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FOR NEW TECHNOLOGIES, ENERGY AND
SUSTAINABLE ECONOMIC DEVELOPMENT

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ERINDA
European Research Infrastructures
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A Project for High Fluence 14 MeV Neutron Source

(New Sorgentina Fusion Source)

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OUTLOOK

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- Performances and main features of the New Sorgentina Fusion Source (NSFS)
- Ion Source
- Rotating Target
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INTRODUCTION

A point of concern in Fusion Technology is represented by the capability of materials and diagnostics to withstand the harsh working conditions expected in next step reactors (e.g. DEMO).

In particular plasma facing components, structural materials, insulator materials and diagnostics components have to withstand very high level of neutron and gamma radiation.

The method to test and validate materials and diagnostics components is to irradiate them in neutron fluxes similar in energy and fluence to that of DEMO.

Already 20 years ago, the international community agrees on the importance to built a large facility devoted to this scope: the ***IFMIF*** project was chosen.

At that time (1990) however ENEA had proposed a facility, named Sorgentina, whose dimensions and cost were much reduced respect to IFMIF.

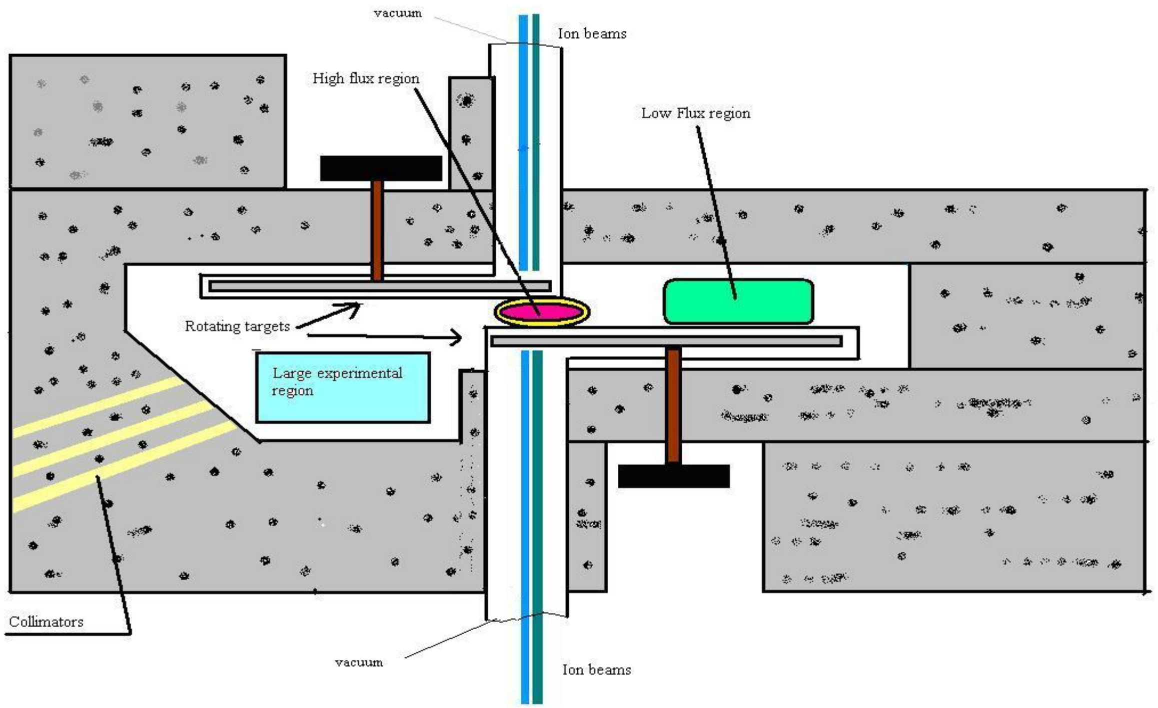
The neutron irradiation data attainable from this facility could represent a valid reason for justifying its construction.

OLD SORGENTINA MOTIVATION

- ✓ There is an urgent need to obtain irradiated material damage data; i.e. material strength vs. Displacement Per Atoms (DPA) @ 14 MeV.
- ✓ Construction time of IFMIF is of the order of some tens of years.
- ✓ Sorgentina could be built in 3-4 years.
- ✓ Sorgentina can produce in a volume of 50 cm^3 a neutron flux of 5E+12 n $cm^{-2}s^{-1}$ corresponding to 1 DPA/year in iron.
- ✓ The idea behind Sorgentina is that the ***experiments on materials damage pertaining to fusion technology could be performed with the existing fission reactors, provided that it can be experimentally demonstrated by using a 14 MeV neutron source, that the variations in materials properties depends only mildly on the neutron energy spectrum*** (Calibration of the Irradiation Tests between a Fission Reactor and a 14 MeV neutron source needed).

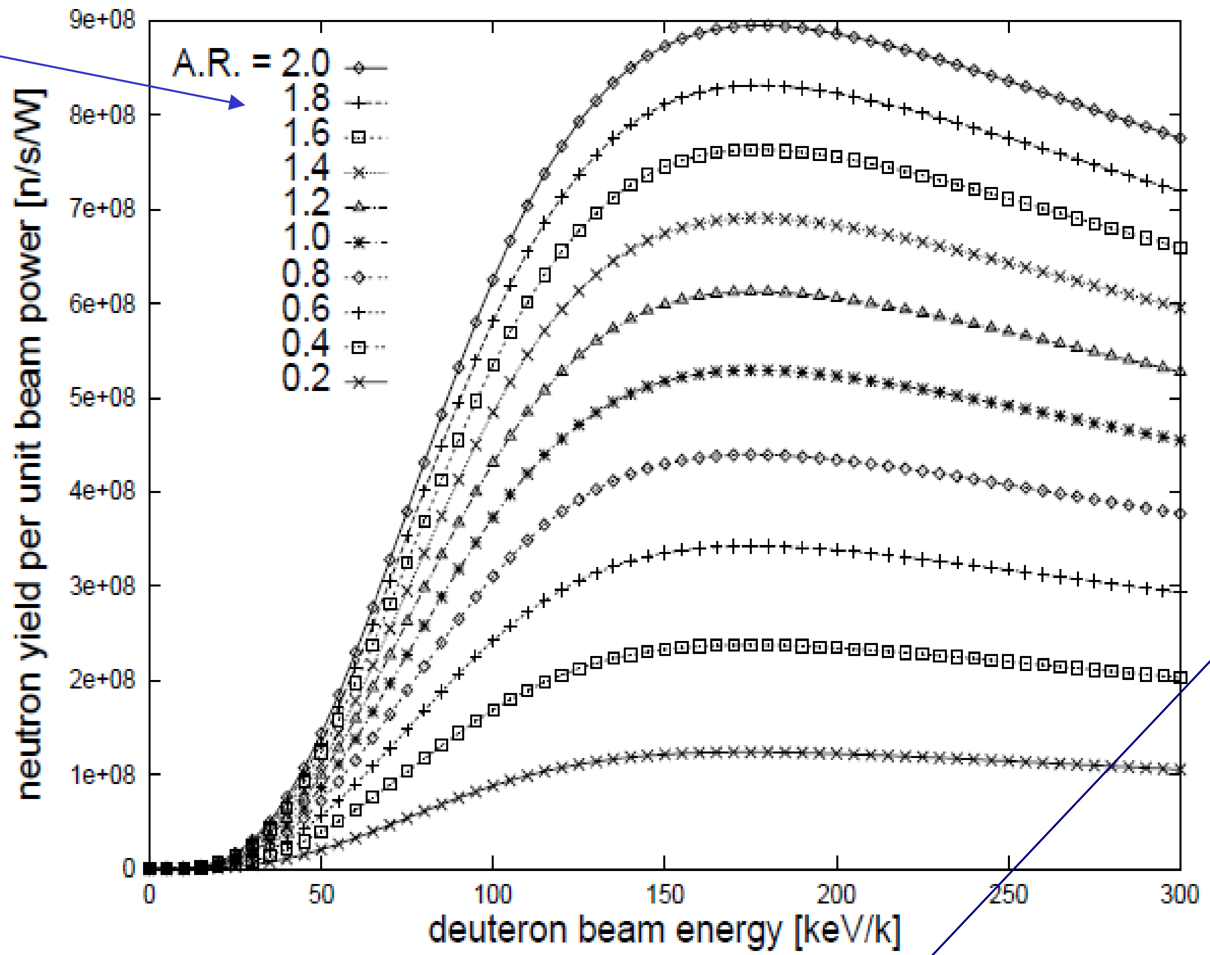
The New Sorgentina Fusion Source (NSFS)

- The ***"New Sorgentina"*** project is based upon ***two intense D-T 14 MeV rotating targets facing each-other.***
- Two beams of ***160 kV, 25 A*** each fire 50-50% Deuterons and Tritons on a ***2 m radius rotating target.***
- ***Deuterium and Tritium are implanted during the beam bombardment*** on a Titanium layer covering the rotating targets.
- The Titanium layer, damaged by ion bombardments, is continuous reformed using a sputtering source



Neutron yield calculation - D beam on T

TiT Atomic Ratio



$D^+ \rightarrow k=1$

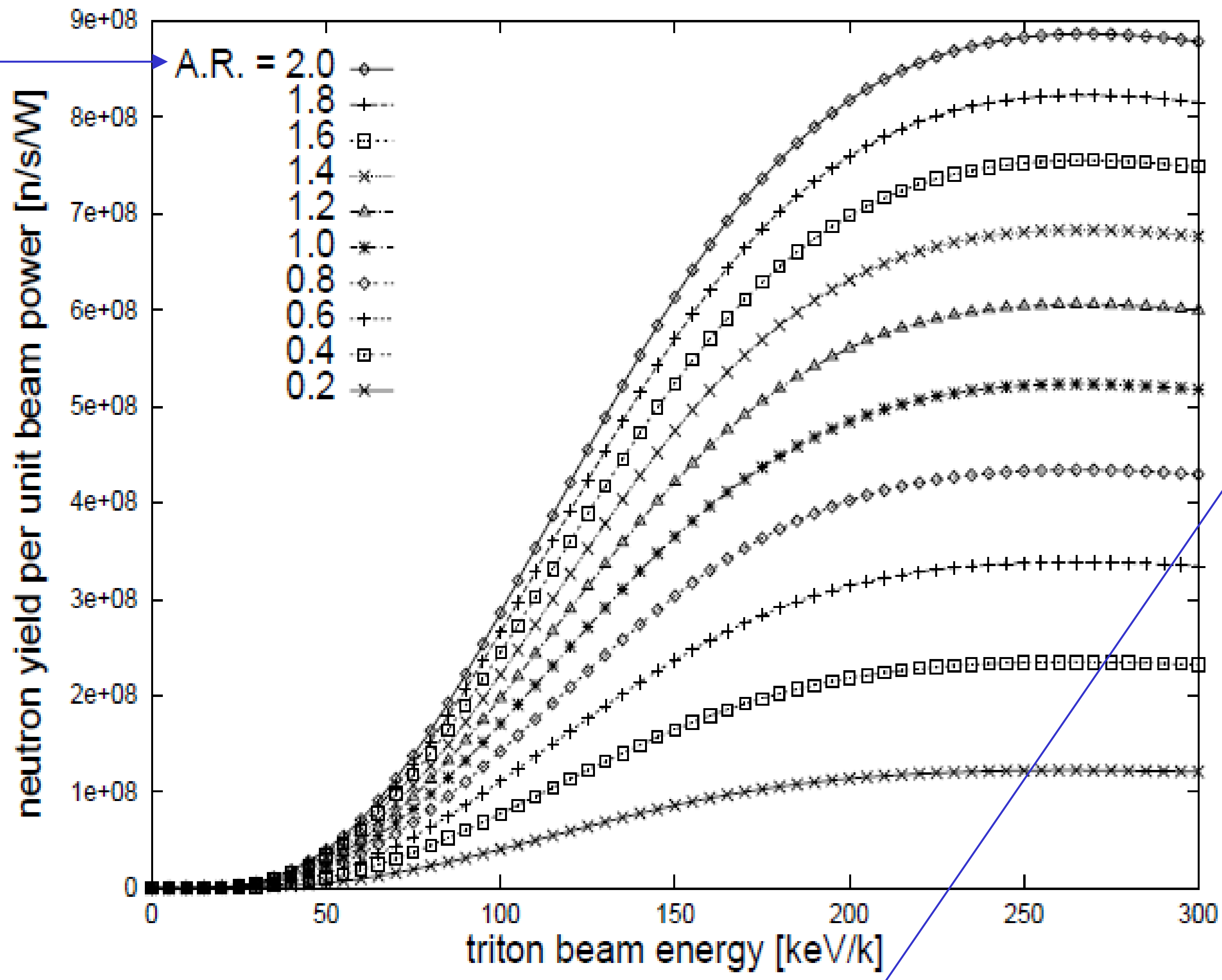
$D_2^+ \rightarrow k=2$

$D_3^+ \rightarrow k=3$

Figure 7.4: Neutron yield per unit beam power versus beam energy for deuteron beams impinging on a titanium target loaded with tritium. k in the units of the energy scale refers to the number of nuclei per ion.

