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Target Designs for Stepwise Developement of SNQ

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Summary

The construction of the SNQ accelerator in two stages (stage I: 350 MeV or above, stage II: 1100 MeV, 5 mA average proton current for both) requires a staged concept for some areas of the proton target station too. Chiefly the target depth dimensions for the various materials such as lead and/or tungsten as well as uranium, in stage I only one fifth of stage II but unchanged outer dimensions of the target wheel, is influenced. Cooling systems for the target, moderators and shielding will also be constructed in two stages. In contrast other components like target block shielding and cooling water pipes embedded in the shielding block respectively target trolley are to be constructed in stage I already in identical size designed for stage II.

1. Introduction

On occasion of last years ICANS-VI meeting at Argonne National Laboratory G. Bauer reporting on the "Status of the SNQ Projekt at KFA Jülich" /1/, pointed out that the facility should be built in a staged way.

Stage I:

Accelerator type LINAC with a mean proton current of 5 mA and about 350 MeV proton energy or

SYNCROTRON with a mean proton current of 0,5 mA and 1,1 GeV proton energy. Both types first using al-cladded lead as target material, followed later by al-zircaloy/cladded depleted uranium.

Stage II:

Accelerator type LINAC with 1.1 GeV proton energy and 5 mA mean current using al-cladded lead first and finally al-zircaloy/cladded depleted uranium as target material.

Stage III:

Implementation of a proton pulse compressor - (pulse length 0.5 μs)

Both possibilities of stage I had been studied to such an extent till january 1983 that a choice on the accelerator type could be made. In february 1983 the scientific advisory committee of the SNQ project recommended to build a LINAC in stage I (see /2/). The main data are given in Table 1.

TABLE 1: MAIN PROTON BEAM PARAMETERS OF SNQ

	STAGE I	STAGE II
ENERGY	350 MEV	1100 MEV
AVERAGE PROTON CURRENT	5 MA	
PULSE PROTON CURRENT	200 MA	
PROTONS/PULSE	$3.12.10^{14}$	
REPITITION RATE	100 Hz	
PULSE WIDTH	250 μs	

Since then the plant lay out work is concentrating on designing a target station using first lead or tungsten[1.)] and finally 238-uranium target rods cladded by al or zircaloy and directly cooled by light water. The concept of the target station is to be elaborated in such a manner that it would allow as easily and fast as possible the technical adaption necessary to be operated with a 1100 MeV/5 mA proton beam in stage II and with the same sequence of target materials as in stage I.

The main results of the work achieved so far will be given in this report.

2. Basic Design of the Targetstation

(Table 2)

During operation, the target is located in

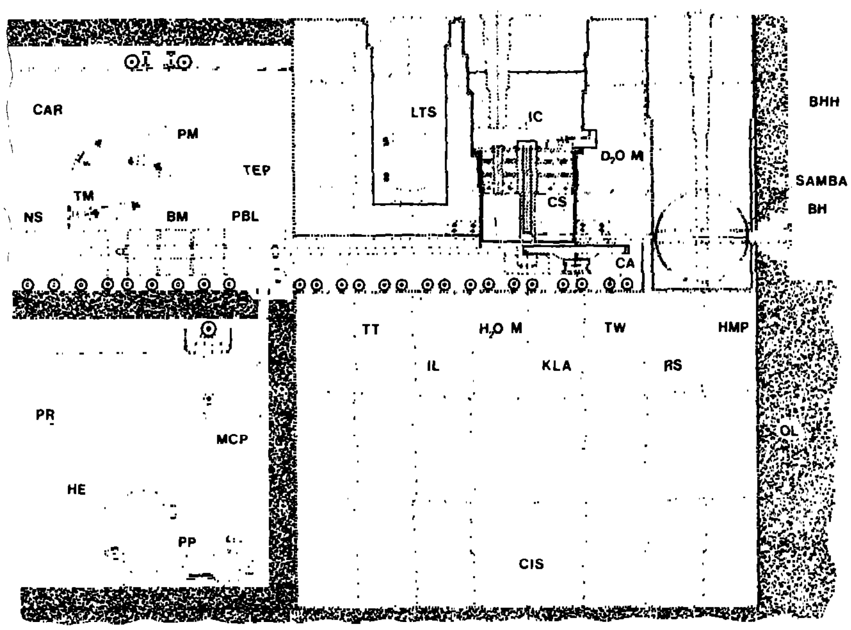
1.) tungsten has become a serious canditate for targets in stage I and II (see/3/)

the centre of the target block, where it is hit by the proton beam (Fig. 1). The fast neutrons emerge from the upper and lower surface of the disc-shaped target wheel at the position of proton incidence. These neutrons are slowed down in moderators of different design (small H_2O moderator below the target and large D_2O tank with cold neutron source and irradi[illegible] cies

