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NEUTARGS

https://sites.google.com/site/neutargs/general

INFN Istituto Nazionale di Fisica Nucleare

GOAL: develop high power neutron production targets

- WP1: ***SEE*** *(Single Event Effects in micro-electronics)*
- WP2: ***FARETRA*** *(Fast Reactor Simulator for Transmutation studies)*
- WP3: ***BNCT*** *(Boron-Neutron Capture Therapy of cancer)*
- WP4: ***BSA*** *(Beam Shaping Assembly target test setup)*
- WP5: *SCAR (for Sub-Critical Accelerator Reactors)*
- WP6: *NUWAC (for Nuclear Waste Characterization)*

3 sezioni INFN:
Padova (WP1)
LNL (WP1, WP2, WP3)
Pavia (WP4)

NEUTARGS:
a community that will share
knowhow, ideas, resources, tools, problems, results

NEUTARGS

"Thick" targets (beam stopped) with moderators

"Thin" targets

Composite targets

SEE (LNL):
W-based target
Protons 70 MeV, 0.7mA, continuous

SEE (LNL):
Be (future Li) targets
Protons 35-70 MeV, 0.7mA, continuous

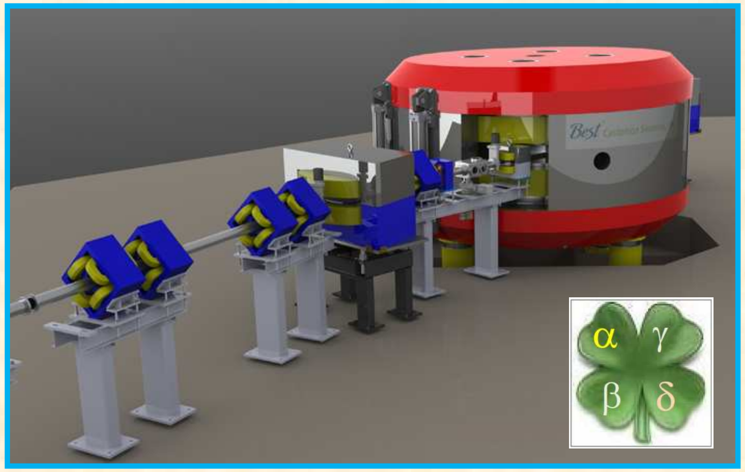
SEE (Padova):
rotating PbBe target
Protons 70 MeV, 0.7mA
continuous

FARETRA (LNL):
W-based target
Protons 35-50 MeV, 0.7mA, continuous

BSA (Pavia)
Beam Shaping Assembly for BNCT
and general test facility

BNCT (LNL):
Be target
Protons 5 MeV, 35 mA, continuous

A high-current (700 μA) variable energy (35-70 MeV) proton cyclotron is under construction for the **SPES project** (*) at the INFN LNL to be commissioned in 2014/15.
This opens up the possibility of high flux neutron irradiation facilities to perform various research activities. But then need to first develop high power production targets.



NEUTARGS Padova

GOAL:

Develop a high power target to produce neutrons with an atmospheric-like continuous energy spectrum in the 1-60 MeV range.

CONTEXT:

A neutron irradiation facility at **SPES (δ-phase)**

APPLICATIONS:

Studies of neutron-induced **Single Event Effects in electronics**.

NEUTARGS INFN PADOVA composition and tasks

COMPOSITION

PADOVA

Ricercatori:

• Silvestrin L. (Assegnista)	70%
• Candelori A.	70%
• Zanella G.	0%
• Pavan P.	0%

Tecnologi:

•_Wyss J. (RESPONSABILE NAZIONALE)	70%
• Pepato A.	30%
• Ferrari L. (dottorando)	??%

Totale ***2.4 FTE***

TASKS

❑ coordinamento generale del lavoro su SEE targets

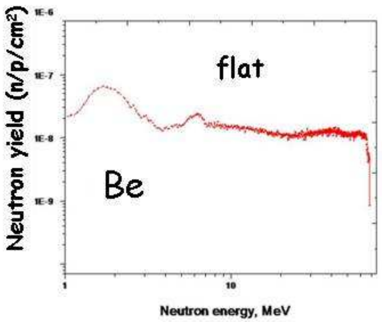
❑ realizzazione bersaglio composito PbBe

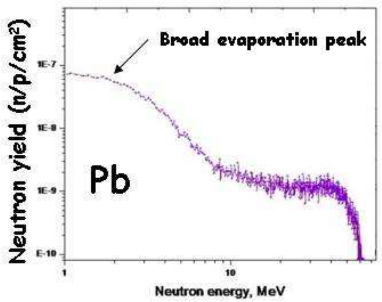
- studio ingegneristico (mock-up, dissipazione potenza (1° anno))
- **acquisto materiale (2° anno)**
- **progetto esecutivo prototipo (2° anno)**
- costruzione prototipo (3° anno)
- test termo-meccanici e di integrità (3° anno)
- …

PADOVA

Idea: A composite target made of Be and a heavy element (such as Ta or Pb) to produce an effective atmospheric-like neutron spectrum in the 1-60 MeV range without the use of moderators.

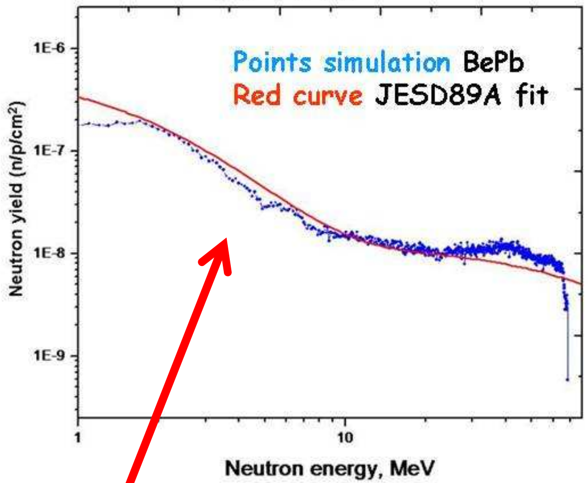
E_p= 70 MeV





Be 23%
Pb 77%

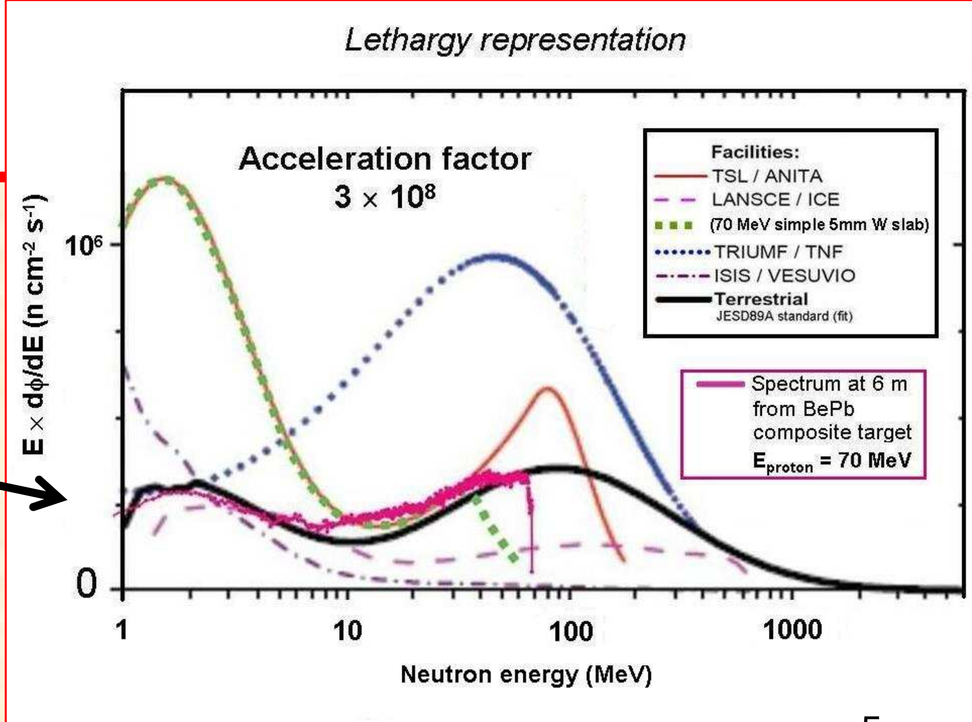
At 6m from composite target



Red curve

The energy spectrum of neutrons in air-showers (atmospheric neutrons)