Neutron yield calculation - T beam on D

TiD Atomic Ratio



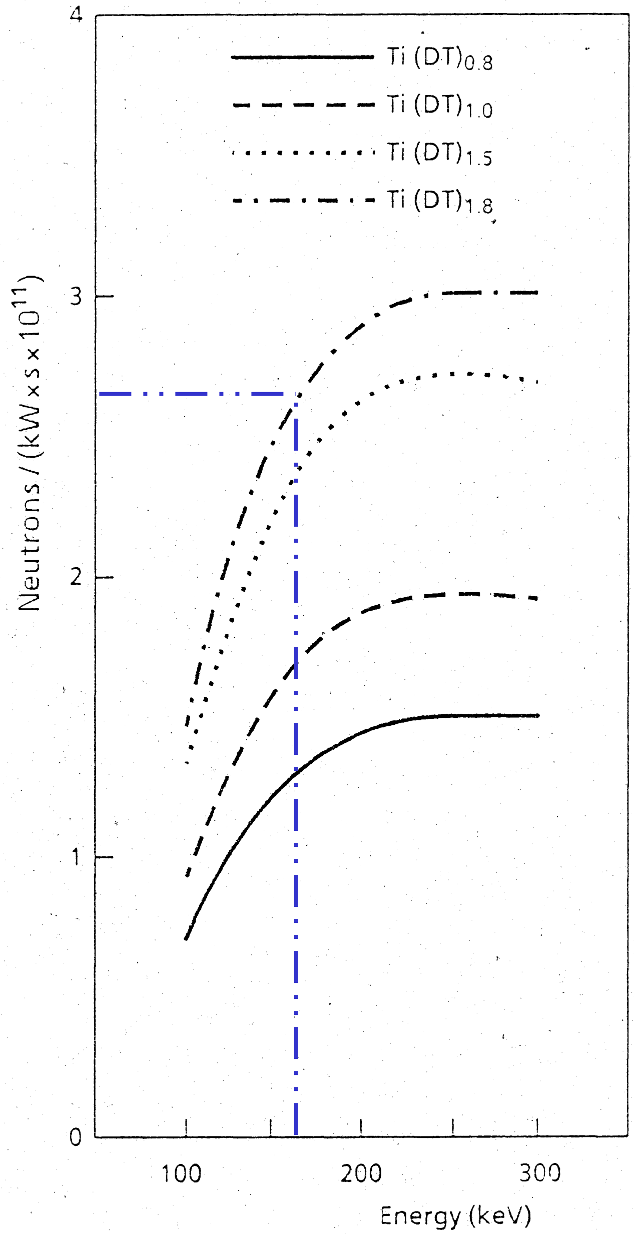
$T^+ \rightarrow k=1$

$T_2^+ \rightarrow k=2$

$T_3^+ \rightarrow k=3$

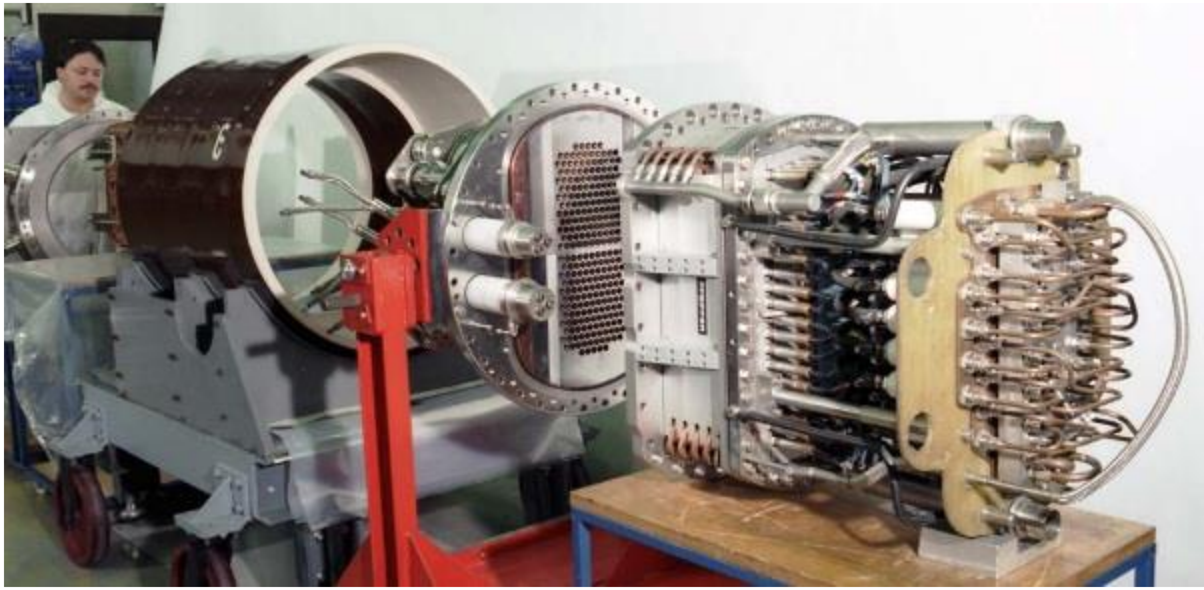
Figure 7.6: Neutron yield per unit beam power versus beam energy for triton beams impinging on a titanium target loaded with deuterium. k in the units of the energy scale refers to the number of nuclei per ion.

Total Neutron yield – one source



Neutron production from 2x25A beam of 160 kV with ion composition D^+ 83% D_2^+ 7% D_3^+ 10% impinging on a Ti $(DT)_{1.8}$-implanted target is 2E15 n/s. This correspond to a total beam power of 8 MW which for a beam spot size of 20x10 cm^2 correspond to a power density of 40 kW/cm^2.

THE ION SOURCES – JET PINI (Positive Ion Neutral Injector) Neutralization is not required!



Extraction voltage (kV)		160
Extraction current (A)	We need 25 A	38
Current density (A/cm^2)		0.15
Current pulse duration (s)		20
Ion species		D^+ $D_2{}^+$ $D_3{}^+$
Species yield (%)		83:7:10
Operational pressure (mtorr)		2.5-10
Gas consumption (torr x l/s)		10
Beam focal length in horizontal plane (m)		10
Beam focal length in vertical plane (m)		14
Beam divergence (deg.)		0.7

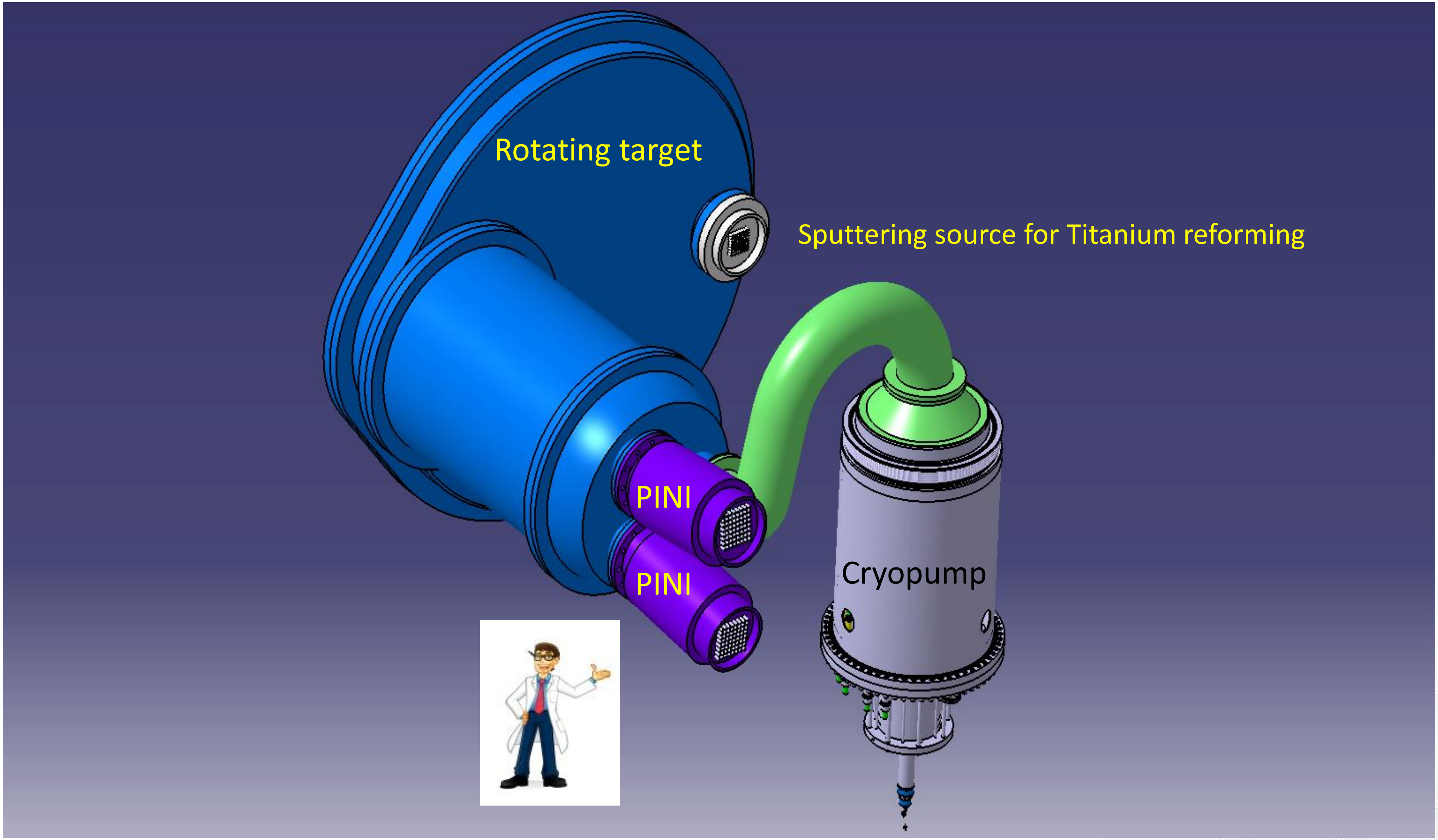
The PINI at JET are operated in pulsed mode (pulse length up to 20 s) with a low duty cycle while NSFS must *operate in continuous mode.* The main modification is to replace the filaments with a RF system to produce the plasma. This has been already tested (A.J.T. Holmes private communication, old Sorgentina Report, sect. 8).

NOTE:* *With RF system ion species is ratio ~ 100:0:0.

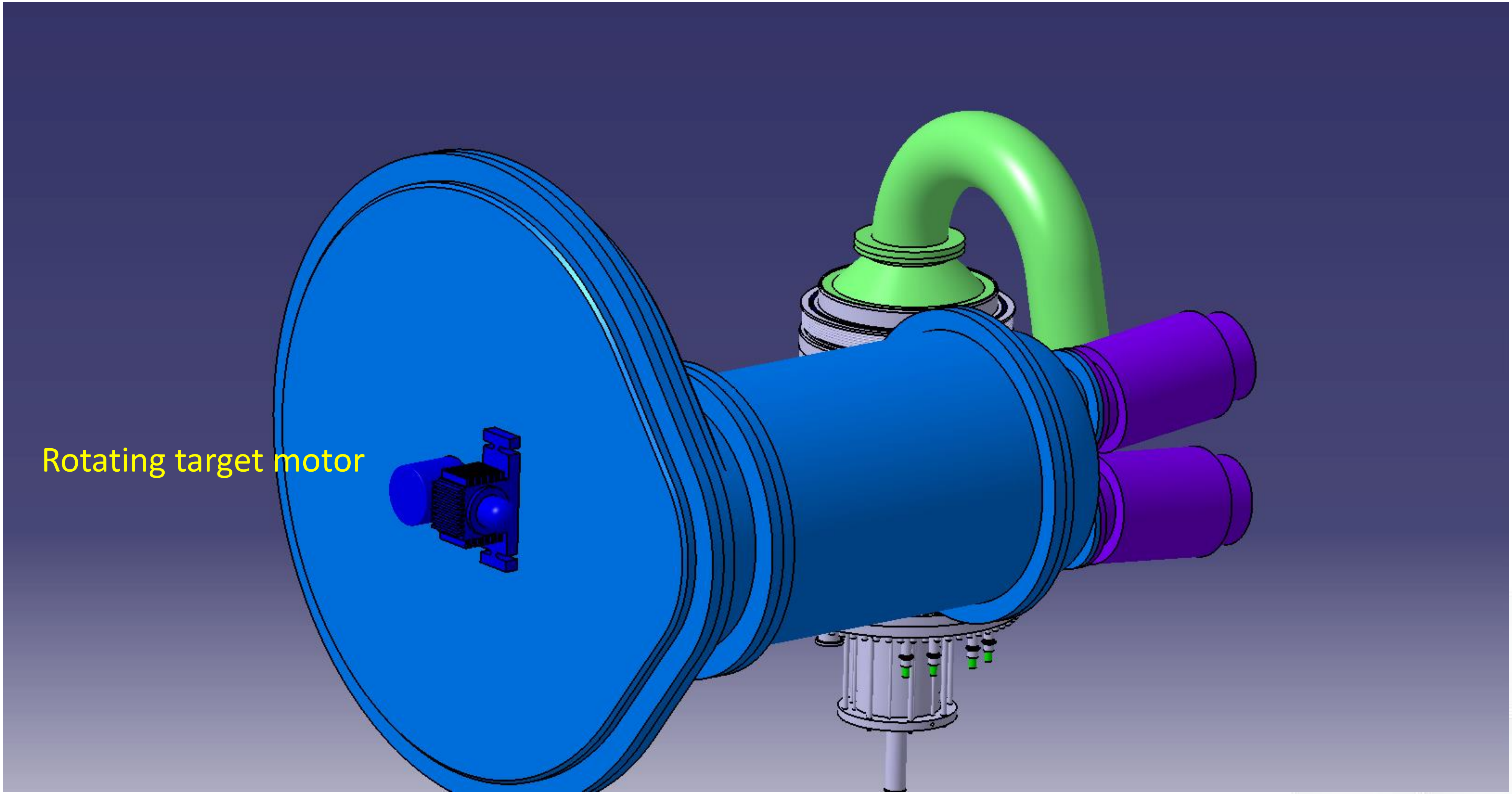
In this case the neutron yield increases of ~ 1.46