TABLE 2: MAIN DATA OF THE TARGET BLOCK

- OUTER DIAMETER TARGET BLOCK	12 M
- TOTAL HIGHT TARGET BLOCK	13 M
- DIAMETER CAST IRON CENTER	10 M
- THICKNESS CONCRETE SHELL	1 M
- HIGHT TARGET BLOCK ABOVE TARGET-WHEEL	5 M
- BEAM HOLES (MULTIPLE), LOOKING AT H_2O-MODERATOR	8 HOLES
- BEAM HOLES (MULTIPLE), LOOKING AT COLD NEUTRON SOURCE	2 HOLES
- DIAMETER ROTATING BEAM SHUTTER	2 M
- NEUTRON BEAM LINES (MULTIPLE, 6 EACH)	2 LINES
- TOTAL WEIGHT CAST IRON	8.10^6 KG

above the target) (Fig. 1)
Several beam tubes and neutron guide tubes which view these moderators and penetrate through the surrounding shielding lead to



the experimental areas where the neutron scattering instruments are located (Fig.2).

Inspection, maintenance and eventually repair cannot be carried out in the operational position of the target wheel, because it is not accessible for any tasks inside the shielding block. Therefore the target wheel is mounted on a trolley also carrying the lower moderator and parts of the shielding. For such IWR (Inspektion-Inspection, Wartung-Maintenance, Reparatur-Repair) tasks the target wheel will be moved by remote handling from its operational position into the service cell, which is directly linked to the target block.

The target wheel has to rotate on the fixed target trolley when in operational position, whereby cooling water for the removal of heat, which is mainly generated by spallation, has to run trough the weel. The wheel has to be connected to a device called KLA (Kühlung-Cooling, Lager-Bearing, Antrieb-Drive water supply system) which supplies the wheel's cooling water, acts as bearing and drives the rotation /4/.

FIG. 1: TARGET BLOCK (VERTICAL VIEW)

BH	BEAM HOLE
BM	BENDING MAGNET
CA	CAVERN
CAR	CAVERN ANTE ROOM
CIS	CAST IRON SHIELDING
CS	COLD NEUTRON SOURCE
D_2O-M	D_2O-MODERATOR
HE	HEAT EXCHANGER
HMP	HEAVY METAL PLUG
H_2O-M	H_2O-MODERATOR
IC	IRRADIATION CHANNEL
IL	INNER LINER
KLA	GERMAN SHORTCUT FOR COOLING, BEARING AND ROTATING DRIVE WATER SUPPLY
LTS	LOW TEMPERATURE SUPPLY
MCP	MAIN COOLING PIPE
NH	NEUTRON HALL
NS	NEUTRON STOP
OL	OUTER LINER
PBL	PROTON BEAM LINE
PM	POWER MANIPULATOR
PP	PRESSURE PUMPS
PR	PUMP ROOM
RS	ROTATING SHUTTER
SAMBA	SIZE ADAPTABLE MULTIPLE BEAM APERTURE
TEP	TROLLY END PLATE
TM	TELEMANIPULATOR
TT	TARGET TROLLY
TW	TARGET WHEEL

