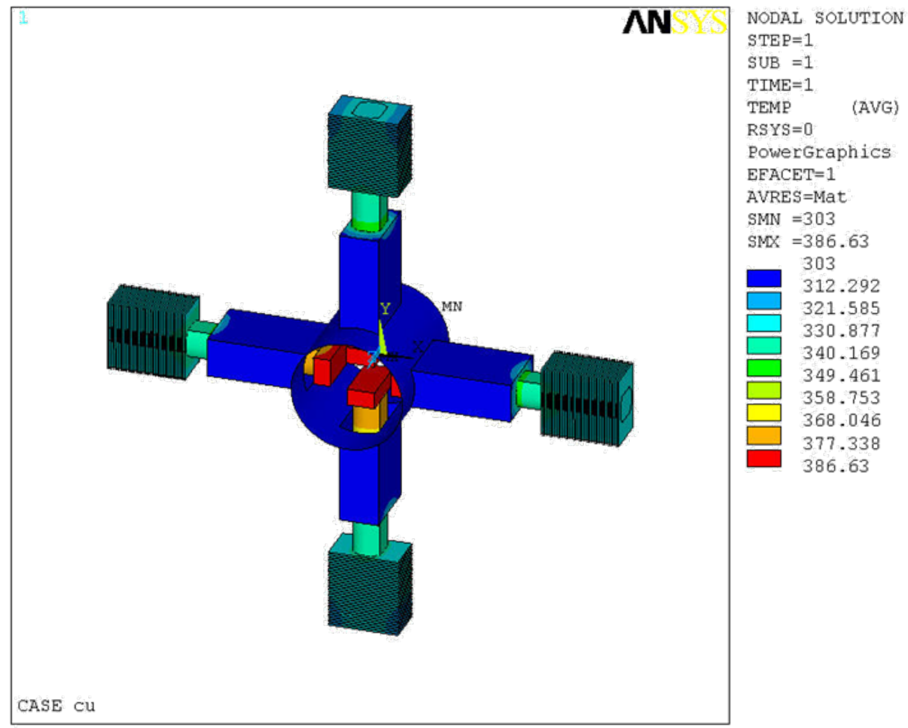


冷却機構の検討②

・銅ブロックサポートアームを太くしてヒートシンクとし、外に逃がす方式を検討

・ANSYS を用いて、サポートアームの熱伝導による冷却効率の評価

・サポートアームをφ140 mm以上の太さにすれば、最大入熱量700 Wでも温度は150℃以下に保たれる。



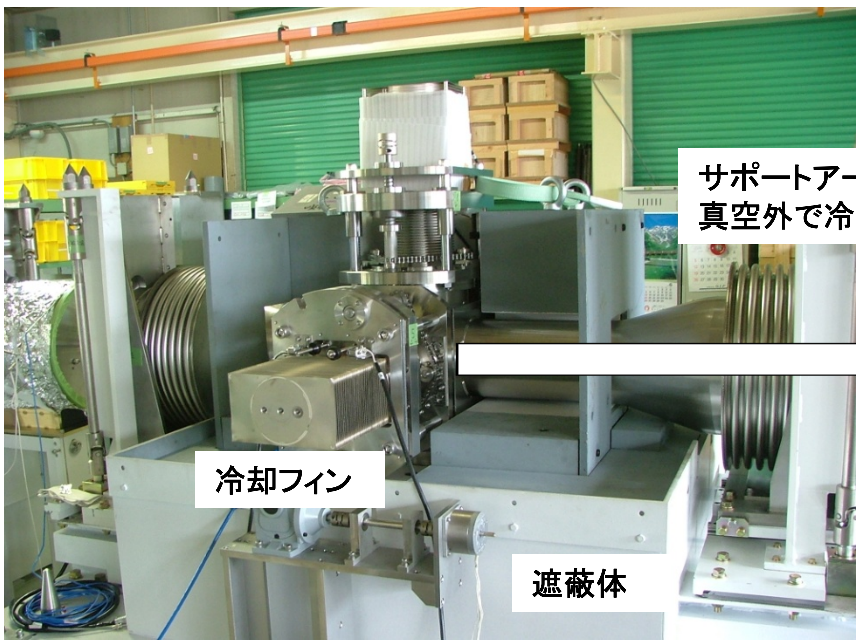
ANSYS計算結果

冷却機構の検討③

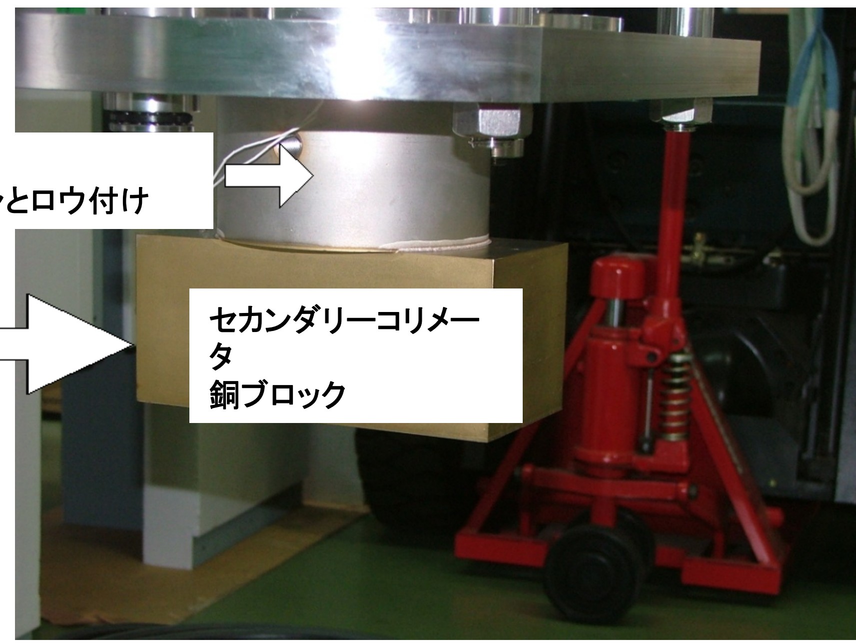
●試作機で試験を行った結果、遮蔽体に覆われた状態でも400 Wまでであれば最大温度が130℃以下に抑えられる。また、強制空冷を行なえば、700 Wの入熱でも120℃以下に抑えられる事が判明