Two JET PINI firing into JET plasma

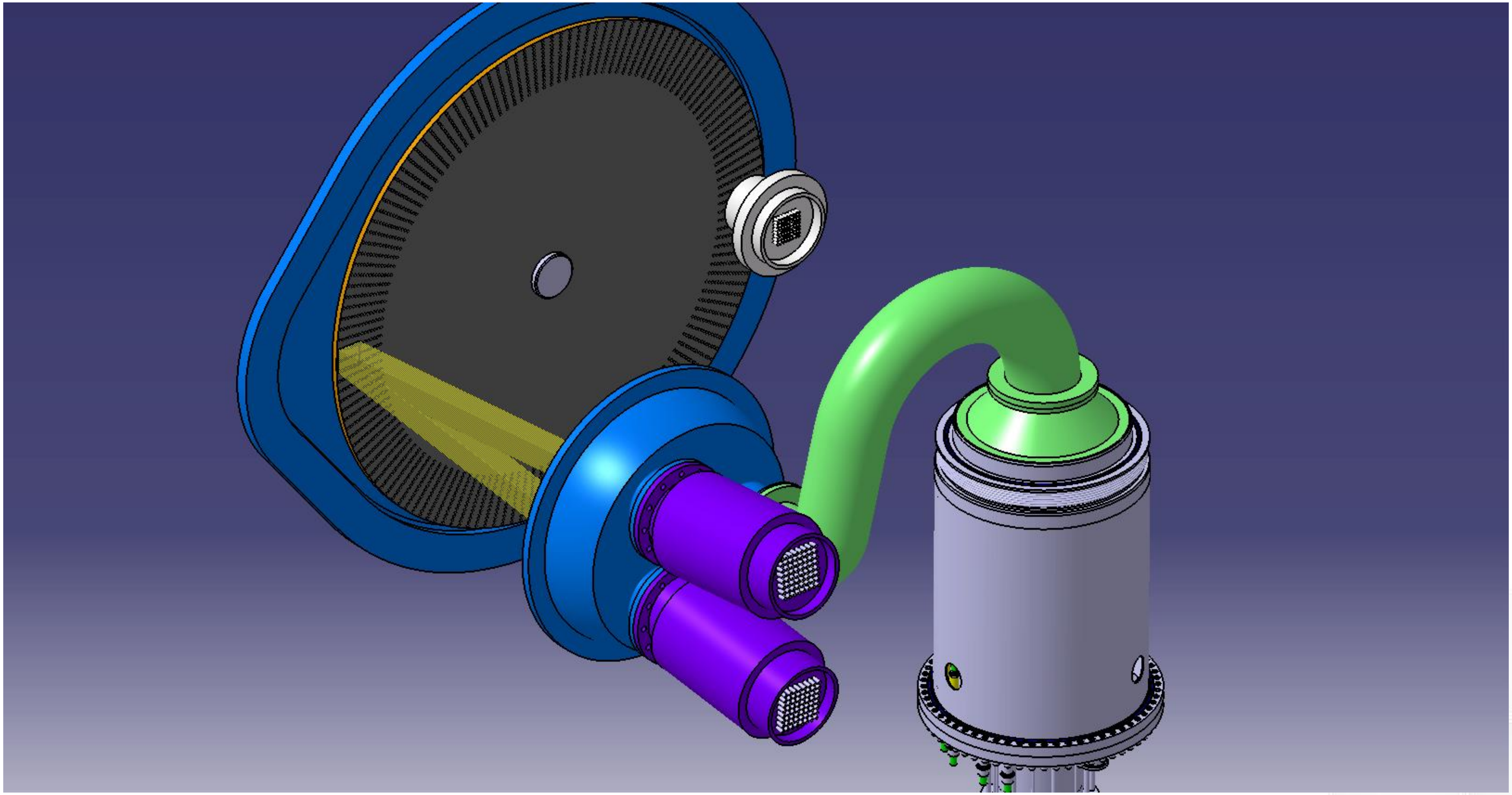
Single source concept



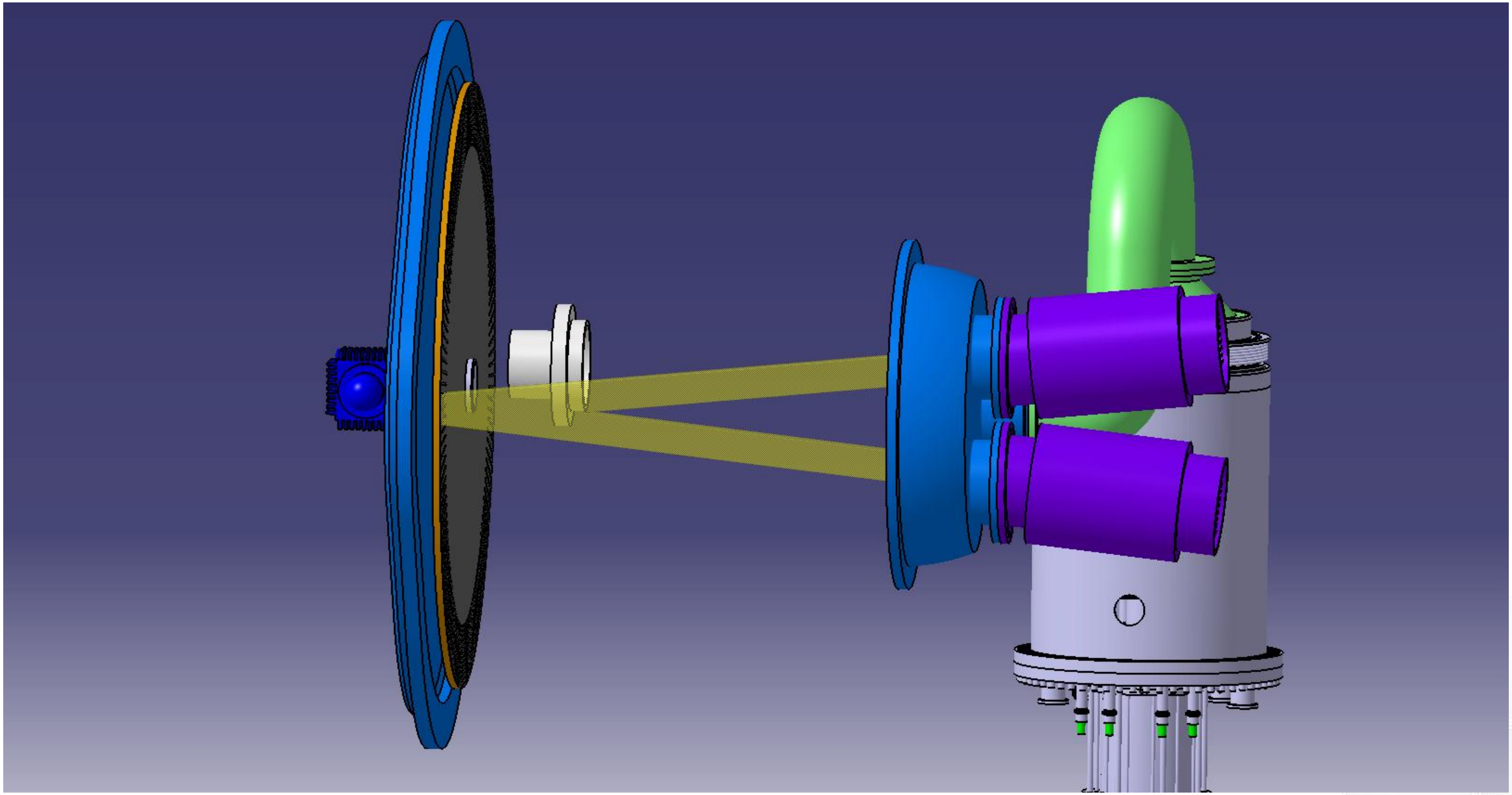
Single source concept



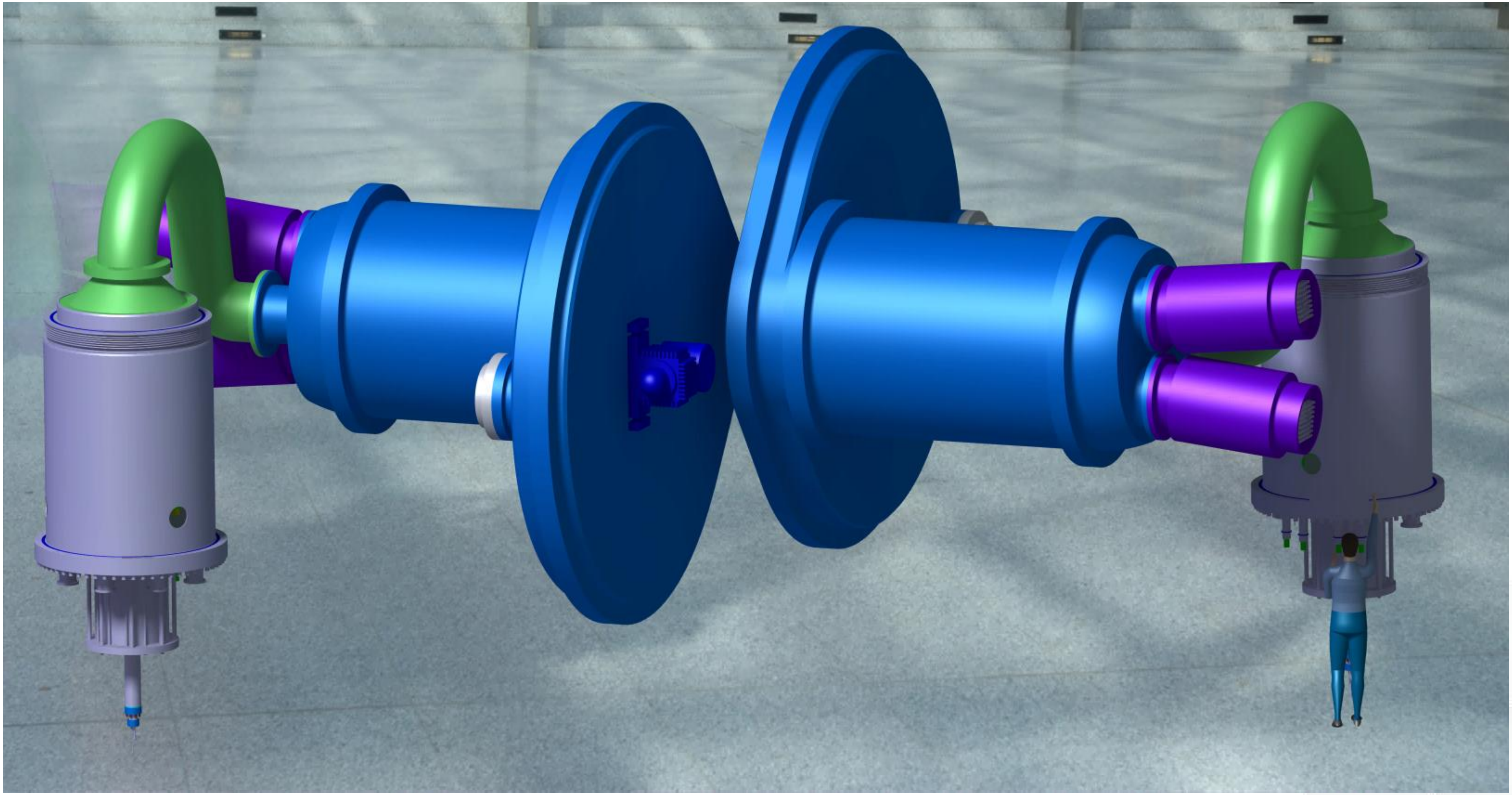
Single source concept



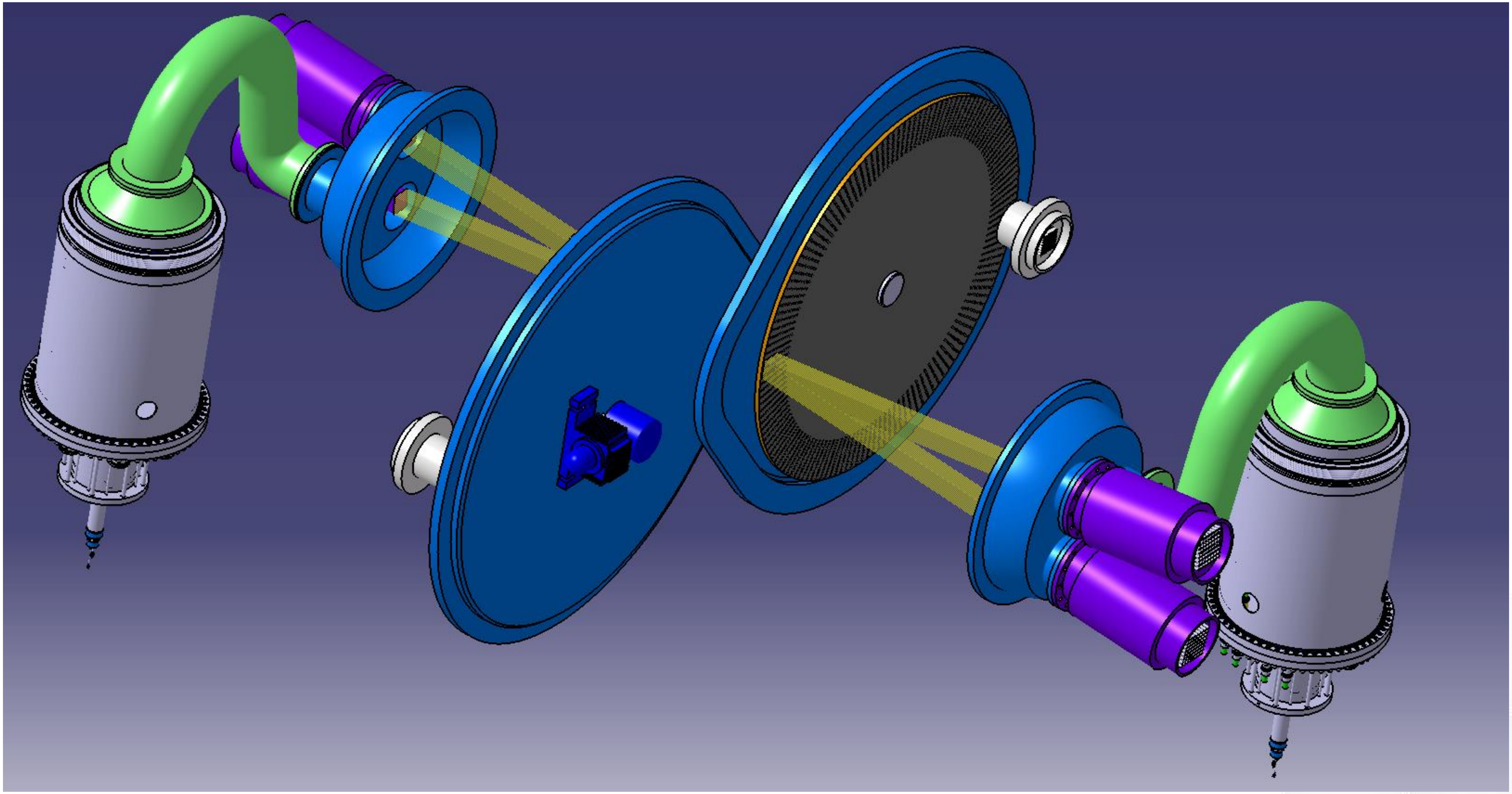
Single source concept



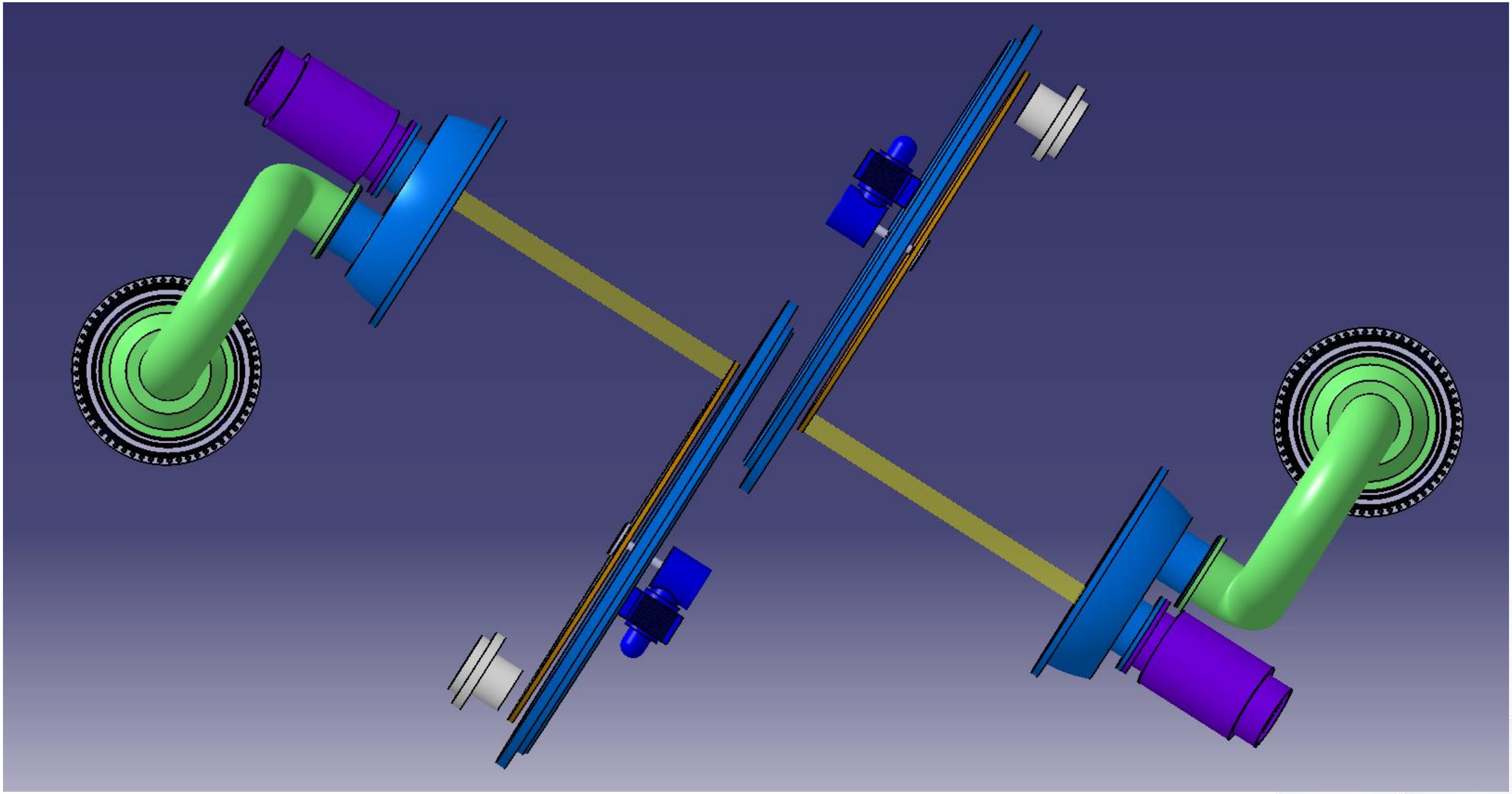
Two source concept



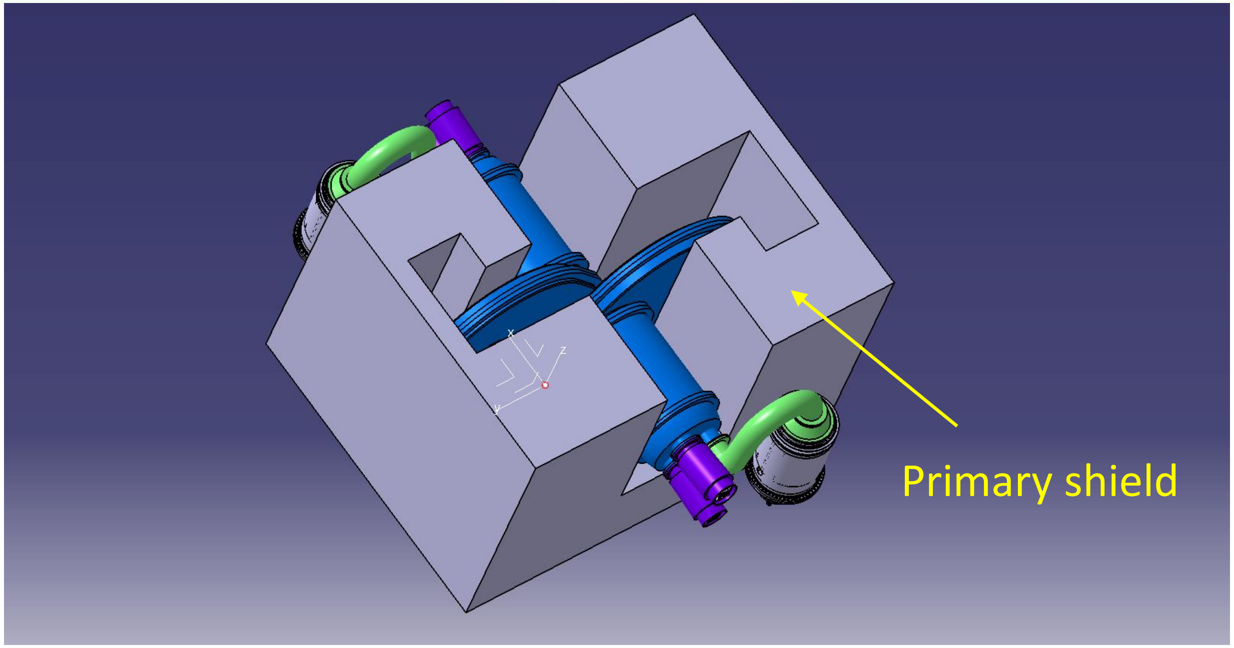
Two Sources Concept

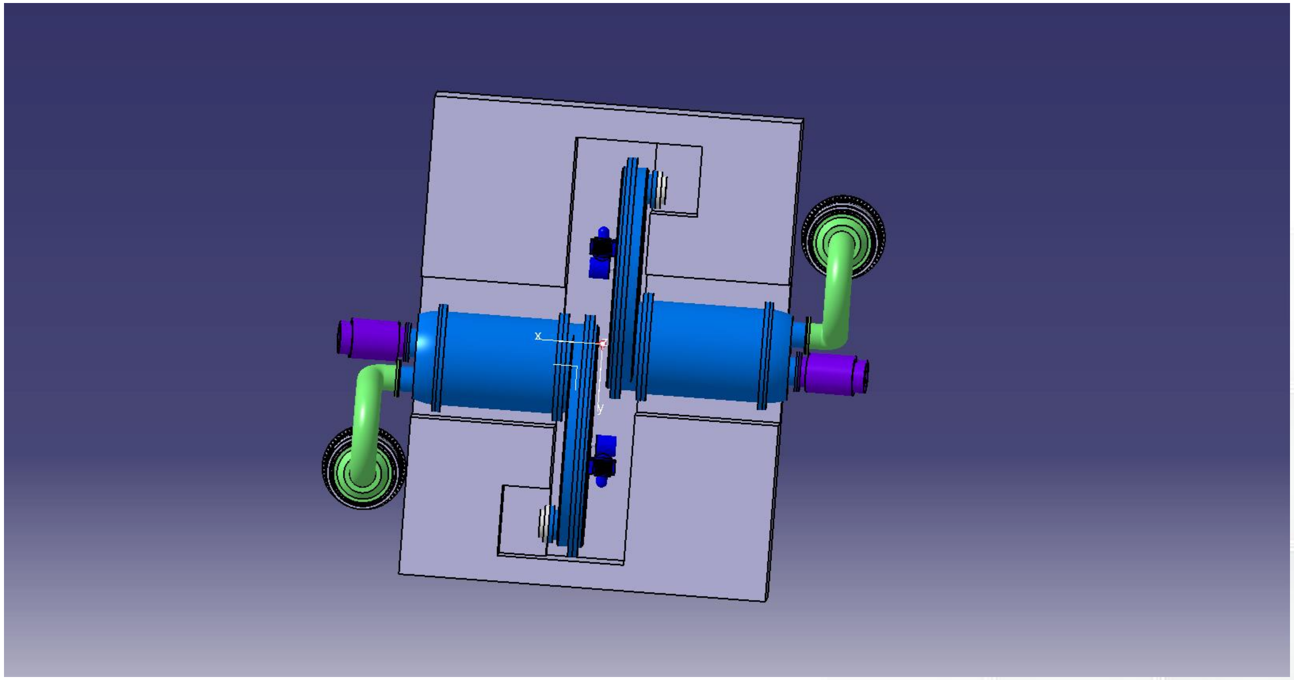


Two Sources Concept



Two Sources Concept

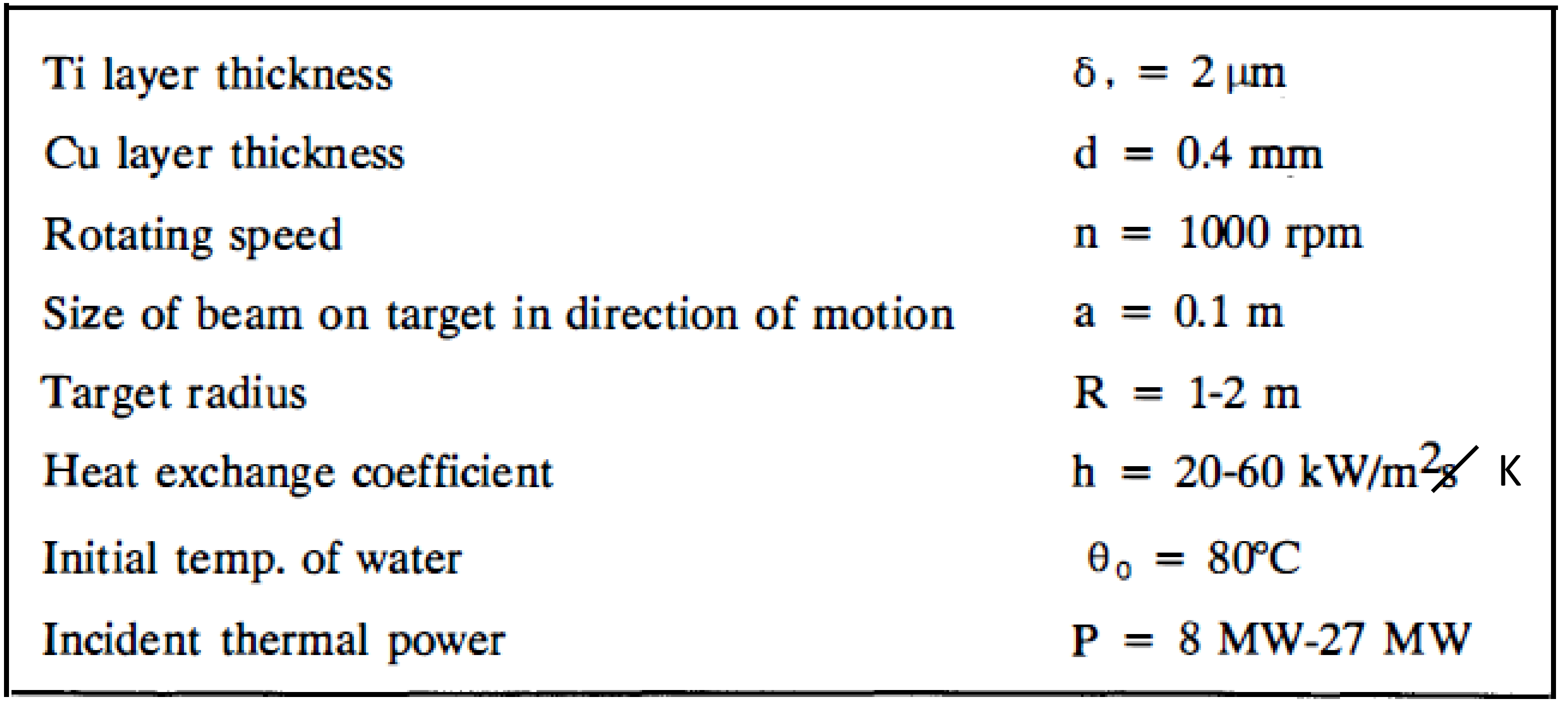




The New Sorgentina Fusion Source (NSFS)

- ✓ NSFS is able to produce an *high neutron flux* region ***(~7xE+12 n/cm²/s)*** of about 1200 cm^3
- ✓ In a restricted volume of ***50*** $\boldsymbol{cm^3}$ the neutron flux is ***~1xE+13*** $\boldsymbol{n/cm^2/s}$ corresponding *to* ***2 DPA/year*** in iron.
- ✓ One basic aspect of the proposed neutron source is the use of available and tested technology, e.g. the intense beams are produced by ***4x4 MW*** power ***Deuterons and Tritons with JET-PINI***.
- ✓ The PINI are adapted in order produce a rectangular spot of *10x20* cm^2 on each rotating target.