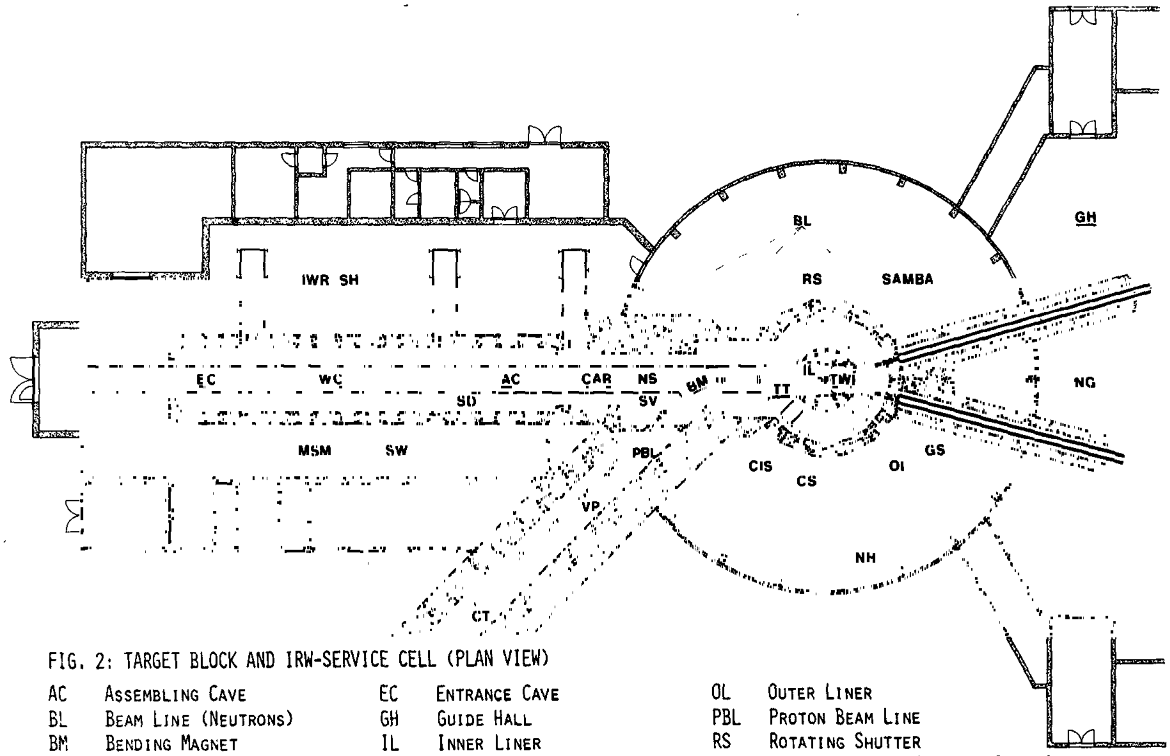


FIG. 2: TARGET BLOCK AND IRW-SERVICE CELL (PLAN VIEW)

AC	ASSEMBLING CAVE	EC	ENTRANCE CAVE	OL	OUTER LINER
BL	BEAM LINE (NEUTRONS)	GH	GUIDE HALL	PBL	PROTON BEAM LINE
BM	BENDING MAGNET	IL	INNER LINER	RS	ROTATING SHUTTER
CAR	CAVERN ANTE ROOM	MSM	MASTER SLAVE MANIPULATOR	SAMBA	SIZE ADAPTABLE MULTIPLE BEAM APERTURE
CIS	CAST IRON SHIELD	NG	NEUTRON GUIDE	SW	SHIELDING WINDOW
CS	CONCRETE SHIELD	NH	NEUTRON HALL	TT	TARGET TROLLY
CT	COLD TRAP	NS	NEUTRON STOP	VP	VACCUM PUMP
				WC	WORKSHOP CAVE

The rotating target is a unit consisting of the connection of the target wheel and the so-called KLA.

Target wheel and KLA are connected force-locking and water-tight by bolts and metallic sealing rings. This connection can be unscrewed in the IWR-service cell.

3. Nuclear Target Data of Stage I and II

The nuclear data for stage I and II using lead, tungsten and depleted uranium as target materials have been calculated by D. Filges et al /5/. Those which are of particular importance for the technical lay out of the targetstation are given in Table 3: range of protons, target depth for 85 % (stage I) respectively 95 % (stage II) of the neutron production, target depth for the centre of moderators, peak energy deposition per pulse, time-averaged total target power.

The proton range for the same material is about five times greater in stage II compared to that of stage I, nearly twice as great for lead than for tungsten and uranium the proton ranges of which are nearly of equal size. The target depths up to which 85/95 % of all neutrons are produced show the same relations between the different target materials and the two stages. It is smaller than the range of

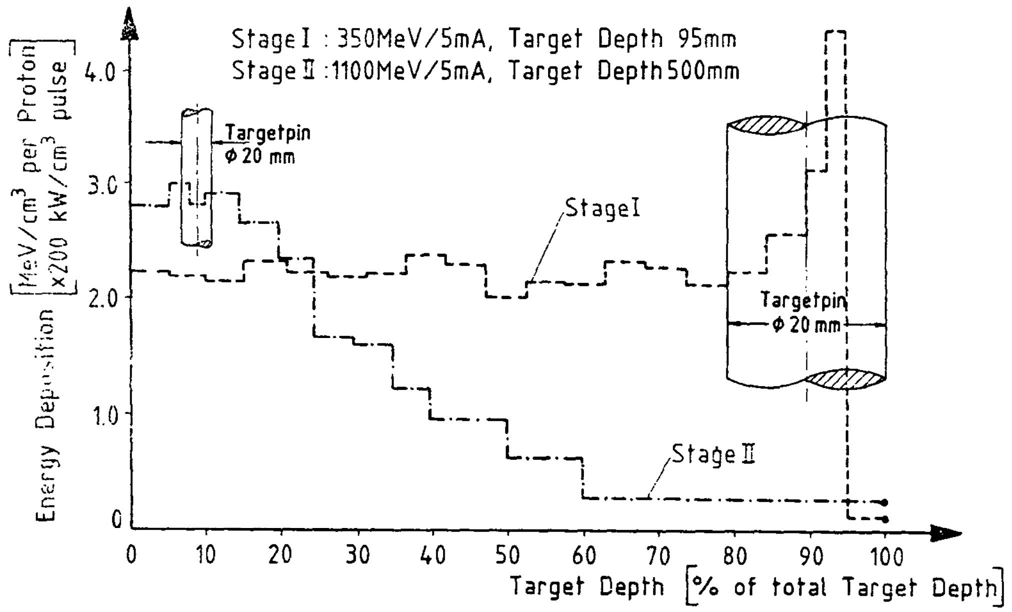
TABLE 3
THERMO/NUCLEAR DATA OF SNQ TARGETS
(STAGE I AND II)