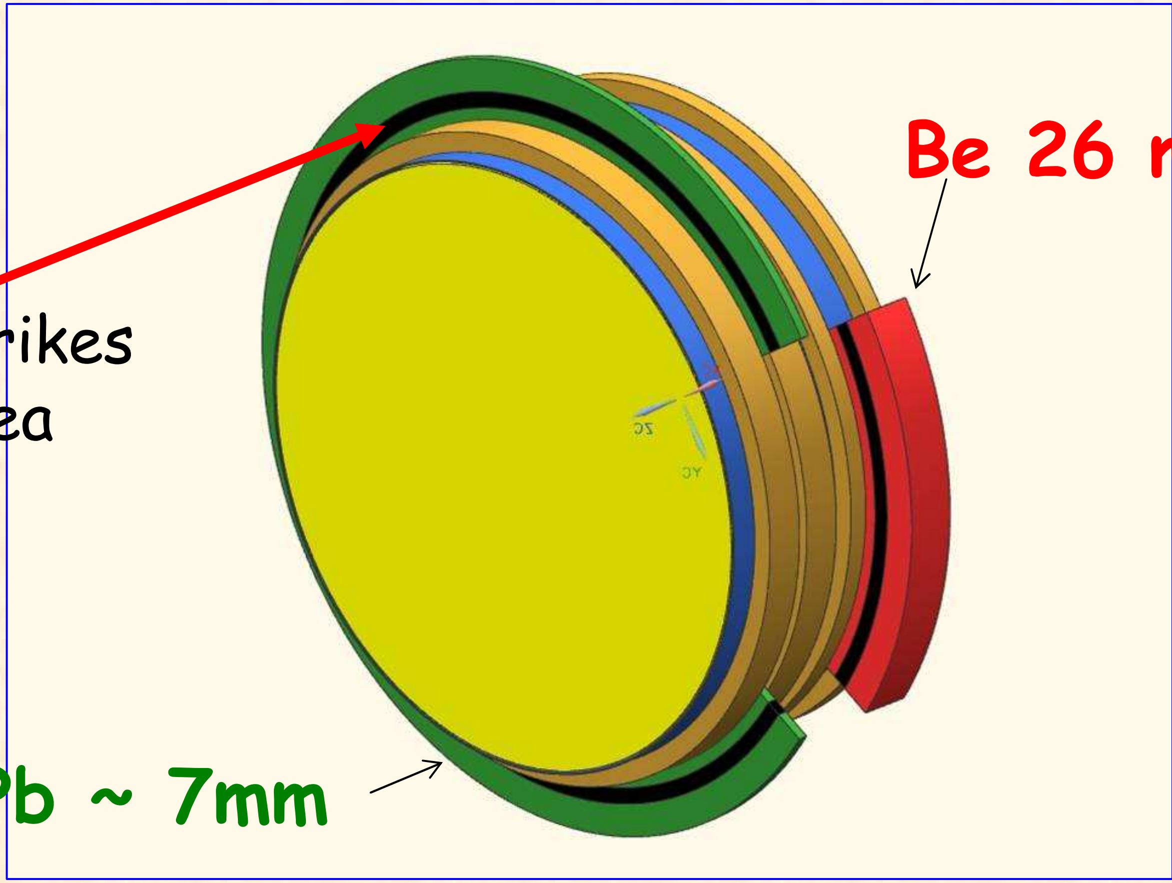
Black curve



Novel rotating composite target:

The beam is alternatively intercepted by the 2 materials

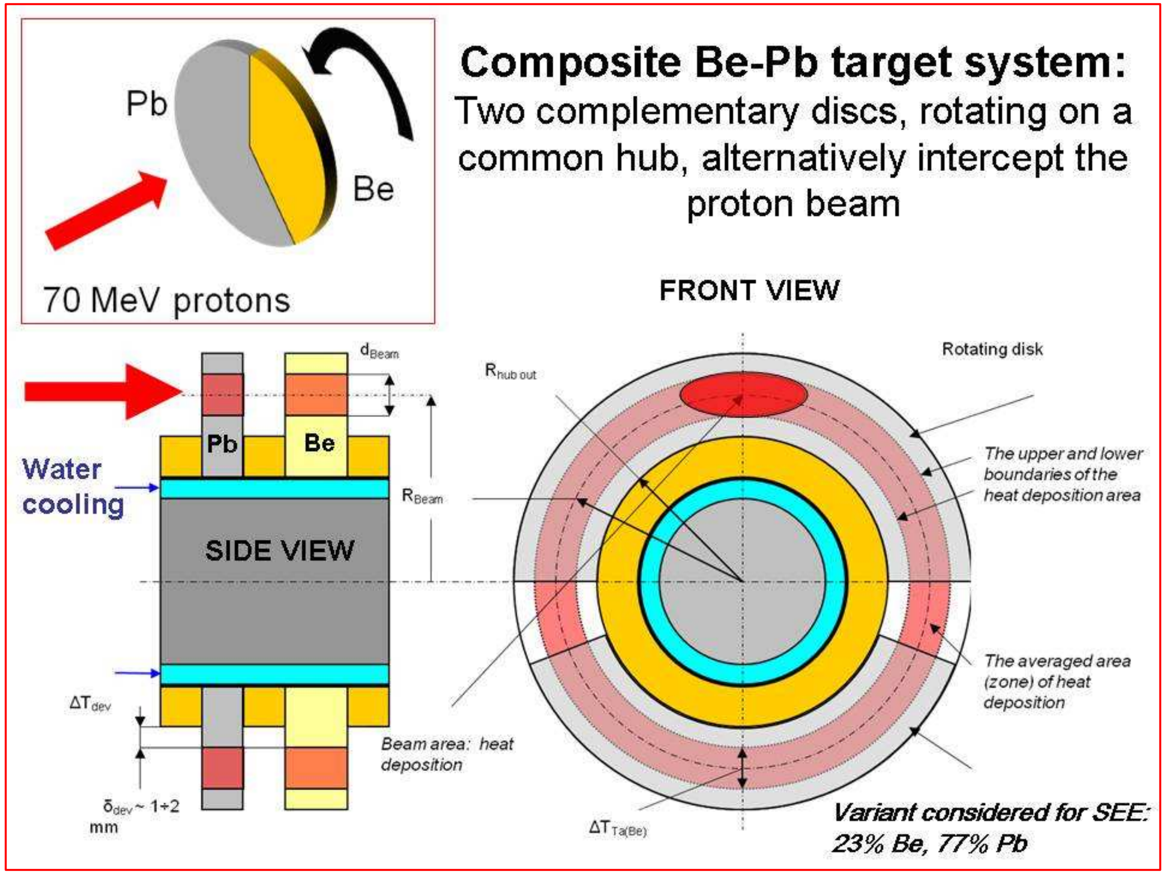
PADOVA



Note: This target is "not-thick"; i.e. does **not stop the protons** (this avoids Hydrogen build up in Be and hardens the spectrum by containing the production of slow neutrons).
Most of the protons pass through without causing nuclear reactions. The *spent proton beam (with residual energy ~ 15 MeV)* is then magnetically deflected towards a beam dump.

Power dissipation

PADOVA



1. Power is distributed in a circular ring (time averaged beam spot)
2. Heat is then conducted inwards
3. and removed by flowing water in coaxial pipe (forced convection)

It is of primary importance to validate ANSYS calculations by measuring the heat transfer coefficient h (W/m^2K) to the flowing water.

heat-transfer coefficient h (forced convection)

- It is not a thermal property, as is thermal conductivity. Its value cannot be looked up in a table of properties.

- **In general h must be determined experimentally; its determination is indeed the primary task of experiments in a forced convective system.**

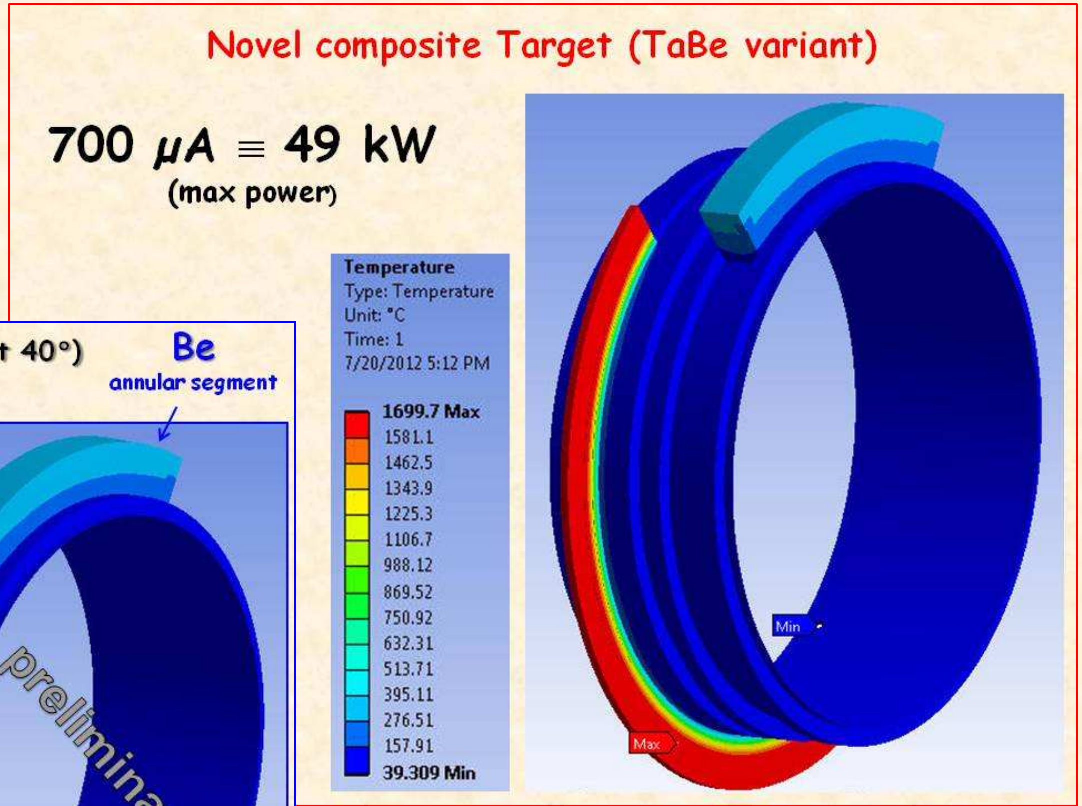
- Once h is determined the performance of a cooling system can be reliably predicted.

