# DESIGN OF THE PRODUCTION TARGET FOR SLOW EXTRACTION BEAM LINES AT K-HALL

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*Abstract*

This paper reports the design of a secondary particle production target used in counter experimental hall at JHF. The primary protons of $3x10^{14}$ppp accelerated by 50GeV are transported to this experimental hall. The production target used in this hall is made from a nickel, and has a cylindrical shape with a diameter of 240mm in 54mm in sum total thickness. The disk of one sheet is 6mm in thickness, and piles up a total of nine sheets with a 1mm space. In order to reduce the incidence proton density in the target, this target is rotating in 60 rpm by using the air bearing. Therefore the proton density can be seemingly lowered even to $1x10^{11}$ppp, and the generation of heat up can also be controlled. The production target and its axis of rotation is force cooled with circulated water in 200 litters. It will operate for annual 4000 hours, and the amount of radioactive decay of Tritium will be estimated about 100Bq /cc.

## 1. INTRODUCTION

The High Energy Accelerator Research Organization (KEK) and the Japan Atomic Energy Research Institute (JAERI) will jointly constructed the High Intensity Proton Accelerator Facility (JHF) in Tokai, Japan [1]. The counter experimental hall called the K-hall for nuclear physics and high-energy particle physics in this accelerator facility is planned. The primary proton beam is accelerated to 50GeV and is taken out to K-hall as slow extraction mode. This K-hall has been designed to handle primary proton beam of up to $3x10^{14}$ ppp (protons per pulse). The power of the primary beam in the K-hall will be 750 kW; it is about 40 times greater than the current design of the north counter hall at KEK 12GeV PS. Therefore it is necessary to develop new technology for handling high intensity beams. Especially the production target has the dirtiest conditions and designed the accelerator and the nuclear institution to reference.

## 2. DESIGN CONSIDERATION

### *2.1 Incident Beam Parameters*

The important parameters of the primary beam that carries out incidence to the production target called the T1 Target are shown in Table 1.

Table 1: Incident Beam Parameters

| | |
|---|---|
| Proton kinetic energy | 50 GeV |
| Proton beam current | 15 $\mu$A |
| Number of particles | $3x10^{14}$ ppp |
| 50GeV ring cycle | 3.27 sec |
| Slow extraction pluse duration | 0.7 sec |
| Beam size on T1 target | ~ $\phi$ 6 mm |

### *2.2 General Layout*

The floor layout of the K-Hall where T1 target is assigned in Fig. 1 is shown. The T1 target for supplying π、K mesons and p-bar to the secondary beam line called K1.8 is first built in K-Hall. The T1 target area is one of the places where a radiation level is the highest in a primary beam line. As a pillar supporting a target's own cover on up the heavy ceilings, the wall of the shape of a thick chimney of iron or concrete is covered over around a target. According to the formula of Moyer [2], the thickness of this ceiling cover is 2.5m of iron, and 5.5m of concretes.

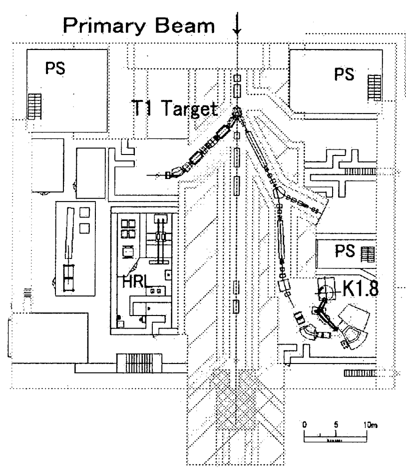


Figure 1: The floor plan of the K-Hall and T1 target

The 40t main crane and 20t sub crane are provided in the ceiling so that maintenance and installation can be performed distantly.

### *2.3 Target Design General Requirements*

This T1 target and its equipment must fulfil the following conditions in respect of operation of a beam line.

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1. The rate of loss of the primary beam allowed from the viewpoint of radiation management here should be a maximum of 30% or less.
2. Make into the maximum the amount of generation of the secondary particle used for an experiment in this beam loss limit.
3. It is the size and shape that consider of the optics of a secondary beam line, and can be regarded in a point-like source.
4. A lifetime of the target itself and its equipment should be more than for at least one year. The operation time with which a physics experiment can be presented is planned as 4000 hours/year by the maximum.
5. Perform installation, withdrawal, and temporary evacuation in remoteness and a short time. The production target, which is most radioactive in order that making it evacuate temporarily for maintenance work, such as a surrounding electromagnets or these equipments, may reduce unnecessary contamination of a maintenance worker.