	R (cm) I	R (cm) II	D-85 (cm) I	D-95 (cm) II	D-MAX (cm) I	D-MAX (cm) II
Pb - TARGET 1.)	14,0	75,9	12,0	66-70	6,0	9,5
T - TARGET 1.)	8,3	44,4	7,8	36	4,0	7,5
U - TARGET 1.)	9,0	48,3	8,0	36	4,5	8,0

	E-MAX (KJ/cm^3) / PULSE I	E-MAX (KJ/cm^3) / PULSE II	E-TOT 2.) (MW) I	E-TOT 2.) (MW) II	ΔT (K) I	ΔT (K) II
Pb - TARGET 1.)	0,182	0,06 3.)	1,5	2,9	124	41
T - TARGET 1.)	0,225	—	1,6	≈3,0	90	-
U - TARGET 1.)	0,215	0,149	2,9	12,5	91	63

R RANGE OF PROTONS
D-85(95) TARGET DEPTH FOR 85(95)% 4.) OF THE NEUTRON PRODUCTION
D-MAX TARGET DEPTH FOR MAX NEUTRON LEAKAGE CURRENT
E-MAX PEAK ENERGY DEPOSITION PER PULSE
E-TOT TIME AVERAGED TOTAL POWER IN TARGET
ΔT TEMPERATURE RISE AT HOT SPOT IN TARGET
1.) AVERAGE MATERIALS COMPOSITION IN THE TARGET
Pb/T/U = 76,5%, H_2O = 16,5%, Al = 7%
2.) RADIAL INTERVALL ABOUT BEAM AXIS 1,0CM
3.) RADIAL INTERVALL ABOUT BEAM AXIS 1,5CM
4.) 85% → STAGE I, 95% → STAGE II

FIG. 3: ENERGY DEPOSITION IN DEPLETED URANIUM TARGETS VERSUS TARGET DEPTH (STAGE I AND II)



protons and therefore determines the "technical" target depth in stage I and II.

The different target depths for the centre of the moderators have to be taken into account for the optimal coupling especially of the H_2O-moderator, whereas they are of minor importance in the case of the large (2 m diameter) D_2O-moderator.

The maximum peak energy deposition per pulse is significantly greater in stage I. Furthermore shape and position of the peaks are different, within stage I and II. Fig. 3 shows the curve of the peak deposition versus the target depth for uranium targets in stage I and II. Typical target pin diameters (20 mm) are indicated for both stages. The very narrow ("Bragg") peaks in stage I at the end of the target, which are much smaller than the pin diameters result in an unsymmetric radial temperature distribution and additional thermal stress, that could be avoided by a reduction of the "technical" target depth in stage I. The uniform radial temperature distribution in stage II. does not require any technical extra-measures.

Table 3 reveals that the time averaged total power generated in the target is significantly higher for the uranium target in stage II compared to all targets in stage I and even the "non-uranium" targets in stage II. This leads to a 2 step concept of the target cooling system.

4. Design for Stage I and II

The concept of constructing SNQ in several stages permits the stepwise construction for some of the components too, whereas other component groups either are needed for functional reasons in their final design right from the start or will, because of construction reasons be used in stage I and II. identically, even though a lesser version would suffice in stage I.