- In order to determine an experimental value for h, three primary properties of the fluid must be determined: temperature, conductivity, and fluid velocity. For most applications, the heat transfer coefficient will be strongly coupled with fluid velocity.

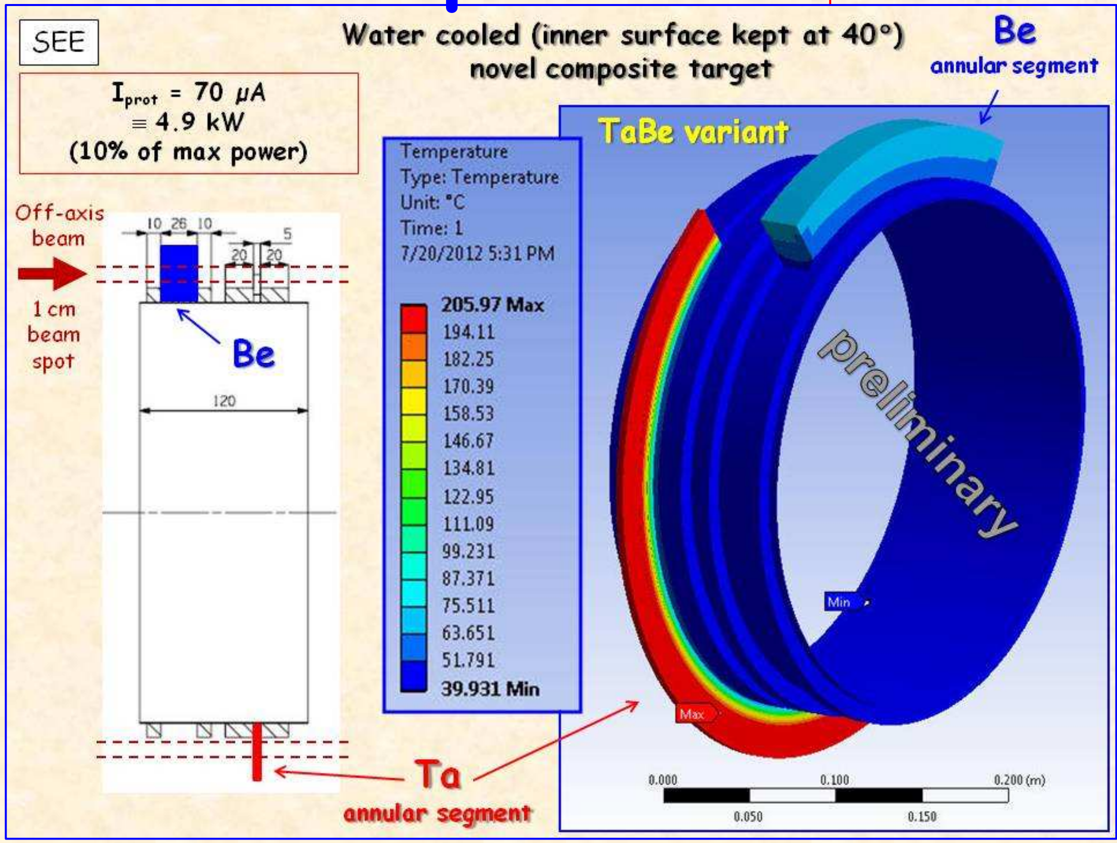
The mock-up target system must be "realistic"; i.e. we want to obtain only pertinent information.

Novel composite Target (TaBe variant)

100% power



10% power



Problems at full power.

Possible solution is to change dimensions (radius disks; waterflow)?

Will address only once ANSYS is reliably tuned (after mock-up test)

Situation summer 2013
NEUTARGS Padova

- We decided to modify an existing chamber system (of the proton energy shaper of LENOS) and devised a **very realistic mock-up** with which to measure h and tune ANSYS.
- Executable drawings are NOW being evaluated.

The mock-up is a true stepping stone towards the final design (if significant modifications are found to be necessary).

E' necessario valutare la potenza massima del bersaglio nel contesto delle possibili caratteristiche della facility di irraggiamento.
Sarebbe forse inutile progettare un bersaglio di altissima potenza, costoso e di difficile realizzazione, che potrebbe non essere mai usata a piena potenza per motivi legati all'utilizzo e gestione della facility.

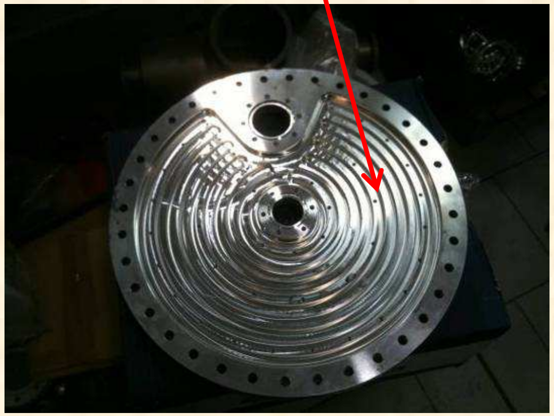
Mock-up

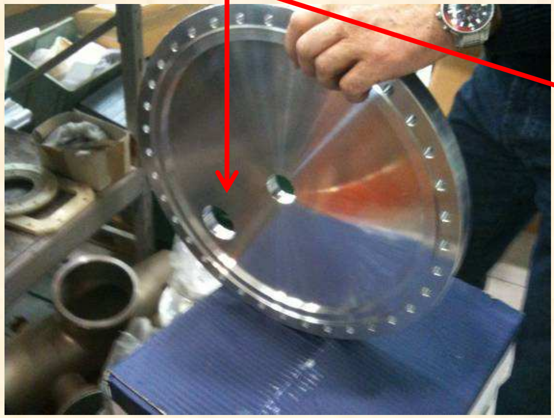
the chamber of the proton energy shaper of LENOS at LNL