↓

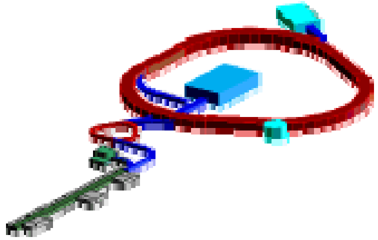
温度が高くなると見込まれる場所には、強制空冷用のエアダクトを追加、遮蔽体外より空気を送り込む事ができるように修正。→**ブロックを150℃以下に保持可能**



コリメータ真空容器と下部遮蔽体



真空容器内コリメータブロック

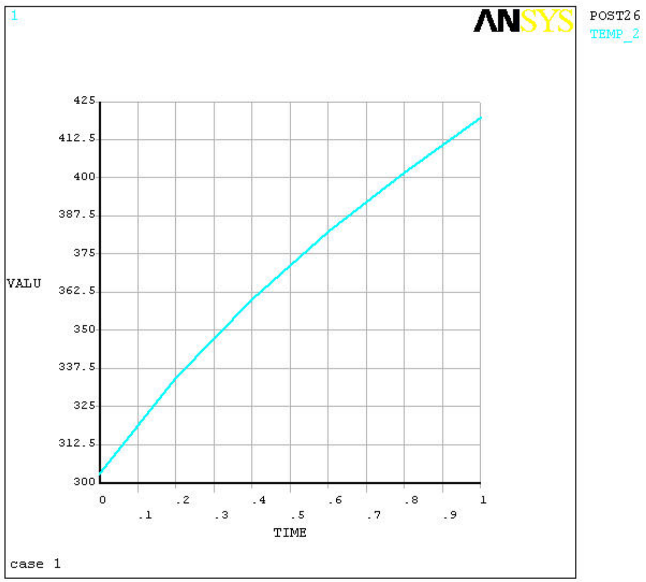


冷却機構の検討④

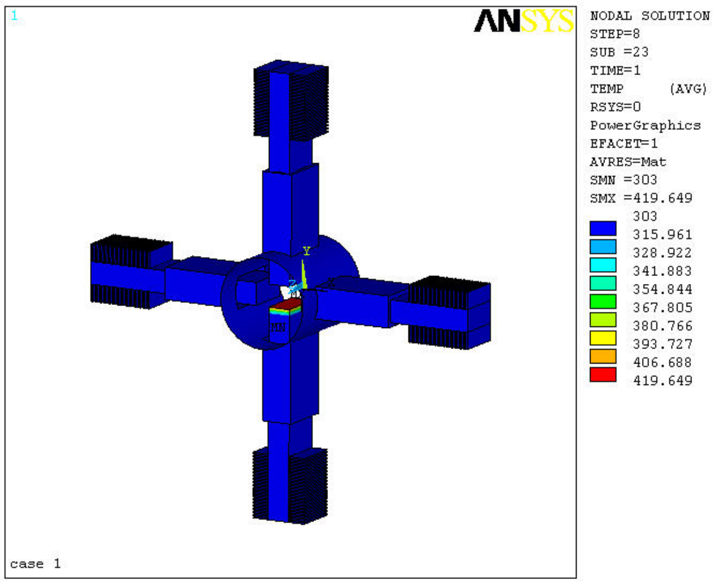
何らかの故障が発生しフルビームロスが生じた場合

→1秒間フルビームが照射しても、温度上昇は420 K程度。

実際は、MPSによって1パルスのフルビームロスが発生した時点でビームを停止



ANSYS計算結果①



ANSYS計算結果②