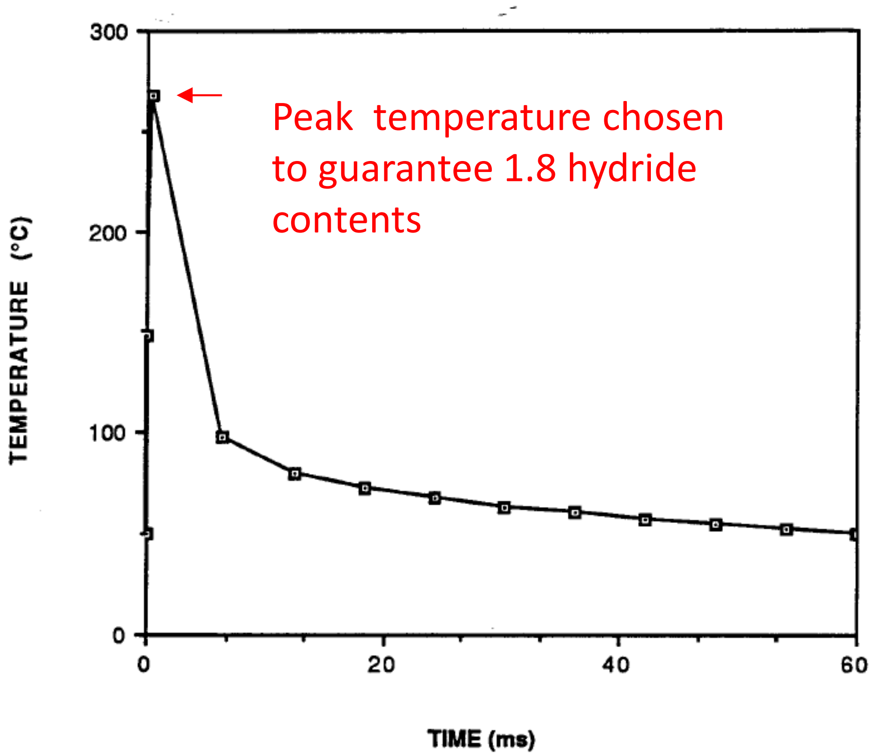
Rotating Target Design



Ti layer thickness	δ, = 2 μm
Cu layer thickness	d = 0.4 mm
Rotating speed	n = 1000 rpm
Size of beam on target in direction of motion	a = 0.1 m
Target radius	R = 1-2 m
Heat exchange coefficient	h = 20-60 $kW/m^2\cancel{s}$ K
Initial temp. of water	θ_0 = 80°C
Incident thermal power	P = 8 MW-27 MW

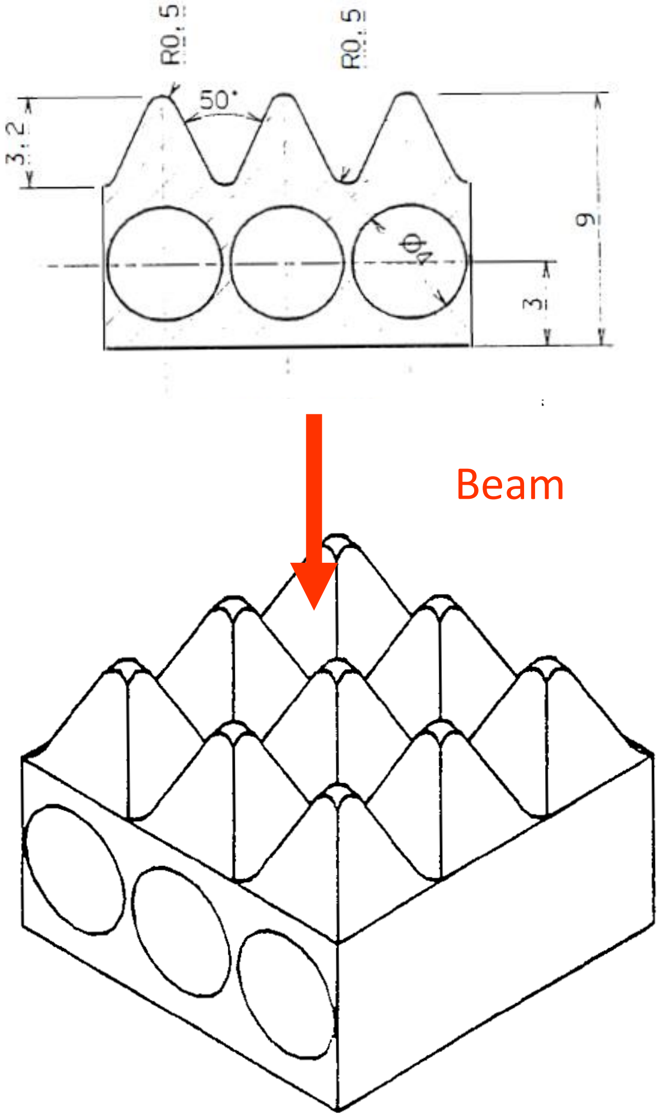
Parameters range considered for the thermal analyses of the rotating target

Rotating Target Thermal Analyses



Peak temperature chosen to guarantee 1.8 hydride contents

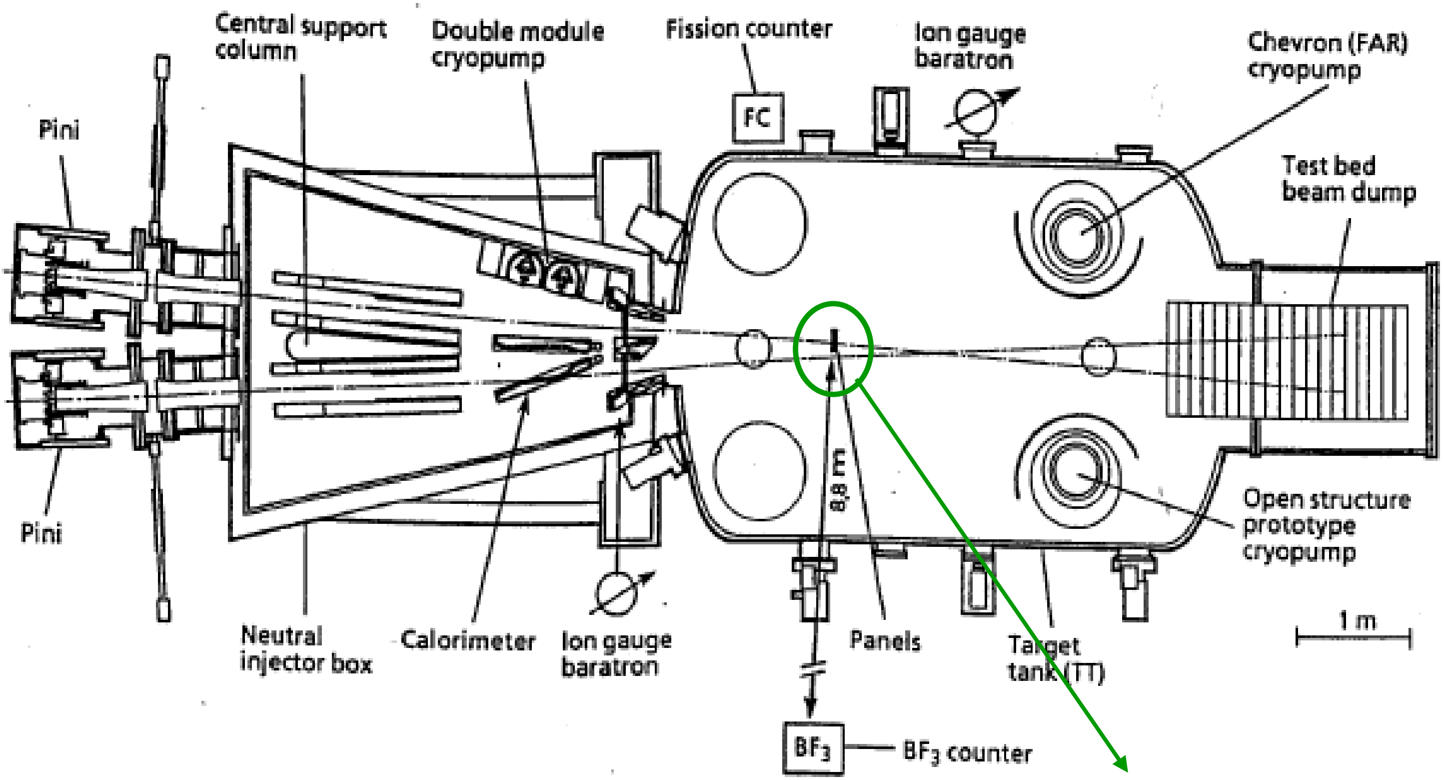
Temperature of the Titanium surface as a function of time, one cycle. (target radius= 2 m, frequency = 1000 rpm, beam power density= 40 kW/cm2, heat exchange coefficient 40 kW/m^2 K)



Shape of the beam facing surface

The JET PINI Test bed experiment.

(Employed for deuterium implantation tests in 1992)

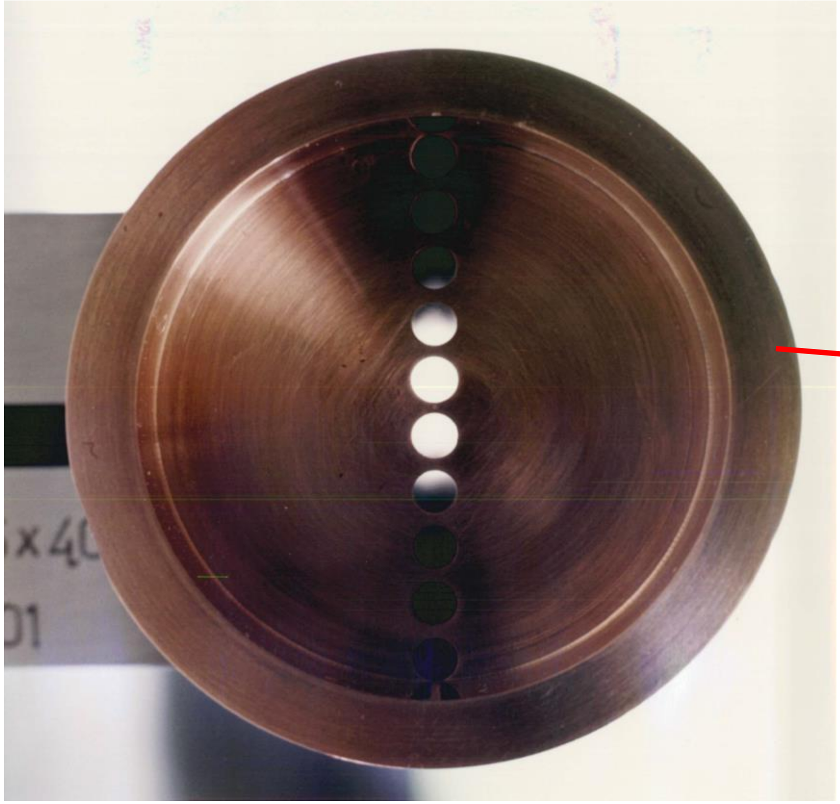


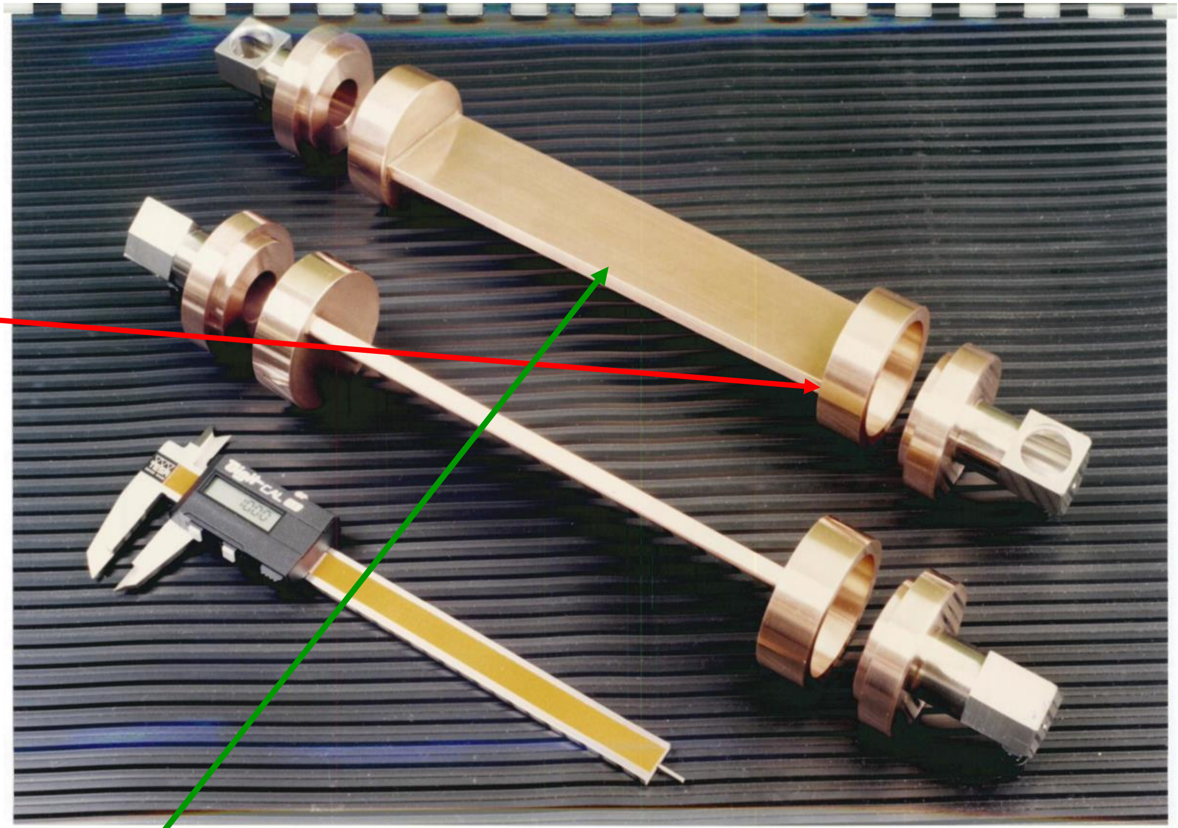
Two neutron detectors (FC and BF$_3$ were employed to measure the neutron production built-up due to the deuterons implantation in the panels

Position of the panels irradiated during the implantation tests

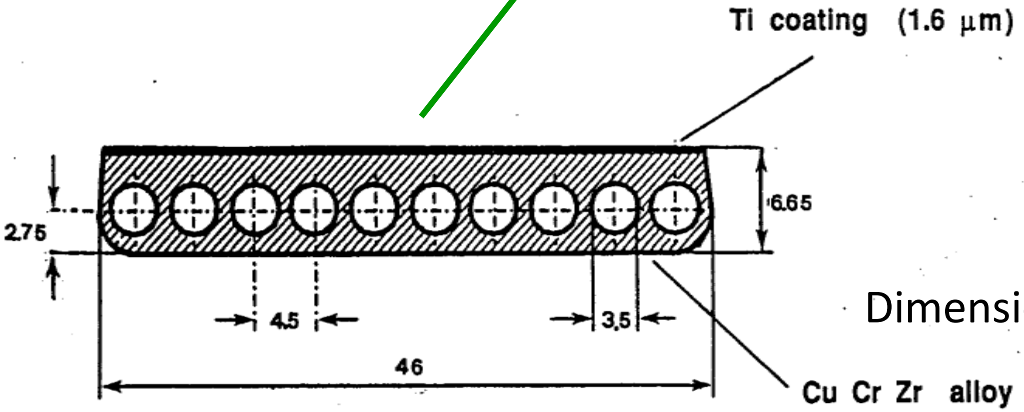
Fig. 4. Schematic plan view of the JET Neutral Beam Test Bed, illustrating the position of panels and neutron detectors.