Water cooled serpentine

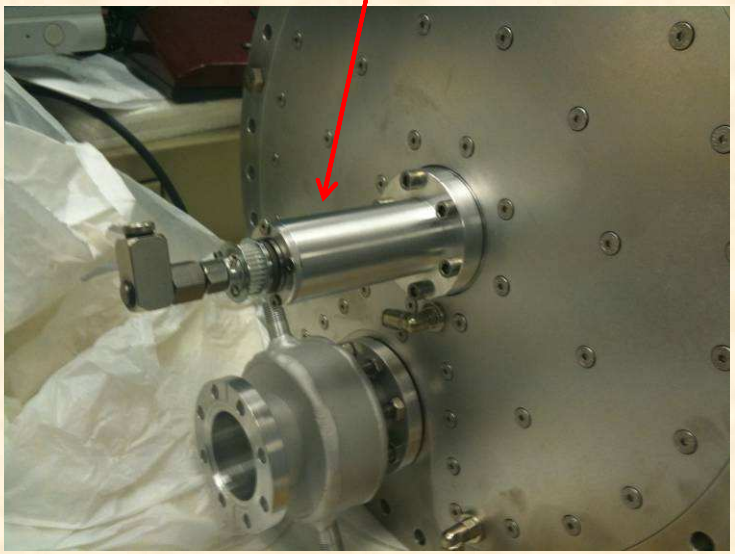
Beam entrance

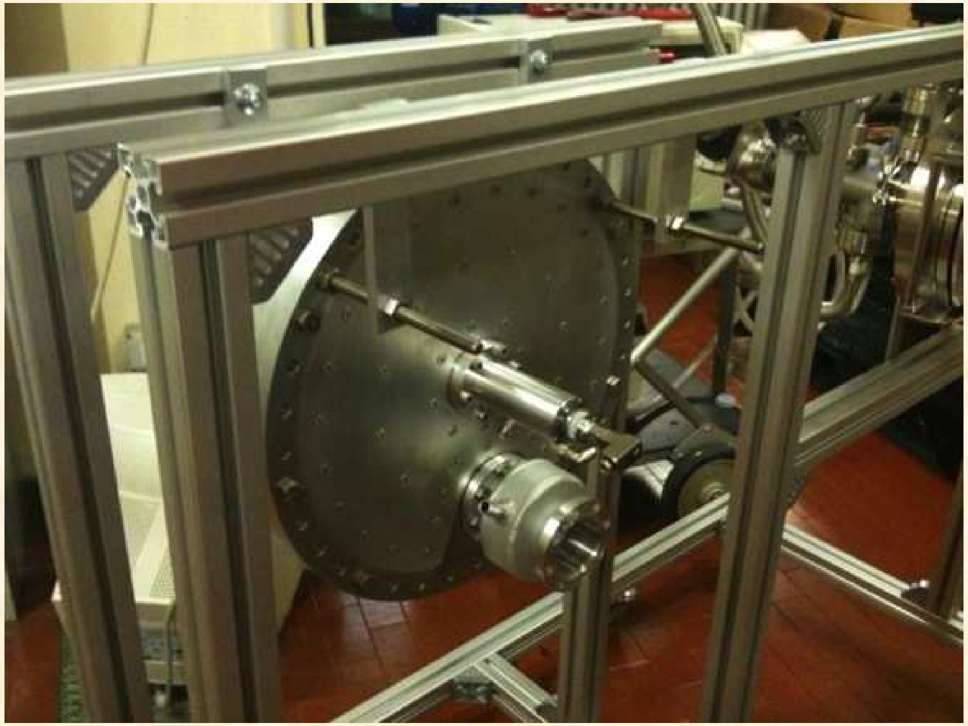
Made by VCS, Parma





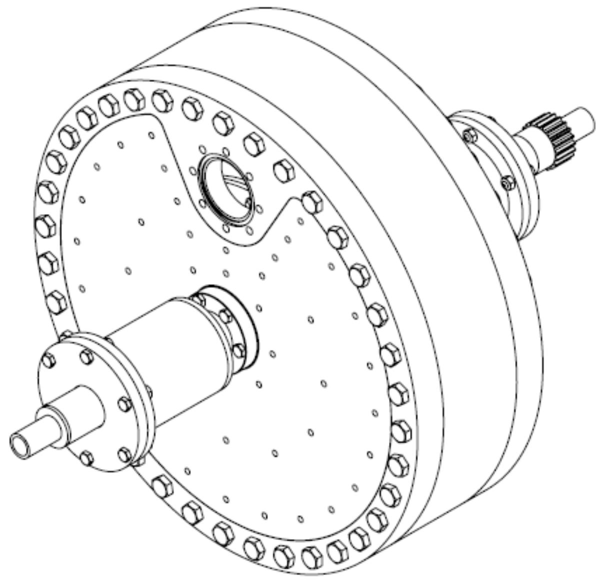
Axial water flow and rotating shaft



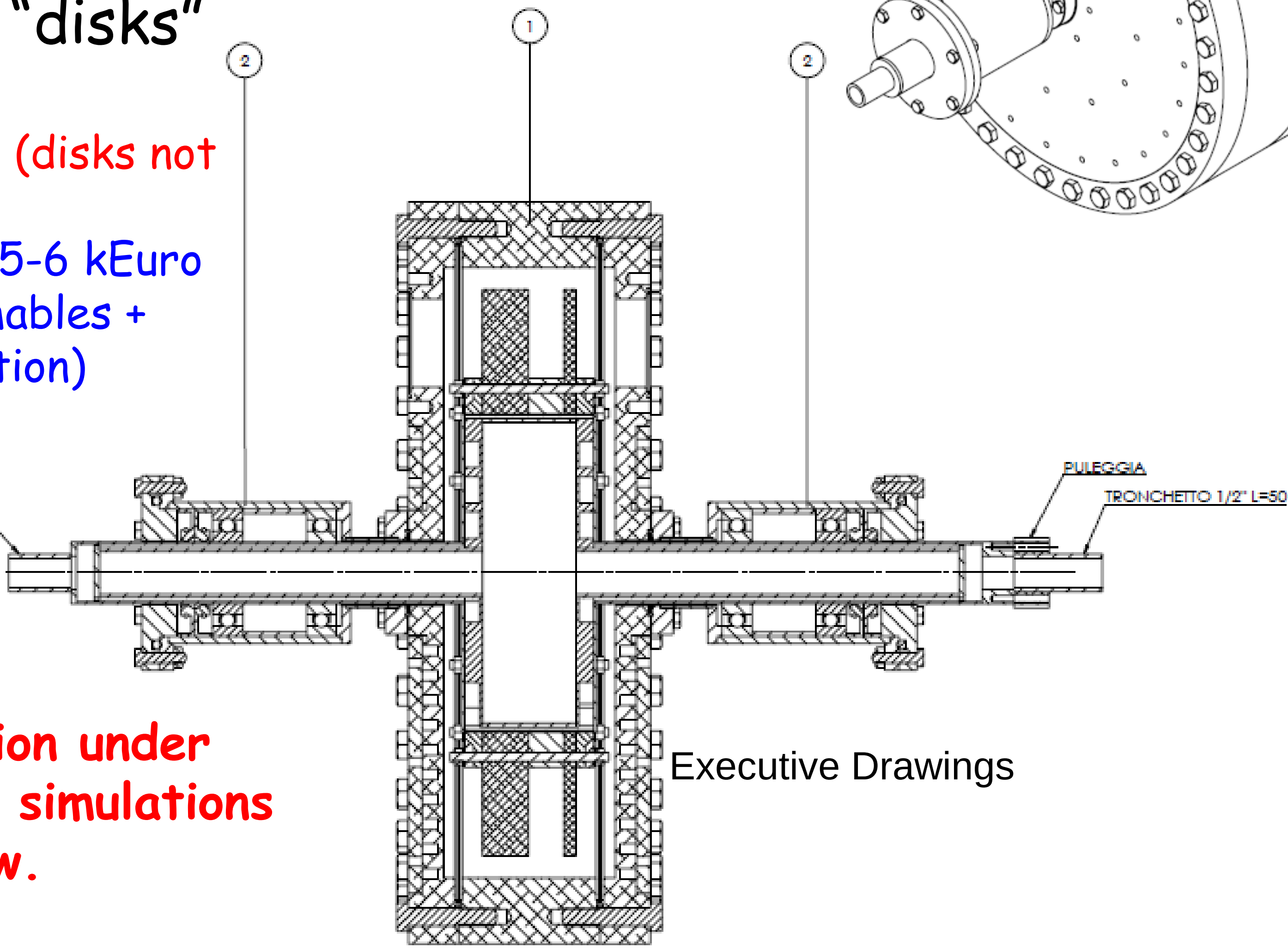


Mock-up

Executive drawings of the MODIFICATIONS of the innards to the LENOS chamber to house Be and Pb (or Ta) "disks"



Cost of parts (disks not included) and construction 5-6 kEuro (2013 consumables + small integration)

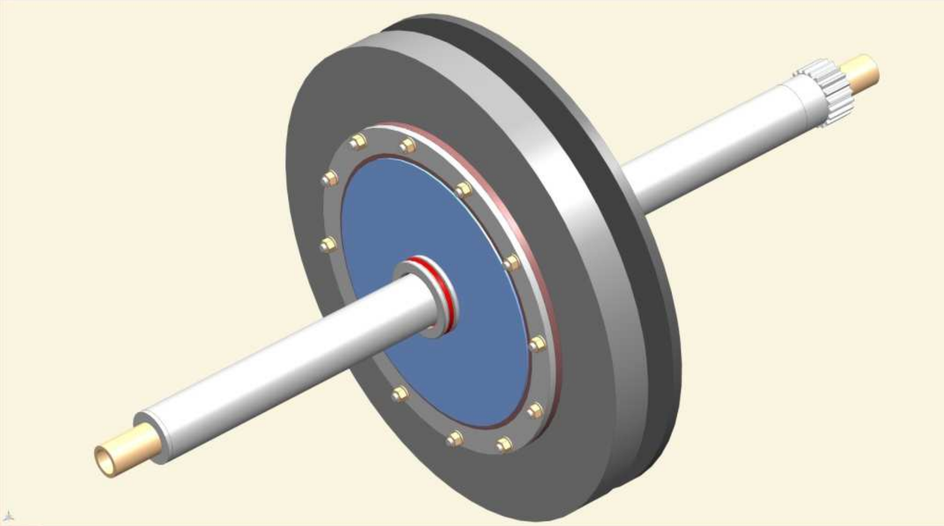


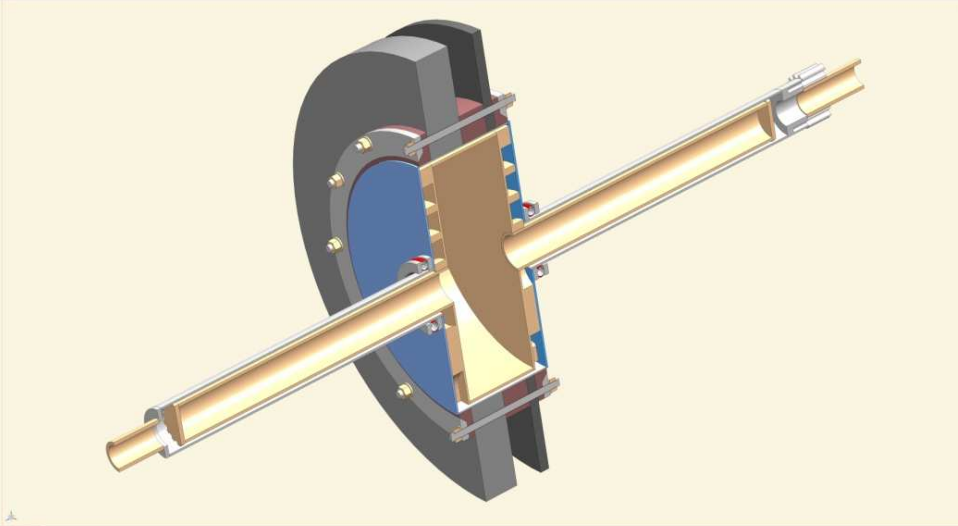
Executive Drawings

Basic validation under way. ANSYS simulations soon to follow.