The T1 production target at the K-Hall was designed based on the above matter.

## 3. A FIXED SOLID TARGET AND ITS PROBLEMS

### *3.1 Solid Target*

Extension of the present fixed solid target has been considered from maintenance and the viewpoint of beam targeting at the beginning of a target design. The temperature distribution of heat up in the target by the incidence proton beam is estimated by calculating for energy deposition using the code name CASIM. With the high-density material (e.g. platinum, tungsten) currently used, it is clear that a problem is in the diffusion speed of heat in the target volume. Since the heat in a target material diffuses at acoustic velocity mostly, it is very difficult to suppress the temperature rise by the heat, which occurs in the small volume by the high intensity beam.

For example, the tungsten metal of high melting point 3387℃ was used as the target material, the inside of a target amounts to a maximum of 1400℃ with the beam of the pulse at a few pulses. If the heat removal is able to attain smoothly, that is a heat transfer coefficient is assumed to realize in 1000 $W\cdot m^{-2}\cdot K^{-1}$ ,and the base temperature of the target is became under 300℃. In this case, a difference between top and base temperature will be too large and will start the metal fatigue by heat stress. We wants to bring cooling water close to an heat up volume in order to cool as much as possible, but the temperature on the target surface which touches a cooling water is over the it's boiling point of atmospheric pressure by this simulation.

### *3.2 Solid Target Design Criteria*

In order for a coolant to perform heat removal for a solid target compulsorily, the target material itself must have the following conditions taken into consideration.

1. The temperature in a solid target must not exceed the melting point and a brittle changes temperature, which a material has.
2. The heat stress produced by an energy deposition or the difference of a heat up down is made not to exceed the permission yield strength of a target material.
3. It is made for the solid surface temperature, which touches cooling water not to reach a boiling point of a coolant.
4. The heat flux on the surface of a solid should not exceed marginal heat flux that a material has.
5. Take into consideration the influence by corrosive gas or radiation irradiation.

## 4. ROTATING DISK TARGET

### *4.1 Target Materials*

The material of the production target referred to the target design study of the g-2 group at AGS [3] that is experimenting using up to $6x10^{13}$ protons with 30GeV and the FNAL antiproton source [4]. Although both targets were fast extraction mode, it is important that the number of incidence particles is high-density on a target. The most important parameters of the target material itself are a latent heat of fusion, yield strength, heat diffusion coefficient, thermal diffusivity and a pressure of the internal shock stress by generation of local heat up. The value of a shock pressure in adiabatic change is given from the state equation of Mie-Gruneisen [5]. These representation values of the materials that serves as some target candidates are shown in Table 2. Furthermore, it decided to adopt nickel or a still stronger nickel alloy in consideration of the corrosive one-proof by cooling water and a $NO_X$ gas.

Table2: Target Materials

| Target Material | Latent Heat of Fusion J/g | Yield Strength MPa | Thermal diffusivity $m^2/s$ | Shock pressure Pa·kg/J |
|---|---|---|---|---|
| Pt | 101 | 185 | 25 k | 56.0 k |
| W | 192 | 550 | 67 k | 31.6 k |
| Cu | 205 | 54/270 | 116 k | 18.3 k |
| Ni | 292 | 150/480 | 23 k | 15.9 k |
| Fe | 272 | 120-150 | 23 k | 13.9 k |

*Material condition: soft/hard

### *4.2 Heat and Thermal Stress Problems*

When using a production target as nickel with the density $8.9g/cm^3$ and an interaction length $\lambda$ are 14.91cm, it makes the rate of beam loss 30%, therefore the maximum target length is 5.31cm. The target has the shape of a cylinder with a diameter of 240mm in 54mm in sum total thickness. The disk of one sheet is 6mm in thickness, and piles up a total of nine sheets with a 1mm space. The reason for having sliced the disk in the direction of a beam axis is for dividing the stress of the shock wave that is spread in the advance direction of a beam. In order to make the path of a heat longer and to lower the temperature of the axis of rotation, there is a cut of a spiral in a disk. A drawing of one target sheet is shown in Fig.2.

According to the cascade simulation, it is the last disk that energy deposition becomes the maximum with a $110\mathrm{MeV}\cdot\mathrm{cm}^{-3}$ per one proton on a beam axis. The distribution of the energy deposition by one proton on a disk is shown in Fig. 3. The amount of energy deposition increases almost linearly in this thickness.