4.1 Target Wheel

The stepwise concept has its strongest influence on the design of the target of course. The target, a large wheel, rotating in the pulsed proton beam in a high energy density is a novel component of a high potential with respect to design, selection of materials, welding techniques and depending upon this its operation life. Because of this it was decided to have identical design and structural materials for the target wheels of all stages in order to use the operation experience for

TABLE 4 TECHNICAL DATA OF SNQ TARGET-WHEELS

	UNIT OF MESURE-MENT	1. STAGE (350 MeV)			2. STAGE (1100 MeV)		
		LEAD	TUNGSTEN	URANIUM	LEAD	TUNGSTEN	URANIUM
-FREQUENCY OF REVOLUTION	sec^{1}		0,5			0,5	
-DIAMETER TARGET-WHEEL	mm	2490	2490	2490	2560	2560	2560
-TARGET DEPTH FOR 85% NEUTRON PROD.	mm	120	77,5	80	—	—	—
-TARGET DEPTH FOR 95% NEUTRON PROD.	mm	—	—	—	700	360	360
-TECHNICAL TARGET DEPTH	mm	121,2	82,2	82,2	700	360	360
-NUMBER OF STAGGERED PIN ROWS		7	5	5	37	20	20
-NUMBER OF TARGET PINS	pieces	2184	1560	1560	9304	5916	5916
-TARGET PINS SERVING AS TIE-RODS	pieces		0		232	0	0
-DIAMETER OF TARGET-ELEMENTS-	mm	23-20,7	23-21,5	23-21,5	24,0-18,0	24,0-18,0	24,0-18,0
-COOLING WATER FLOWRATE	m^3/h	250	250	250	250	250	500
-PRESSURE DROP IN TARGET DEPTH	bar	0,13	0,09	0,09	1,01	0,35	0,94
-CLADDING MATERIAL			AlMgSi1		AlMgSi1	AlMgSi1	(Zircaloy)
-HIGHT OF TARGET-ELEMENTS	mm		100			100	
-HIGHT OF TARGET-WHEEL	mm		156			156	
-STRUCTUREMATERIAL TARGET-WHEEL			AlMgSi 1			AlMgSi 1	
-TOTAL WEIGHT TARGET MATERIAL	kg	1045	1283	1262	3350	3508	3460
-TOTAL WEIGHT TARGET-WHEEL	kg	2945	3093	3072	4600	5145	5095

improving the life expectancy. The design life of the first target wheel is two years corresponding to 12.000 h of full power /6/.

The main load for the target wheels does not arise from the weight of the target material but from the hydraulic pressure of the cooling water flow onto the wheel discs comprising the inner walls of the target wheel. The wheel discs of the lead target of stage II (700 mm target depth) are loaded that much, so that they are to be held together by 232 tie rods in order to avoid excessive elastic deformation. The elastic buckling of the target discs is thus reduced from 3,5 mm down to 0,2 mm. These tie rods comprising target pins with stronger canning and threaded bolts on either end /4/ are not needed for tungsten and uranium targets of stage I and II as well as for the lead target of stage I, as the lesser target depth reduces the hydraulically stressed areas of the wheel discs especially because the inner target zones with a smaller number of cooling water channels are not existing in those designs. Because of this the pressure loss and thus the average static water pressure at the same cooling water flow in the target (table 4) are reduced. The same is valid for a cooling water flow through the uranium target of stage II doubled from 250 m³/h to 500 m³/h.
The cooling water channels within the target structure of the uranium target have been altered with respect to save after-heat removal. All water inlet and outlet channels within the target structure are designed like a syphon, so that in the first instance the target pins remain under water in the case of loss of coolant. (fig. 4 and 5)

4.2 Target Pins

The target material itself is also strongly influenced by the staged concept. It is arranged in form of pins in the inner of the target wheel for better heat removal. For each construction stage of the accelerator different target materials are to be used starting with lead and/or tungsten and ending with uranium (Table 4) The target pins will always be inserted in cans to avoid direct release of spallation products from the pin surfaces of the target materials into the cooling water. Direct contact of water with uranium because of the well known uranium-water reaction has to be avoided in any case. For minimising the release of spallation products from the canning surfaces surrounded by cooling water the canning material must have a low atom weight and a low density. Therefore aluminium is a suitable canning material especially, as aluminium has in addition a low neutron and proton damage rate /3/, a good corrosion resistance and a high heat transfer coefficient. As a back-up material for targets at higher temperatures, likely to occur in