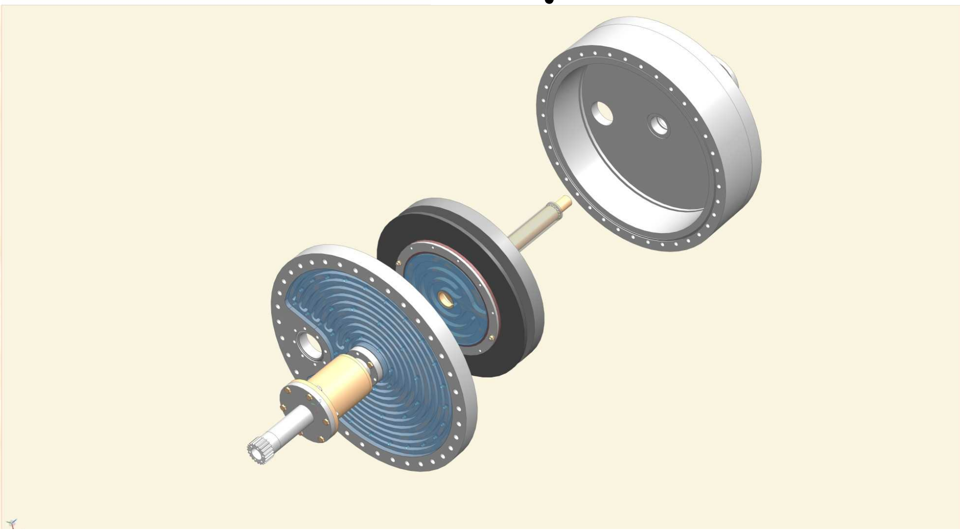
Executive drawings of mock-up system

innards



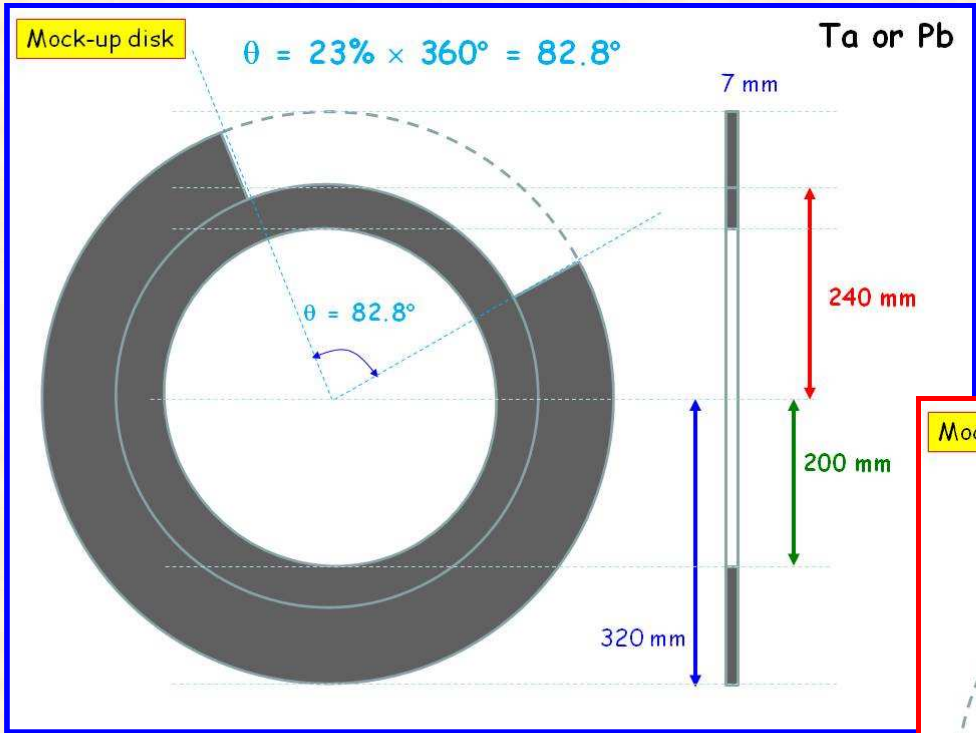


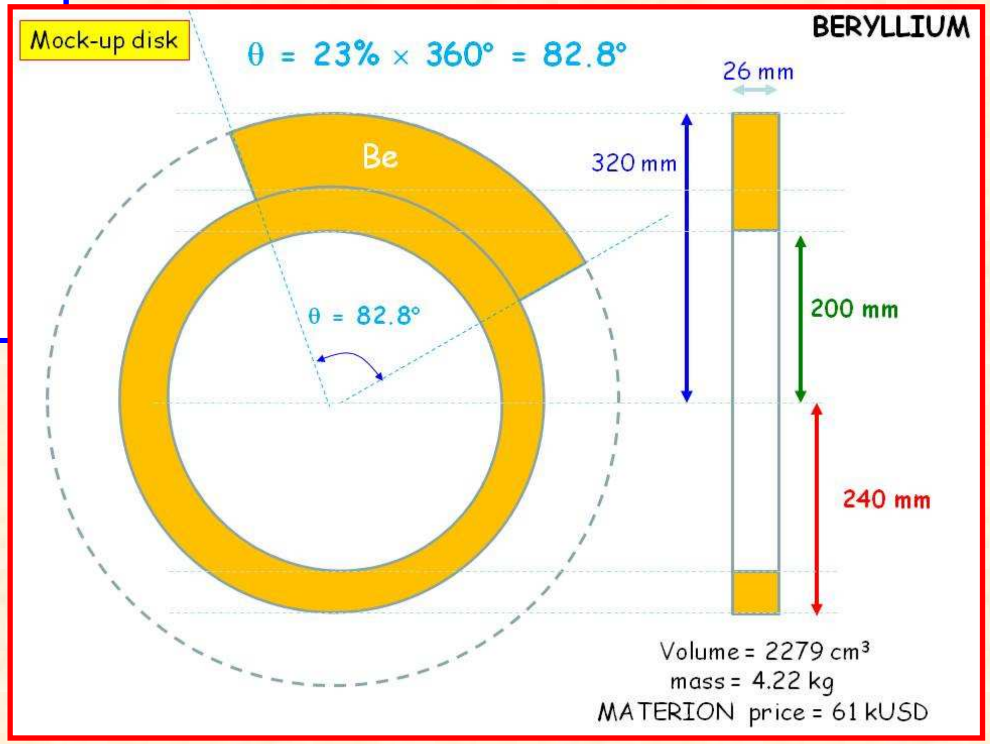
assembly



Mock-up

"disks" for the target system with the present design mock-up





Mock-up

Mock-up for tests:

- The **high cost of Beryllium (machined)** guides the design of the targets. In particular the cost of the test targets of the mock-up should be contained (within NEUTARGS funding, plus some additional funds from other sources).

- The thickness of the test disks depends on where the beam test is made (on the proton energy). ***See Next slide.***

- **BUT one can evaluate the h of the forced water cooling by using another material instead of Be, say aluminum or copper.**

- **Because of high cost of Be, we could change the design of the test Be disks… an idea in to pursue towards the final design** ("sector" instead of "disk")

Thickness of test-disks depends on where beam tests are made

- *Pavia 18 MeV proton cyclotron (for thin QMN targets only)*
- **JRC 40 MeV (up to 30μA) cyclotron at Ispra (Varese)**
- iTHEMBA 66 MeV (300 μA) cyclotron (a possibility in Dec 2013)
- and of course … SPES cyclotron 70 MeV (500 μA)

Energy (MeV)	Range in Be (mm)(*)	Range in Pb (mm)(*)	Range in Al (mm)(*)
18	*2.30*	0.79	1.75
40	**9.77**	2.97	7.23
66	**24.17** (**)	6.97(**)	19.57(**)
70	**26.85**	7.70	19.57

(*) SRIM tables
(**) linear interpolation

Choice Be test disk 9 mm

Choice Pb test disk 2.8 mm

Choice Al test disk 7 mm

Cost of Be

Very high cost of Be (machined!)