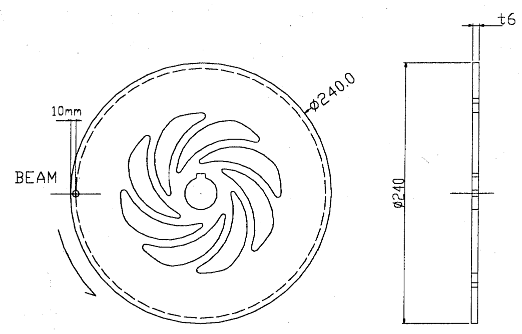


Figure 2: A drawing of one target sheet

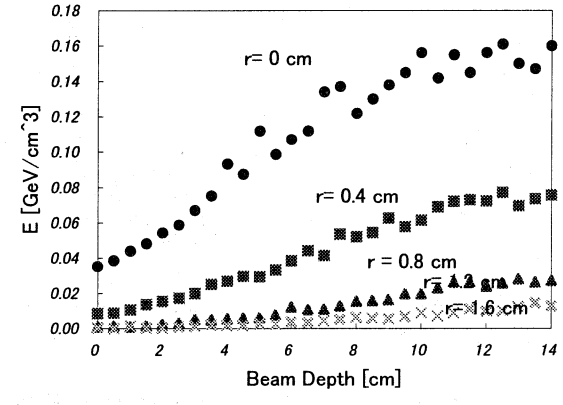


Figure 3: The distribution of the energy deposition

The method of making rotate a target and lowering the beam incidence density per place was adopted. Therefore the incident beam density can be seemingly made small to about 1/50 by rotating per minute 60 times. The incident Beam density and the highest temperature in the disk are in fix/rotation state is shown in Table 3. The incident beam is applied to a 10mm place from the edge of a disk. The heat by incident beams can be directly removed from the disk target surface by this method.

Since the temperature rise became small, a heat stress hardly becomes a problem. Rather the cooling of a temperature rise with the axis of rotation and the airtight container supporting a disk is a problem.

Table3: Comparison with a the fixed and a rotating state

| | Fixed | Rotating |
|---|---|---|
| Incident beam density | $3\mathrm{x}10^{14}$ppp | $1\mathrm{x}10^{11}$ppp |
| Target cross section of heat up | $\phi$ 6mm | Width 6mm Length 506mm |
| Energy deposition | 5.28 kJ/cm$^3$ | 104 J/cm$^3$ |
| Max. Heat-up per pulse* | 1344 K | 25.4 K |

*One pulse is a $3\mathrm{x}10^{14}$protons in 0.7 sec duration.

## *4.3 Beam Window*

In order that contamination of the nitrogen oxide and ozone gas generated in a target chamber, a target chamber must have air tightness and the closed circulatory system must be made. Therefore we think that the beam window of an aluminium alloy thin foil with 80 $\mu$ m thickness in 100mm diameter by grinding machining, or a zirconium ceramics (3mol%$Y_2O_3$-$ZrO_2$) with 30 $\mu$ m thickness in 60 mm diameter will be adopted as this partition.

## *4.4 Cooling Water*

The production target is force cooled with circulated water in 200 litters. It will operate for annual 4000 hours, and the amount of radioactive decay of Tritium will be estimated about 100Bq /cc.

## 5. SUMMARY

We designed the rotating disk target by a nickel for the K1.8 beam line. The distribution of energy distribution and temperature was estimated on the target, it is possible to remove heat by making it rotate, and it proves out that there is the manufacture possibility as a solid target.

## 6. ACKNOWLEDGMENT

This work was partly supported by a Grant-in Aid for Scientific Research (B), No. 11440084 and No. 12554009, of the Japan Ministry of Education, Culture, Sports, Science and Technology (Monbu–kagaku-sho).

## REFERENCES

1. The Joint Project Team of JAERI and KEK, “The Joint Project for High-Intensity Proton Accelerators”, KEK Report 99-4, July 1999.
2. S.Ban and H.Hirayama, “Comparison Study of Shielding Design Method for High Energy Protons”, KEK Internal 80-9, 1980.
3. G. Bunce, H. Brown, “G-2 target meeting notes”, September 1995.
4. S. O’Day, F. Bieniosek K Anderson, “New Target Results from the FNAL Antiproton Source”, IEEE PAC, p.3096-3098, 1993.
5. K. Anderson, et al., “An Antiproton Target Design for Increased Beam Intensity”, IEEE PAC, p.1946-1948, May 1991.