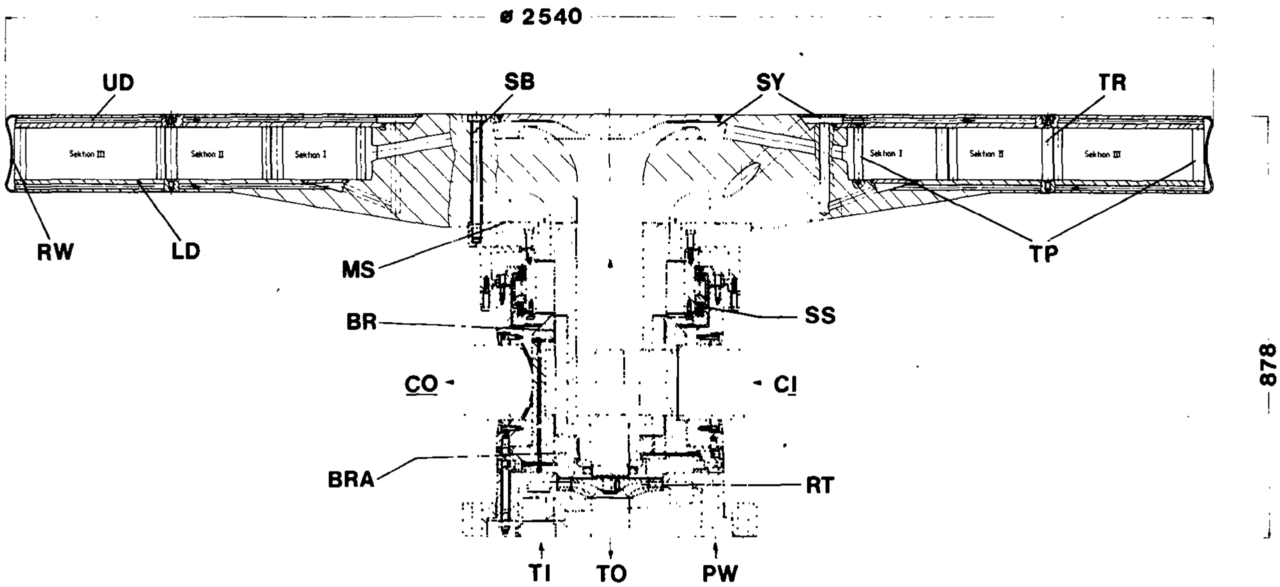


FIG. 4: PB-TARGET, 1100 MeV, MOUNTED ON KLA TYP I
(KLA TYP I: HYDROSTATIC AXIAL AND RADIAL BEARINGS, RADIAL TURBINE)

BR	Radial hydrostatic Bearing	PW	Pressurized Water Inlet hydrostatic radial Bearing	TJ	Turbine Water Inlet
BRA	Radial and axial hydrostatic Bearing	RT	Radial Turbine	TO	Turbine Water Outlet
CI	Coolingwater Inlet	RW	Rotating Window	TP	Target Pin
CO	Coolingwater Outlet	SB	Screw Bolt	TR	Tie Rod Pin
LD	Lower Wheel Disc	SS	Slide Ring Seal	UD	Upper Wheel Disc
MS	Metallic Seal	SY	Syphon		

uranium pins with failed cooling, circaloy is considered.
Special attention must be paid to the manufacture of the canning. Galvanic processes or evaporation of nickel and chromium layers are not favourably looked at because their higher atom weights are of disadvantage (see above) and there are doubts concerning radiation resistance of these materials.