- MATERION (USA) (*)
- GOODFELLOWS (UK) (**)
- Kazakhstan (prices not quoted officially)

(*) prices refer to I-70-H Grade Beryllium (99%)

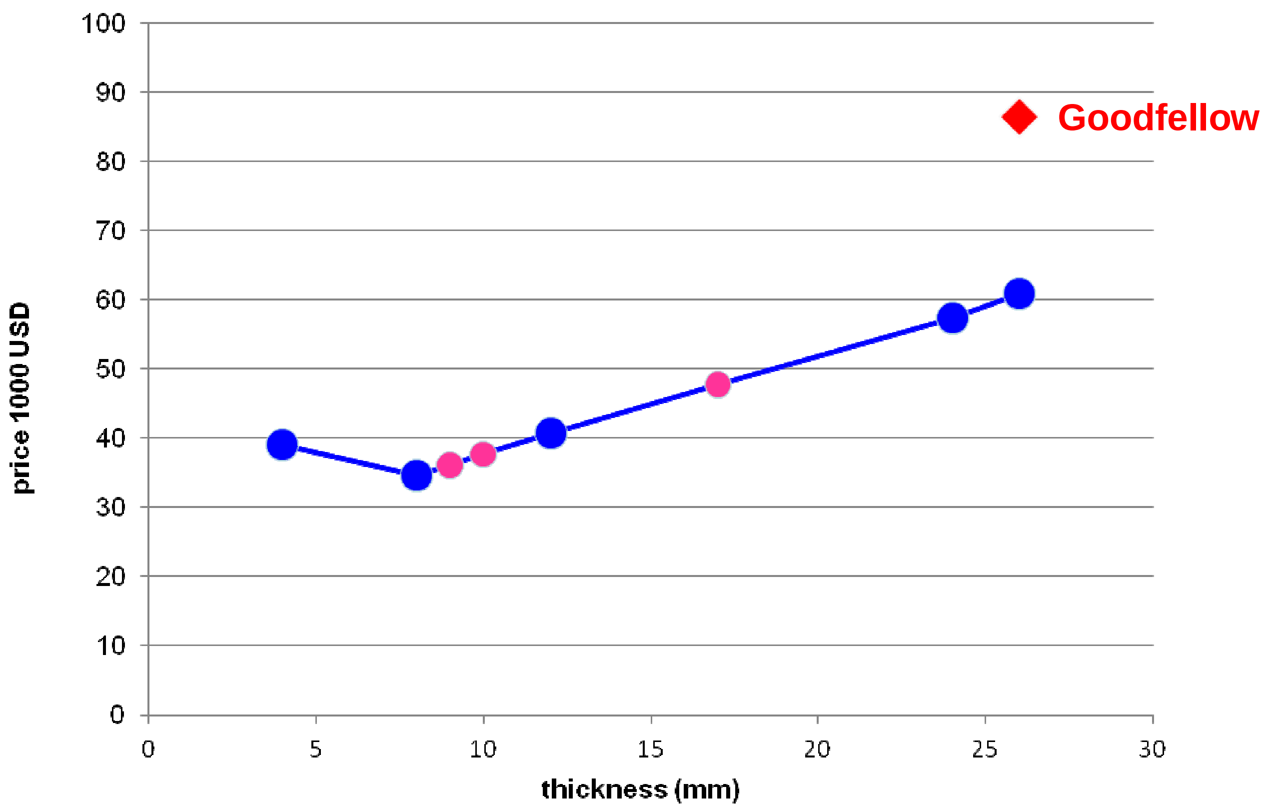
NOTES:
• the S-200-F Standard Grade Beryllium (98.5 %) would cost about 30% less
• the "nuclear standard" (Juan Esposito) S-65 Grade Beryllium (also 99%) would cost significantly more.

(**) 99% Be

Cost of Be

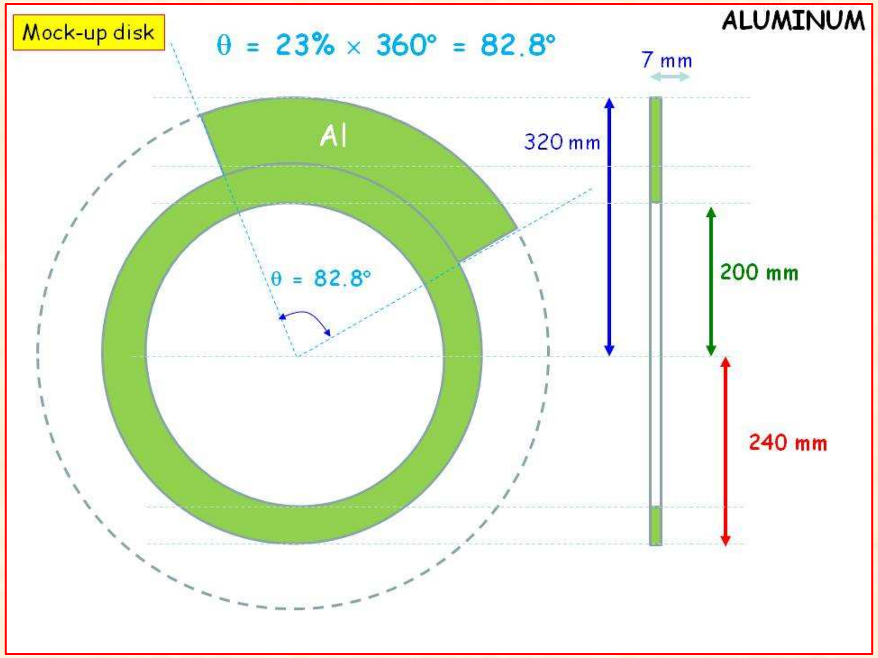
	thickness (mm)	price (USD)	density Be (g/cm³)	volume (cm³)	mass (kg)	price/kg
MATERION prices of original shapes			1,85			
	4	38,969		351	0,65	60,0
	8	34,555		701	1,30	26,6
interpolation	9	36,093		789	1,46	24,7
interpolation	*10*	*37,632*		877	1,62	23,2
	12	40,708		1052	1,95	20,9
interpolation	17	47,653		1490	2,76	17,3
	24	57,377		2104	3,89	14,7
	26	60,853		2279	4,22	14,4

Note: The Kazakhstan prices are not quoted here. The representative estimates are about 17-20 kUSD/kg, but as of today it is not clear for what thickness.

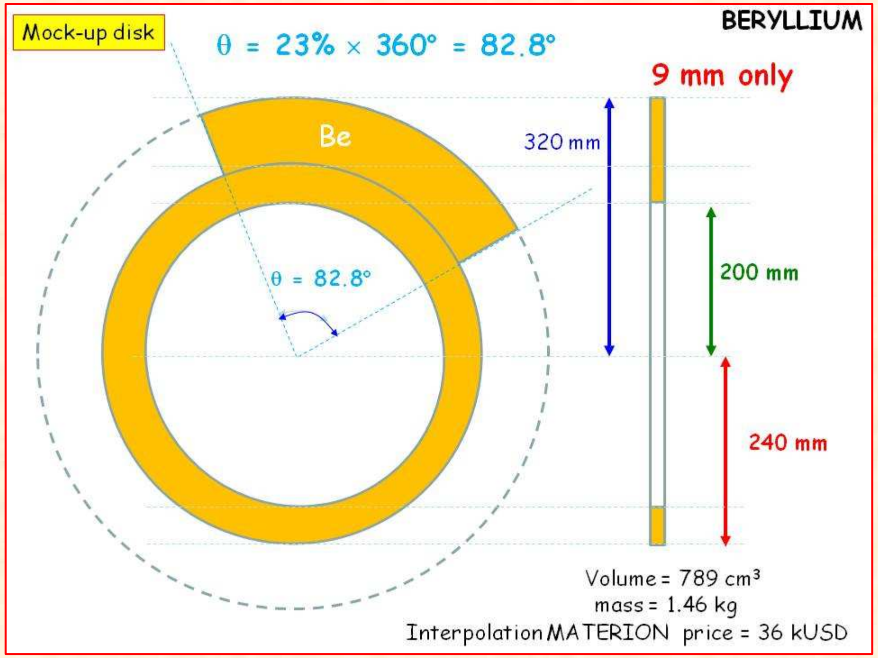


Possible test "disks" for mock-up

7mm Al



9mm Be



Commercially available (ADVENT):
5mm × 300mm × 300mm
- **99.5% £ 100 1 piece**
- **99.999% £ 1943 1 piece**