Panels





Water cooled!



Dimension in cm

Panels

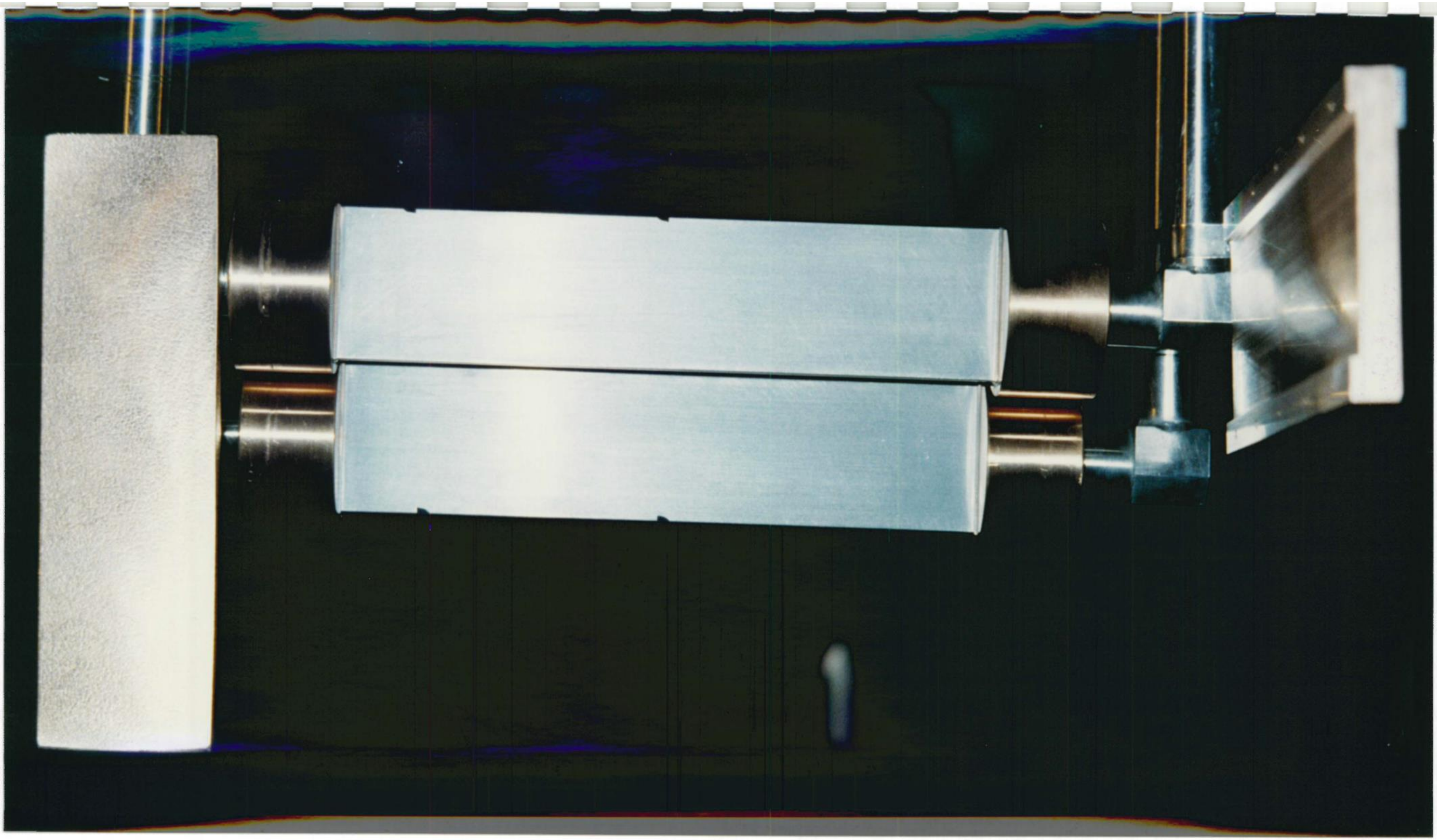
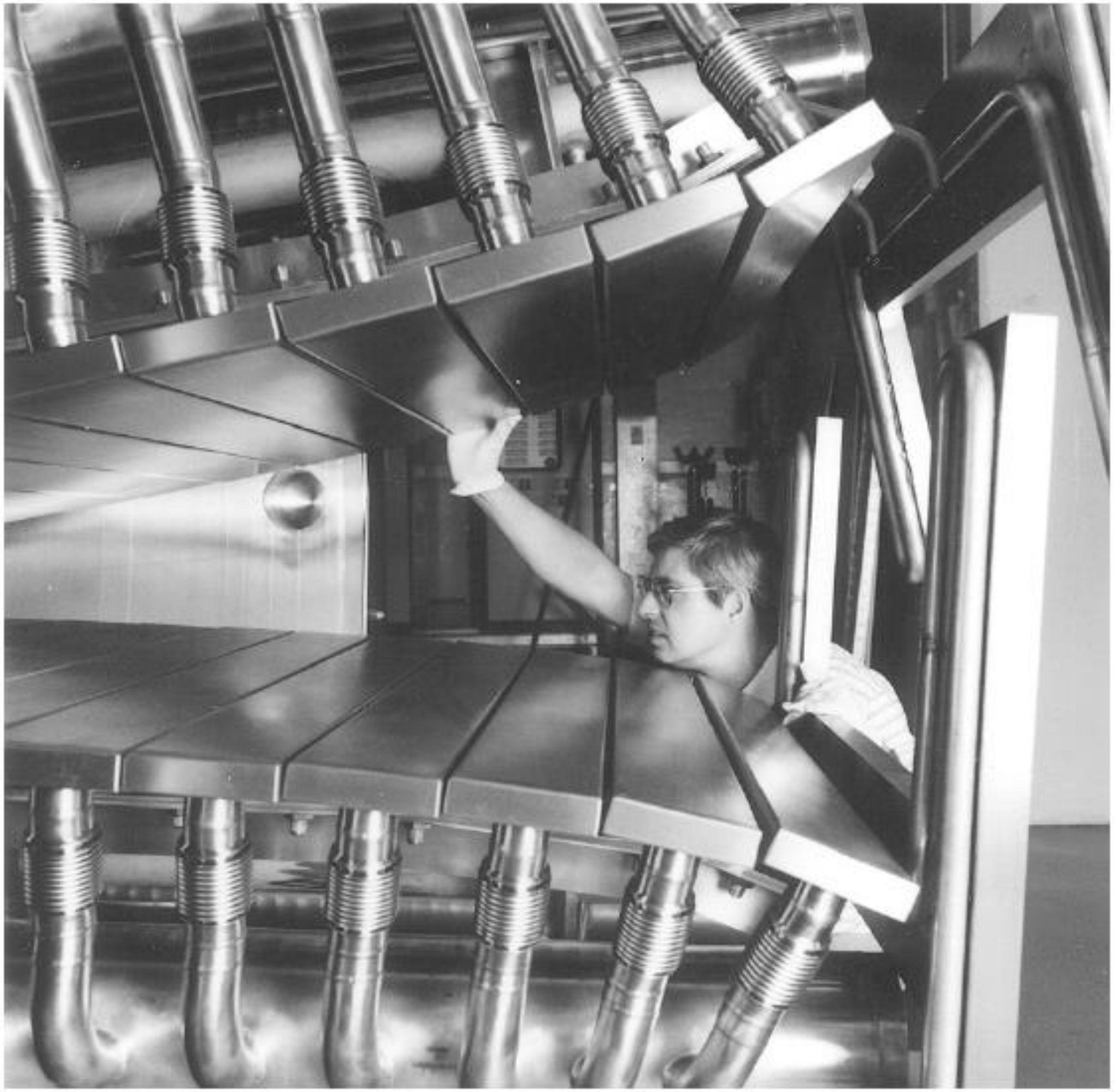


Fig. 16. View of the two panels in position for irradiation.

The final BEAM DUMP

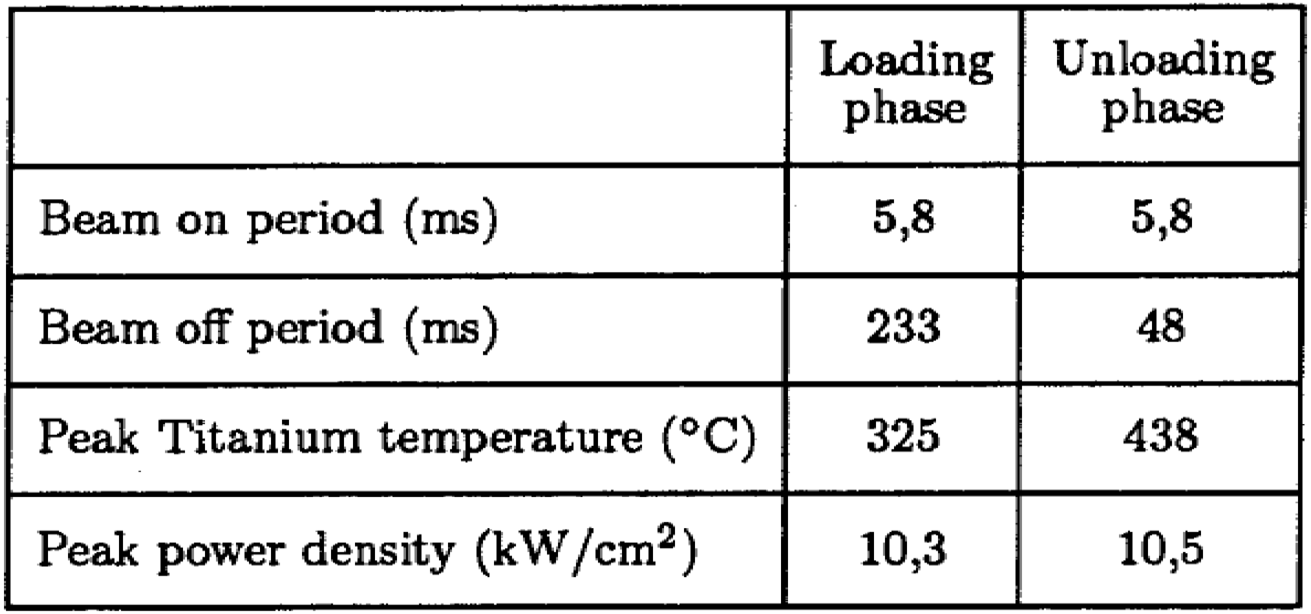


HIGH FLUX HIGN ENERGY DEUTERIUM ION IMPLATATION, IN HIGH TEMPERATURE TITANIUM (PRELIMINARY EXPERIMETAL TESTS FOR AN INTERMEDIATE INTENSITY NEUTRON SOURCE, OLD SORGENTINA)

To reproduce the thermal cycle of a rotating target on the panels without moving them, a modulated beam was used; varying the on/off periods of the modulation the panel temperature was varied. A 140 keV deuterium beam, with 5 s pulse duration, was fired, modulated, onto the panels. The average beam power density was 10 kW/cm^2, the panels were cooled with 10 m^3/h water flow and they were instrumented in order to measure all the important temperatures. Panels surface temperature was monitored with a calibrated infrared camera. The ion implantation build-up and remain if the temperature of the titanium is below about 400°C.

The modulation of the beam was varied in order to obtain a loading and an unloading phase of deuterium in titanium. The saturated implantation was estimated during the unloading phase.

Table 1.



	Loading phase	Unloading phase
Beam on period (ms)	5,8	5,8
Beam off period (ms)	233	48
Peak Titanium temperature (°C)	325	438
Peak power density (kW/cm^2)	10,3	10,5

LOADING PHASE

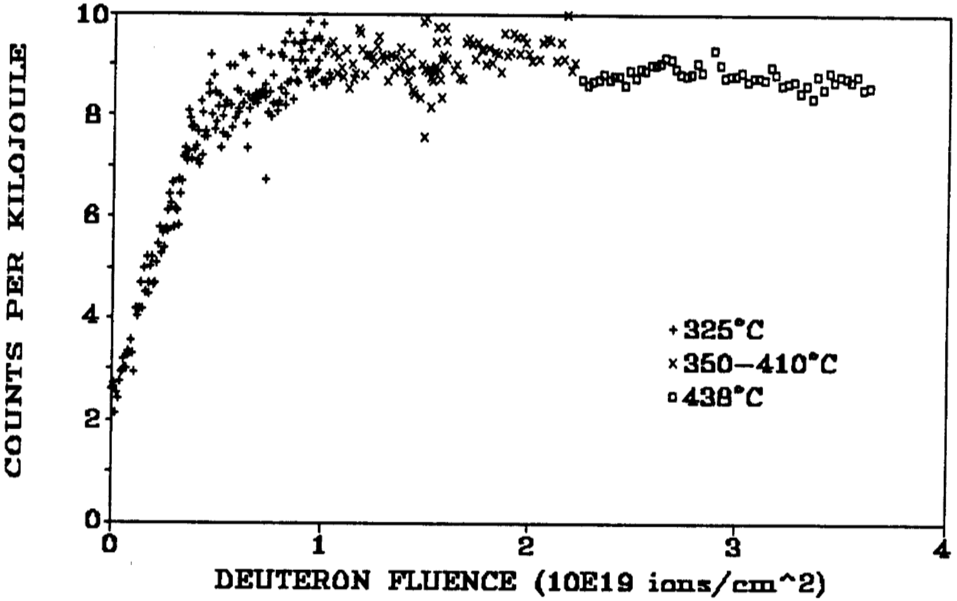


Fig. 5. BF_3 detector counts per kJ of beam energy on the panels, as a function of deuteron fluence for different values of Titanium temperature.