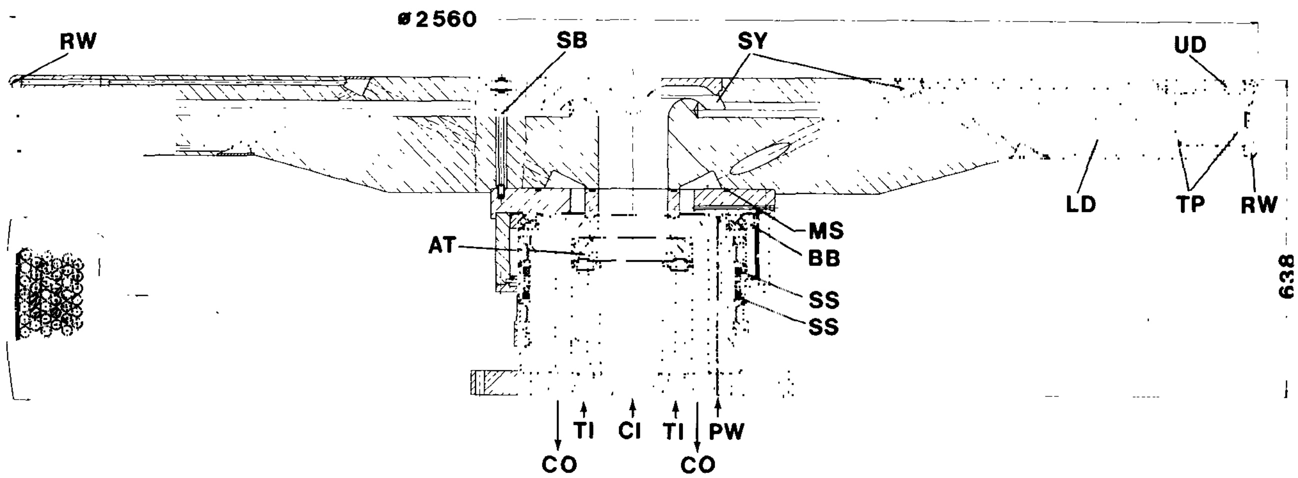


FIG. 5: U-TARGET, 350 MeV, MOUNTED ON KLA TYP II
(KLA TYP II: HYDROSTATIC AXIAL BEARING, RADIAL BALL BEARING, AXIAL TURBINE)

AF	Axial Turbine	MS	Metallic Seal	SS	Slide Ring Seal
BB	Ball Bearing (radial)	PW	Pressurized Water Inlet for hydrostatic axial Bearing	SY	Syphon
CJ	Coolingwater Inlet	RW	Rotating Window	TI	Turbine Water Inlet
CO	Coolingwater Outlet	SB	Srew Bolt	TP	Target Pin
LD	Lower Seal Disc			UD	Upper Wheel Disc

The canning in the form of tubes is to be put over the target pins and it is important to achieve a maximum surface contact ratio as the heat transfer coefficient and therefore the temperature level in the target pin is influenced by this. Table 3 shows the importance of this at high local energy depositions of stage I. For a lead target pin it is sufficient to push a lead pin of a tight fit into the aluminium tube. When the proton beam hits the lead it is heated up and expands against the water-cooled aluminium tube, so that lead and aluminium press against each other. As lead possesses virtually no elasticity a high plastic deformation at the surfaces takes place giving a ratio of surface contact of over 95 %.

This principle does not work with the hard and non-plastic materials tungsten and uranium. These materials require a plastic deformation of the cladding material at the surfaces of the target pin. In this case the aluminium tube is to be pressed onto the core of tungsten and uranium by iso-static pressing. Manufacturing processes of different pressing methods and the measuring of surface contact ratio are under preparation.
The differences of the stage concept and the variation of target materials caused by it present themselves only in the number of rows of target pins, that means the depth in the inner of the target wheel (table 4).
The targets of stage II with the same material are about five times deeper than the ones of stage I and the lead targets are always about double as deep as the tungsten or uranium targets (tungsten and uranium target are of the same depth).
Fig. 4 shows the target wheel with the largest target depth using lead at 1100 MeV. In contrast the uranium target at 350 MeV shown in fig. 5 is extremely short. The targets of stage I are problematic be-cause of extremely high energy deposition at the end of the proton range due to an eminently narrow "Bragg"-peak. As shown for a uranium target of stage I in fig. 3, the specific heat deposition in a part of the pin abruptly increases by about 100 % leading to significantly increased hot-spot temperatures compared with its surrounding and leads to problems concerning thermal stress due to an asymmetric temperature profile. This unwandet thermodynamic effect has to be avoided either through "thinning" of target material in the area of the "Bragg"-peak or through reduction of target depth (replacement of last pin row by water). The losses in neutron production in the order of about 15 % (see table 3) due to shortening of the target seem to be tolerable, as they occur for the probably short time operating targets of stage I only. Therefore the latter method will be preferred in the design.

4.3 KLA-unit
Fig. 4 and 5 show target wheels mounted on KLA units. The KLA-unit carries the load of the total target wheel (table 4), moves it at 30 rotations per min. in a vacuum atmosphere and has openings for cooling water entry and outlet for the rotating target wheel /4/.
Already now this KLA unit as an important part is extensively beeing tested, taking into account radiation damage of materials for slide ring seals /3/ as well as overall mechanical performance of the KLA unit. The dynamic behaviour of a KLA unit type I as shown in fig. 4 without radiation damage has been tested in original size. This type I unit has hydrostatic axial as well as ra-dial bearings. Repeatedly problems occurred with the hydrostatic radial bearings lea-ding to mechanical damages. These problems seem to be related to thermal causes and testing is continued. In any case, the developement of a KLA unit typ II (Fig. 5) has been started in parallel, which features the well performing hydrostatic axial bea-ring and a special stainless steel roller bearing as a radial bearing. In addition the remote handling of the KLA unit is facilitated, as there are no more outer

cooling water inlet and outlet pipes like for type I.
A stainless steel roller bearing in original size is unter test right now.