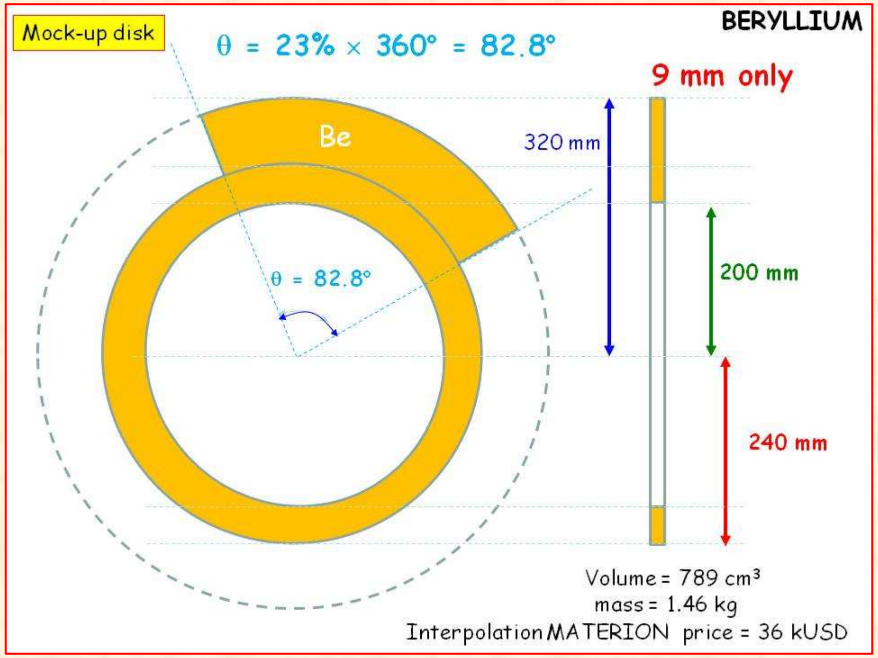
36000 USD

Al (99.5%) costs << Be

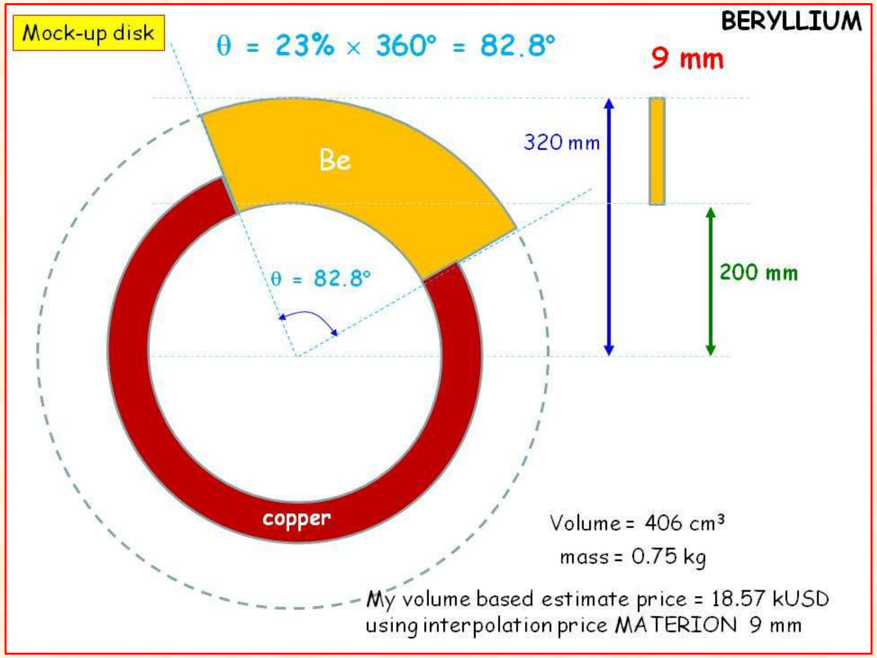
A possibility to reduce cost of Be disk for the final prototype.

Needs to be investigated in 2014 with calculations and tested with the mock-up.

"disk"



"sector"



Sector costs ~ 50% less than disk

New Plans 2014

1. Power dissipation experiments with Al 7mm thick "disk"
2. ... and with Al 7mm "sector"

3. power dissipation studies and optimization might suggest changing inner and outer diameters of the disks/sectors

4. NOTE: protons are not stopped. Must perform detailed simulations to couple the final target prototype with bending magnet and beam dump of the facility (that need to be designed in concert) while preserving atmospheric-like energy spectrum. Must optimize the thickness of the Be and Pb (or Ta).

Ordering expensive Be target is on HOLD until final shape is completely defined.

ACTIVITY 2013-2014-2015	
Jan-April 2013	Design mock-up (modifications to existing LENOS chamber)
May	Executive drawings ready
July-August	ANSYS thermal-mechanical calculations (nominal target thicknesses)
July-September	Simulations and study of coupling of target with magnet and beam-dump system of LNL facility. Conference UCANS 2013
October	Evaluation and modifications, if any. Order of chamber parts and purchase of aluminum test disk
November	Construction
December	Delivery, vacuum tests and static tests (induction coil)
January 2014	Preparation Beam tests,
February-June	Beams tests at various accelerators
June-early September	Analysis and evaluation of results
Mid September-October	Conferences (UCANS 2014, RADECS)
November	Tender for final Be disk
2015	**Purchase of Be disk. High power test and measurement of neutron spectrum (at iThemba: missioni estere + other funds)**

Richieste 2014-2015

NEUTARGS PADOVA 2014-2015

Pd

2014: Aluminum test disks and final chamber (no Be). Final Be in 2015

Richieste sezione 2014:
Officina meccanica: 1 m.u.
Progettazione meccanica: 3 m.u.

Asked/assigned PADOVA 2013	
Missions Internal	4→ **2.5**
Missions foreign	2→ **2**
consumables	15→ **5**
inventory	**0**
total	21→ **9.5**

	2014		2015	
Viaggi	**Nazionali:** PD-LNL, riunioni, thermal mechanical tests at LENA and JRC **using Al disk**	3k	**Nazionali:** PD-LNL, riunioni, thermal mechanical tests at JRC **using final Be disk**	2k
	Esteri: congressi (UCANS, RADECS)	3k	**Esteri**: congressi, misure lab esteri	4k
Cons.	• realistic test Al (99.5%) disk and sector 7 mm • definitive Pb 208 (99.9%) ingot • ancillary parts and mechanics • setup for final test at JRC	2k 3k 2k 5k	• *final* Be sector or **disk** (**26 mm** thick) machined and nuclear-grade	**40-80**k
	total consumables	**12k**	**total consumables**	**40-80k**
Invent.	• motor • definitive chamber (without disks)	2k 12k		
	total invent.	**14k**	**total invent.**	
totale	**32 kEuro**		**46-86 kEuro**	

Extra slides

Schematic of modifications (the innards) to LENOS chamber

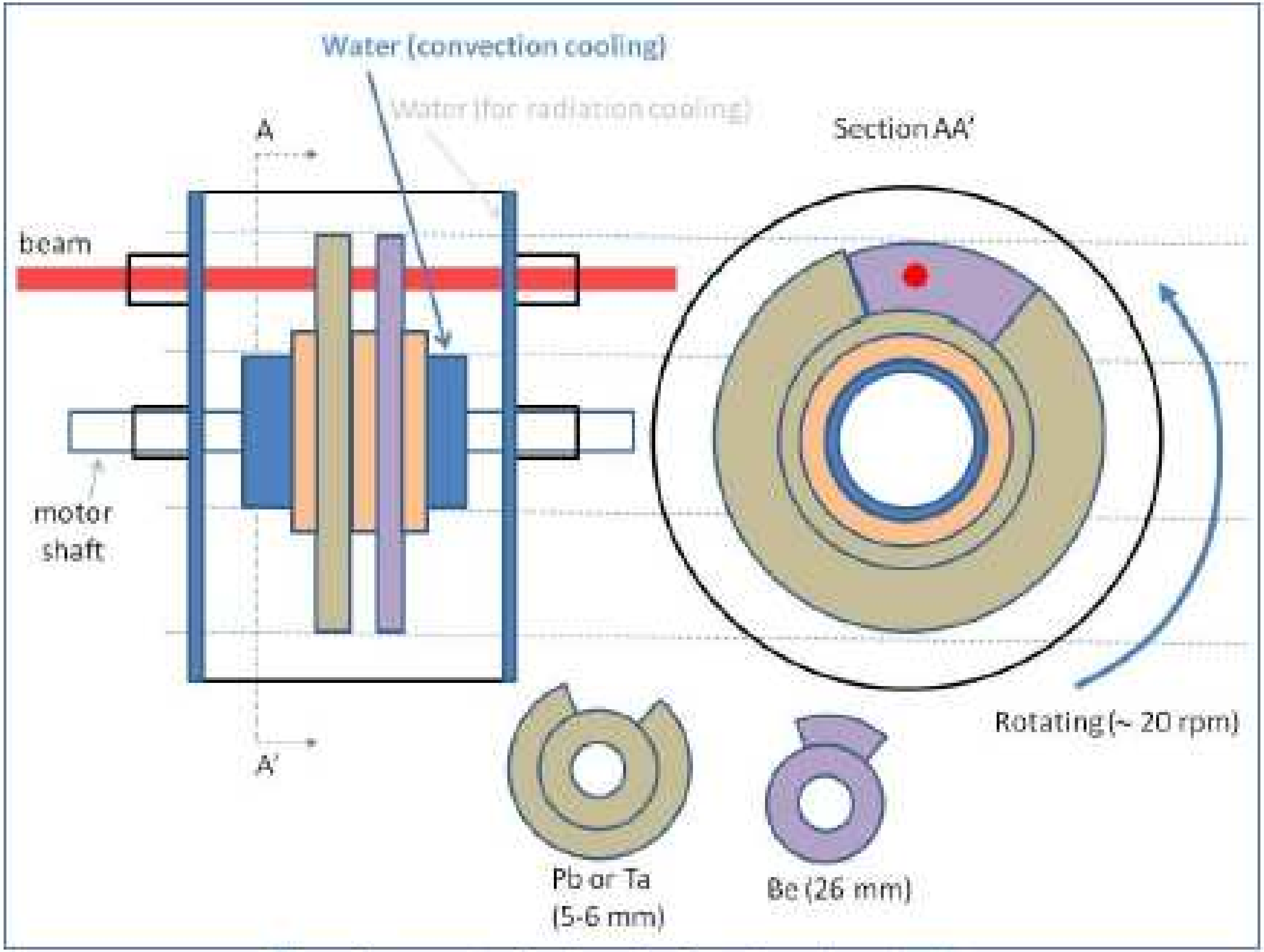


Figure 1: conceptual schematic of mock-up target system

PADOVA

PREVENTIVO GLOBALE DI SPESA PER L'ANNO 2013

Struttura	A carico dell'I.N.F.N.									
	interno	estero	consumo	trasporti	manutenzione	inventario	licenze-SW	apparati	spservizi	TOTALI
LNL	4.00	2.00	23.00			30.00				59.00
PD	4.00	2.00	15.00							21.00
PV	1.00							10.00	5.00	16.00
Totali	9.00	4.00	38.00			30.00		10.00	5.00	96.00