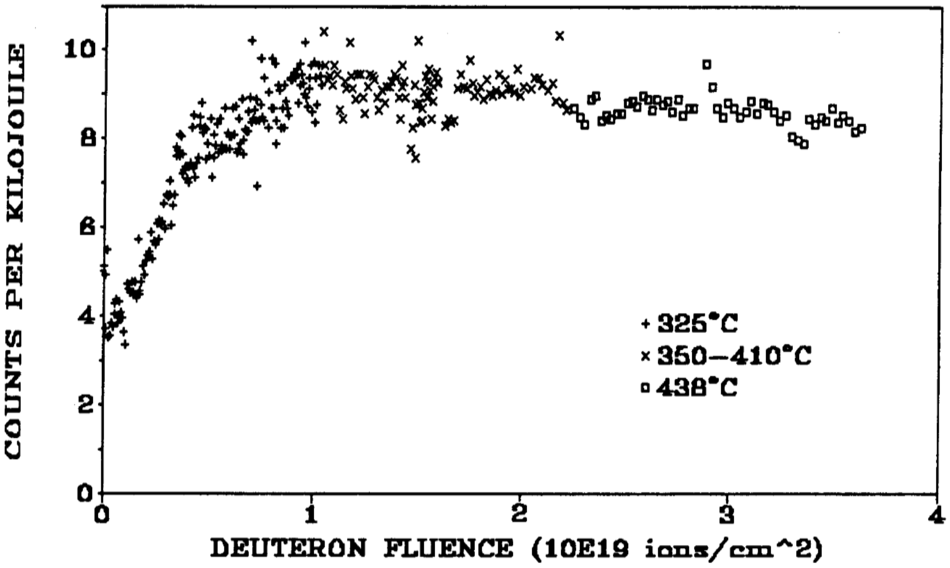


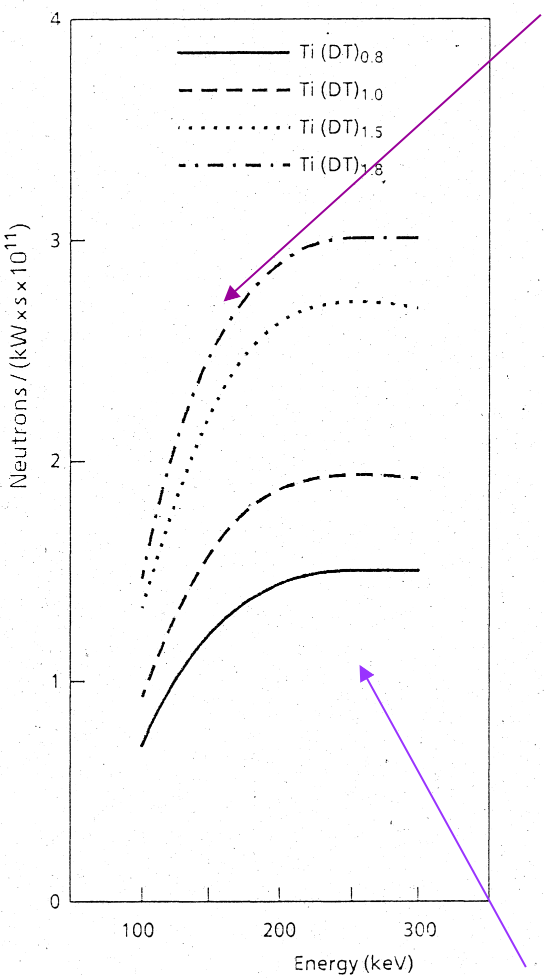
Fig. 6. FC detector counts per kJ of beam energy on the panels as a function of deuteron fluence for different values of Titanium temperature.

The absolute neutron yield was derived with activation technique and a MCNP modelling of the whole experiment. The neutron rate was 2.1E12 n/s D-D and would correspond to 3E14 n/s if a mixed 50%,50% Deuterium/Tritium beam could be used. The measured neutron rate permits to validate the computer routine used to estimate the beam-target calculation neutron yield and consequentially the ion implantation efficiency.

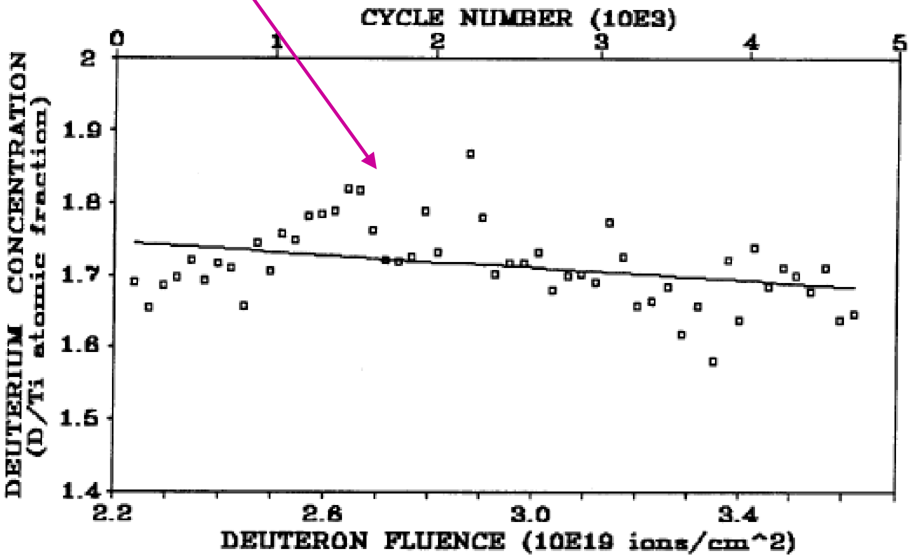
Neutron yield calculation, mixed beam + ion species

8 MW beam with energy 160 keV produces 2E15 n s^{-1} (x 1.46 with RF PINI)

The possibility to reach hydride contents 1.8 has been demonstrated experimentally



Neutron yield per kW vs. beam energy from a 50-50% D-T beam striking a Titanium target with different hydride contents. Ion species 83:7:10



Deuterium concentration in the unloading phase obtained with line fit of the experimental points.

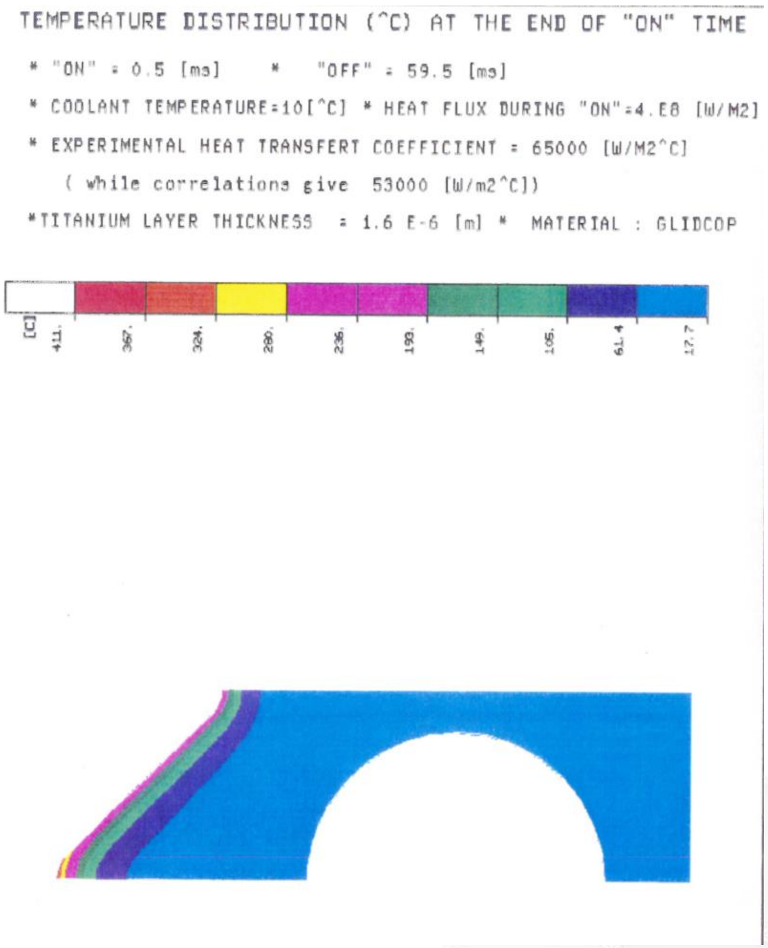
The work principle of NSFS is that Deuterium and Tritium are implanted during beam bombardment and reach an equilibrium saturation. The equilibrium saturation depends upon target surface temperature

Thermal analyses results derived from the implantation experiment

A 2D thermal analyses was used on the panels to obtain important parameters. Measured and calculated (in bracket) thermal data are shown.

	Loading phase	Unloading phase
Power density on panels (kW/cm²)	10,3	10,5
Titanium temperature (°C)	325 (317)	438 (423)
Back surface temperature (°C)	30,5	41
Cooling-channel wall temperature (°C)	(76)	(146)
Heat exchange coefficient (kW/m² K)	(65)	(95)

Very high heat exchange coefficient obtained



TEMPERATURE DISTRIBUTION (^C) AT THE END OF "ON" TIME

* "ON" = 0.5 [ms] * "OFF" = 59.5 [ms]

* COOLANT TEMPERATURE=10[^C] * HEAT FLUX DURING "ON"=4.E8 [W/M2]

* EXPERIMENTAL HEAT TRANSFERT COEFFICIENT = 65000 [W/M2^C]

(while correlations give 53000 [W/m2^C])

*TITANIUM LAYER THICKNESS = 1.6 E-6 [m] * MATERIAL : GLIDCOP

The accident. We lost some important data!

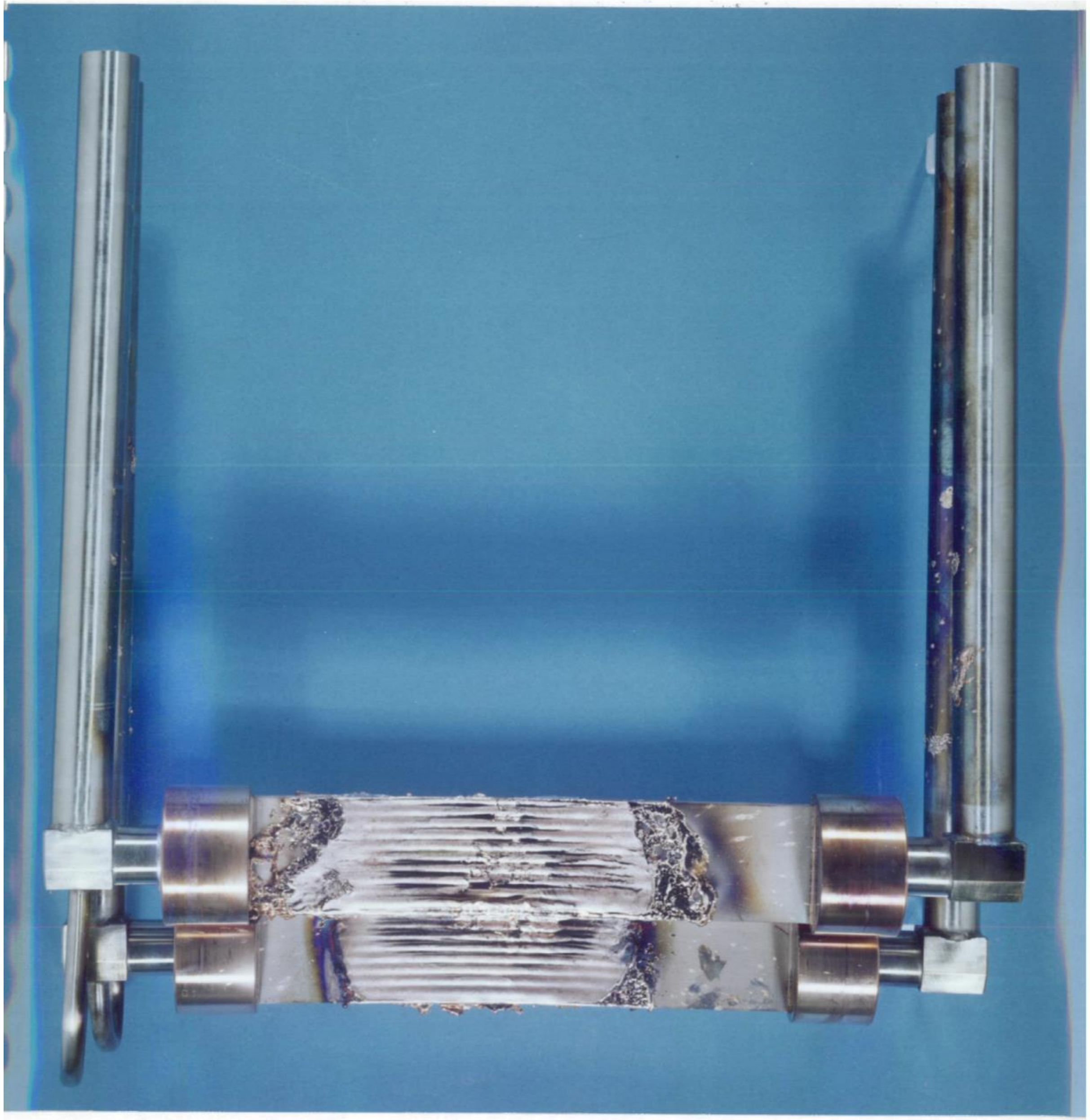
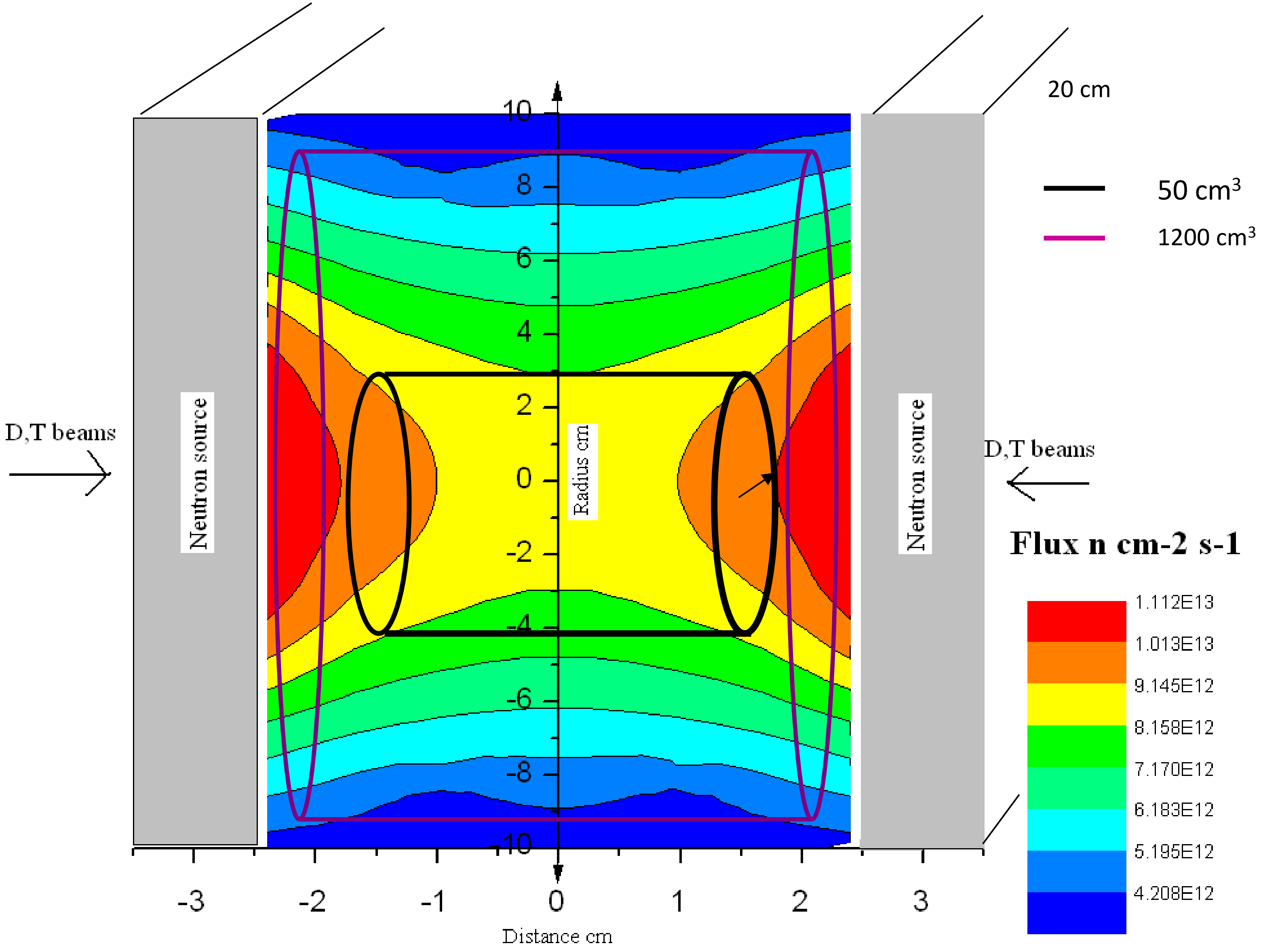