4.4 Diameter of Target Wheel

The diameter of the target is determined essentially by thermodynamical parameters. During one rotation at a pulse distance of 10 ms (frequency 100 Hz) the same area at the wheel circumference has to be hit by one proton pulse only. That gives a circumferential velocity of 40 mm/10 ms = 4 ms^{-1} with a proton beam diameter of 40 mm (FHWM see /5/). Furthermore a sufficiently long cooling period of about 2 seconds was chosen before reentering the proton beam, from which a wheel diameter of 2,5 m results.
The target station is designed for the uranium target of stage II. The two moderators, located above and below the target wheel, have to be placed in an optimum position depending on the neutron flux distribution emerging from the target wheel. This is a target depth of 8 cm (see table 3) and of special importance for the small H_2O-moderator. Eight neutron beam tubes are directed at the H_2O-moderator. As they are in fixed positions in the target block, they thus determine the location of the H_2O-moderator in the cavern. Table 3 shows, that for the same target material the target depth for the optimum positioning of the moderator for stage I is about 3,5 cm smaller than for stage II. In addition, the depth for lead compared with tungsten and uranium, for which the depth is about the same, is about 1,5 - 2 cm more. These differences are taken into account by reducing the radius of target wheels of stage I by 3,5 cm in comparison with stage II wheels. For lead a further adjustment of the target wheel radius does not seem to be necessary, as the existing wide maximum of the neutron flux distribution /5/ will compensate differences of 1 to 2 cm in the moderator arrangement. Final optimisation calculations for real geometries will have to decide wether or no

TABLE: 5
THERMOMECHANICAL DATA OF SNQ-TARGET - COOLING SYSTEMS
(STAGE I AND II)

		Stage I	Stage II
I.	KLA-H_2O-Moderator System		
	Total Heat Dissipation		
	in Target + Structure	4 MW	13,5 MW
	in H_2O - Moderator	0,2 MW	0,4 MW
	Flowrate		
	Turbine (max)1.)	126 m³/h	
	Bearings (radial, axial)1.)	4,5 m³/h	
	Target Cooling	250 m³/h	500 m³/h
	H_2O-Moderator	15 m³/h	30 m³/h
	Total	265 m³/h	530 m³/h
1.)	in Target Cooling included		
	Purification	20 m³/h	
	Pressure		
	Turbine	37 bar	
	Bearings (radial/axial)	60 bar /	30 bar
	Target (Entry/Outlet)	7 bar /	2 bar
	H_2O-Moderator	3,5 bar	
	Coolant Temperature at Entry	50° C	
	Temperature Rise in Coolant	14,5 K	24,0 K

		Stage I	Stage II
II.	D_2O-Moderator Systems		
	Total Heat Dissipation	0,5 MW	1,0 MW
	Flowrate	6 kg/s	10 kg/s
	Pressure	2 bar	
	Temperature at Entry	45° C	
	Temperature Rise	20,0 K	30,0 K
III.	Shield Cooling System		
	Total Heat Dissipation	1,0 MW	2,0 MW
	Flowrate	40 m³/h	70 m³/h
	Pressure	4 bar	
	Temperature at Entry	45° C	
	Temperature Rise	21,5 K	24,5 K
IV.	Shut Down Cooling System		
	Total Heat Dissipation		
	immediately after shut down	100 kW (U)	450 kW
	1 d after shut down	7 kW (U)	30 kW
	Flowrate	1,5 kg/s	
	Pressure	3 bar	
	Temperature at Entry	45° C	
	Temperature Rise	(max) 20 K2.)	

1.) Uranium
2.) within 1st hour after shut down

radius adjustments have to be carried out.

4.5 Cooling systems

It can be seen in table 5, that for stage II only the use of uranium leads to significantly higher heat deposition in the target, the H_2O- and D_2O-moderators and the shield systems. Therefore, for the cooling systems of these components a stage concept was adopted too. The first stage of this concept provides for save heat removal for all targets of stage I and for the non-uranium targets of stage II.
All cooling systems are of a modular design for the components influencing the cooling capacity.
The increase in cooling capacity for stage II is carried out by adding pumps and heat exchanger moduls in parallel. All necessary provisions for extra space have to be made in stage I of course. All parts, which can lateron not be altered, like the pipes fixed into the targetblock and the target trolley, have to be of the dimensions necessary for stage II at stage I already.

4.6 Shielding Block

With regard to /5/ the shielding of the target wheel (fig. 1 and 2) in stage I could be constructed some what smaller (shielding thickness of stage I 5 to 10 % lesser than for stage II). As a later increase would be very time consuming and costly a stepwise construction of the target block shielding is not considered.

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