Mod. EC/EN 4 (a cura del responsabil

Bilancio 2013 > Globale > Gruppo V > Esperimento NEUTARGS > Riassuntivo assegnazioni

Sez. & Suf.	MI	MI Sj	MI Dot.	MI Ant.	ME	ME Sj	ME Dot.	ME Ant.	CON	CON Sj	CON Dot.	CON Ant.	SEM	SEM Sj	SEM Dot.	SEM Ant.
LNL	4.0				2.0				23.0							
	2.5				0.0				4.0			11.0				
PD	4.0				2.0				15.0							
	2.5				2.0				5.0							
PV	1.0															
	1.0															
TOTALE	9				4				38							
	9				4				38				0			
	6		0	0	2		0	0	9		0	0				
	6.0				2.0				9.0				0.0			

Sez. & Suf.	TRA	TRA Sj	TRA Dot.	TRA Ant.	PUB	PUB Sj	PUB Dot.	PUB Ant.	MAN	MAN Sj	MAN Dot.	MAN Ant.	INV	INV Sj	INV Dot.	INV Ant.
LNL													30.0			
													0.0			
PD																
PV																
TOTALE													30			
	0				0				0				30			
													0		0	0
	0.0				0.0				0.0				0.0			

Sez. & Suf.	APP	APP Sj	APP Dot.	APP Ant.	LIC-SW	LIC-SW Sj	LIC-SW Dot.	LIC-SW Ant.	SPSERVIZI	SPSERVIZI Sj	SPSERVIZI Dot.	SPSERVIZI Ant.	TOTALE	TOTALE Sj	TOTALE Dot.	TOTALE Ant.
LNL													59			
													6.5			11
PD													21			
													9.5			0
PV	10.0								5.0				16			
	5.0								5.0				11.0			0
TOTALE	10								5				96	0		
	10				0				5				96			
	5		0	0					5		0	0	27		0.0	0.0
	5.0				0.0				5.0				27.0			

NEUTARGS PADOVA (SEE: the composite PbBe target)

Pd

	2013		2014		2015	
Viaggi	**Nazionali:** PD-LNL, riunioni, thernal-mechanical tests at CN and LENA	4k	**Nazionali:** PD-LNL, riunioni	2k	**Nazionali:** PD-LNL, riunioni, thermal mechanical tests at LENA	4k
	Esteri: congressi	2k	**Esteri**: congressi	2k	**Esteri**: congressi	2k
Cons.	• Be test disk • Pb test disk • Ta test disk • ancillary parts and mechanics • cooling system for test disks • setup for test at CN and LENA	5k 1k 2k 1k 3k 3k	• definitive Be (machined and nuclear-grade) • definitive Pb • ancillary parts and mechanics	20k 3k 5k	• cooling system • setup for final test at LENA	15k 5k
	total consumables	**15k**	**total consumables**	**28k**	**total consumables**	**20k**
Invent.			• motor	2k		
	total invent.		**total invent.**	**2k**	**total invent.**	
totale	**21 kEuro**		**34 kEuro**		**26 kEuro**	

Preventivi 2013-2015 presentati 2012

Officina meccanica: 2 mesi ogni anno

To evaluate the feasibility of the proposed target system we need a realistic mock-up. Indeed the power dissipation of the proposed target occurs in three steps:

1) the beam spot is off-axis and, as the target is rotating, the power is effectively deposited in a peripheric circular ring;
2) the heat is then conducted radially inwards towards the axis of rotation
3) the heat is finally carried away by flowing water (forced convection).

While the first two can be reliably simulated, the third step cannot. The heat-transfer coefficient h of forced convection is not a thermal property, as is thermal conductivity, so one cannot look up the value in a table of properties[1]. For most situations of practical interest h must be determined experimentally; the determination of h is indeed the primary task of experiments in a forced convective system. Once h has been, the performance of a cooling system can be predicted[2]. In order to determine an experimental value for h, three primary properties of the fluid must be determined: temperature, conductivity, and velocity. For most applications, the heat transfer coefficient will be strongly coupled with fluid velocity.

To furnish pertinent information in order to evaluate the proposed target scheme and guide us towards the final design, the mock-up target system must be realistic. For this purpose we have decided to modify an existing chamber system. The high cost of Beryllium will guide the design of the targets.

---

[1] Only when simple geometries and laminar flow conditions are involved, the heat-transfer coefficient can be determined analytically.

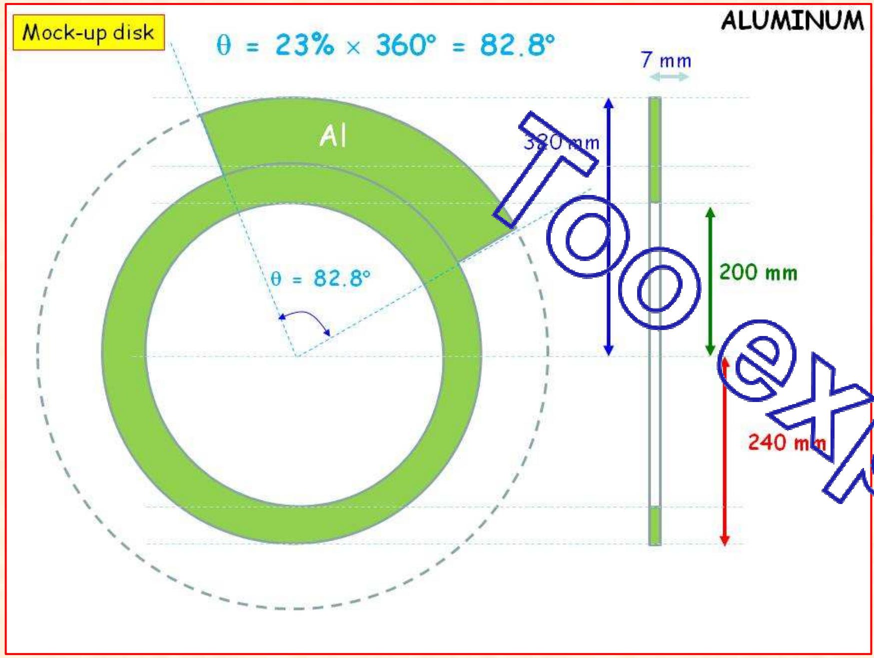
[2] The determination of the heat transfer coefficient h is specific to each geometry and flow pattern. Standard experiments for determining h are done as follows:

1. Specify the heat transfer system and flow pattern realistically.
2. Evaluate the power dQ/dt (W) on the target.
3. Measure the temperature of the fluid flow to determine the fluid properties.
4. Determine the velocity of the fluid flow.
5. Determine the surface temperature of the target
6. Calculate the area A through which the heat is being transferred.
7. Determine h from the formula $dQ/dt = hA\Delta T$

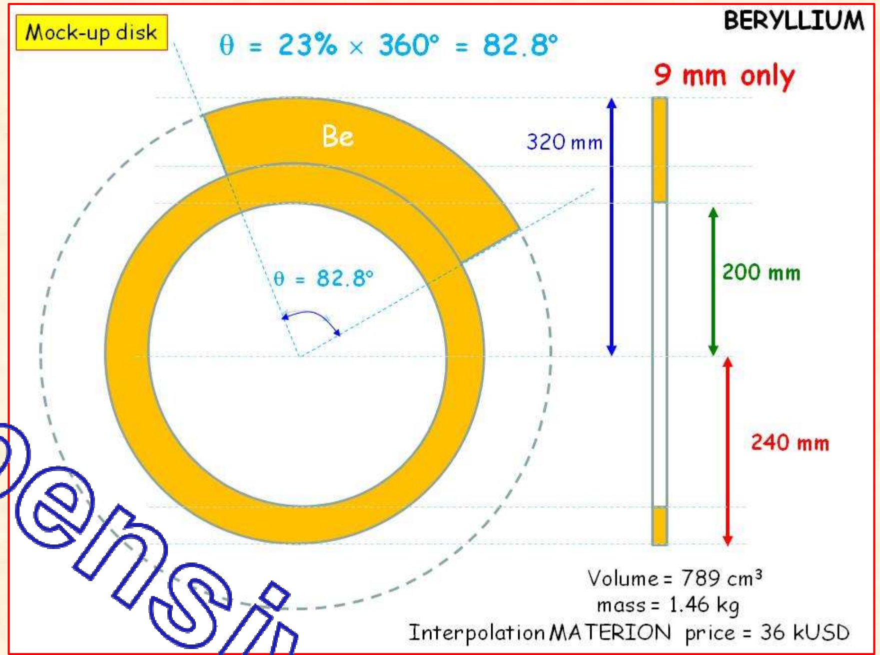
Mock-up

Possible test "disks" for mock-up

7mm Al



9mm Be



Too expensive

Commercially available (ADVENT):

- **99.999% £ 1943 1 piece**
- **If cost scales with volume then a 5mm×640mm ×640mm slab would cost ~ £ 9000**

36000 USD

Al costs ~ 1/2 Be