Fig. 17. View of two panels having the surface melted due to an accidental overheating. The dimensions of the beam spot are clearly discernible.

Because of the temporary lost of the beam control by the Test Bed operators when the experiment was almost finished the panels has melted.

We have lost the possibility to study the titanium layer degradation due to the high ion flux implantation!

Neutron Flux Contours with two rotating targets



Neutron Flux increases by 1.46 by using RF PINI → 3dpa/y !

Rotating Target Vacuum Seal Concept

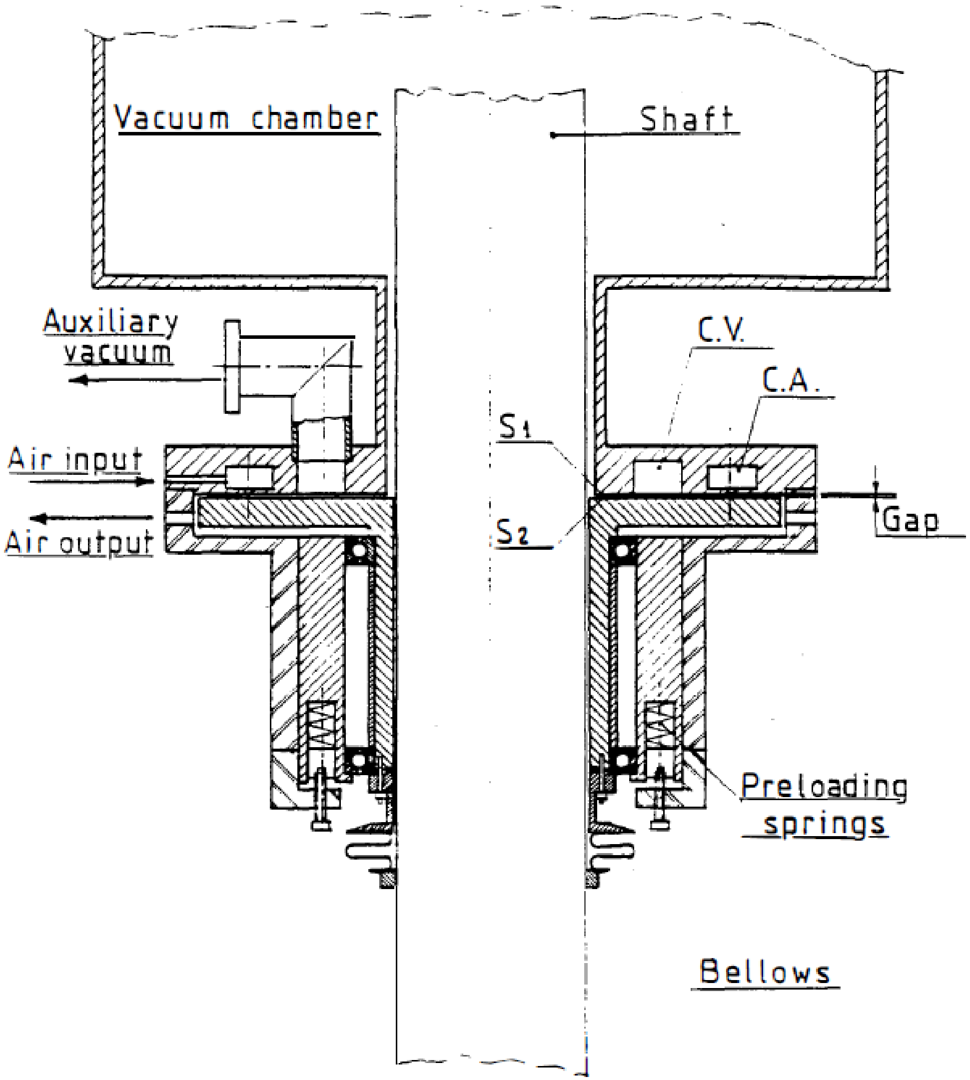


Fig. 15 Rotating vacuum seal for the target.

Vacuum & Tritium System

- ✓ Plasma source pressure 2-3x10^{-3} torr
- ✓ PINI gas flow 20 torr x l/s for two PINI
- ✓ Chamber pressure 2 x 10^{-3} torr (accelerator operation pressure)
- ✓ Cryo pumping speed 10^3 - 10^4 l/s
- ✓ Condition: Removal of the impurities (He and H from D-T and D-D reaction)
- ✓ Max Impurities concentration in the vacuum chamber 0.1%

- ➢ Design to collect exhaust gas downstream to the vacuum system;
- ➢ To separate the impurities from the exhaust gas (mainly deuterium and tritium);
- ➢ To process the impurities in order to recover deuterium and tritium for recycling into NSFS
- ➢ Based on palladium alloy permeator to separate the impurities from the exhaust gas stream, followed by high temperature isotopic exchange and cryogenic distillation to process the impurities in order to recover the deuterium and tritium for recycling into the gas beam feeding;
- ➢ Max estimated tritium inventory 7 g i.e. 2800 TBq ~ 74000 Ci;
- ➢ Tritium burn-up/year ~1 g

Electrical Power Supply System

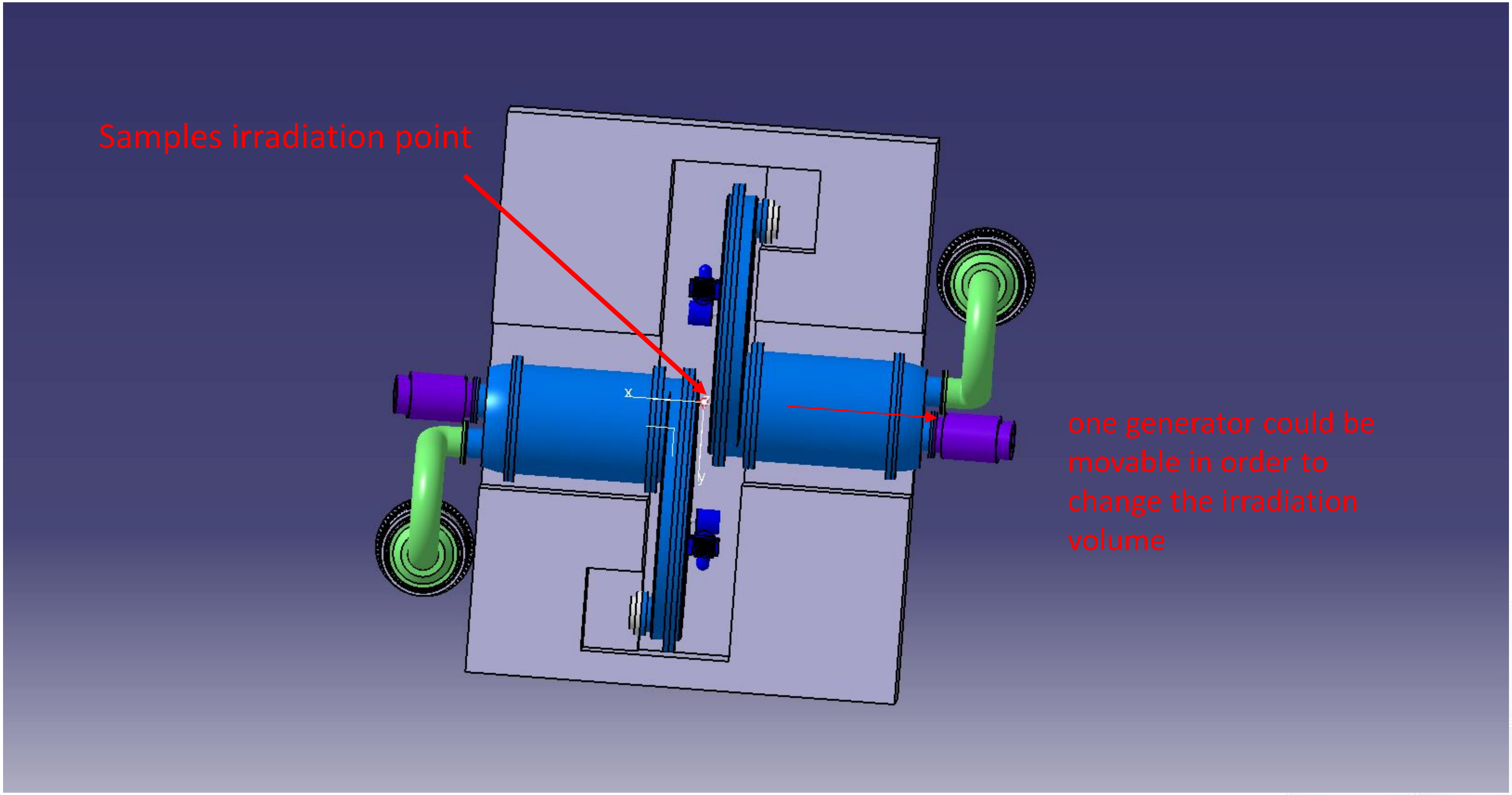
The complete electrical power supply and protection system consists of the following main units:

- high voltage power supply (HVPS);
- protection and voltage regulation unit;
- auxiliary power supplies (i.e., arc, RF source, snubber, gradient, and suppression grid p.s.);
- high voltage transmission line.

The HVPS is formed of two, thrystor-controlled, series connected units having the same main electrical characteristics and performance. Each unit adopts the "star point control" principle to regulate the 80-kV output voltage within ±0.5% (overall precision and stability).

The high voltage transmission line consists of a coaxial cable, with an insulation level up to 240 kV CW.

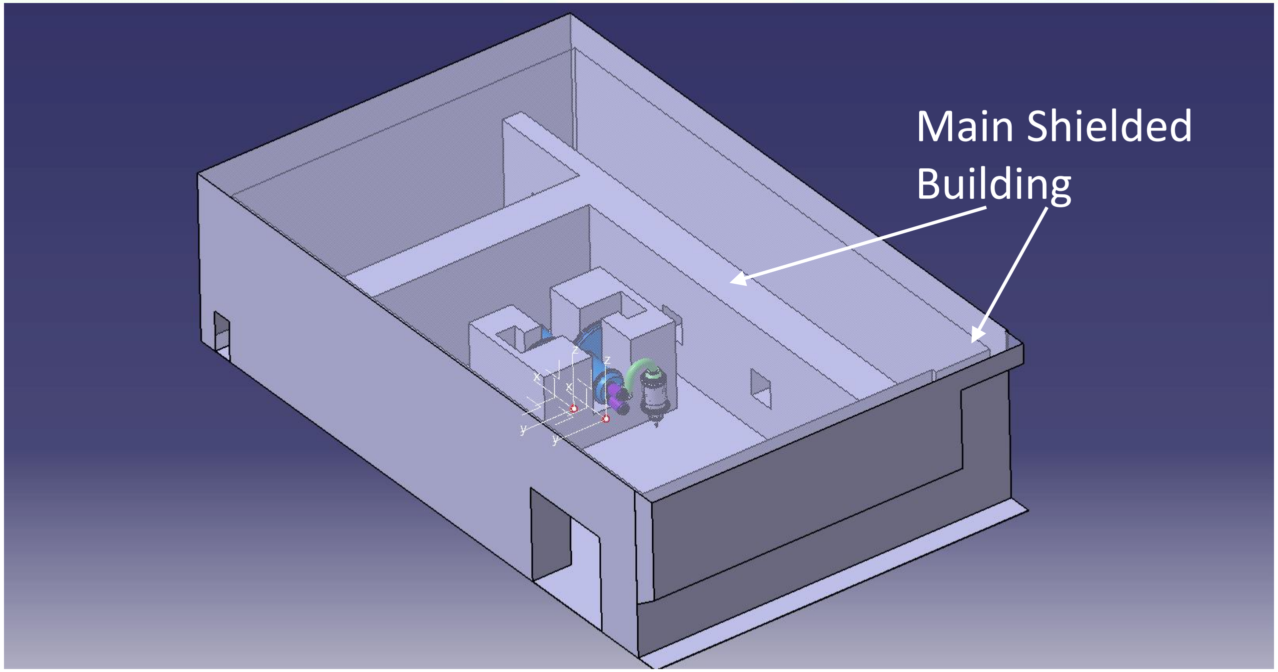
Layout

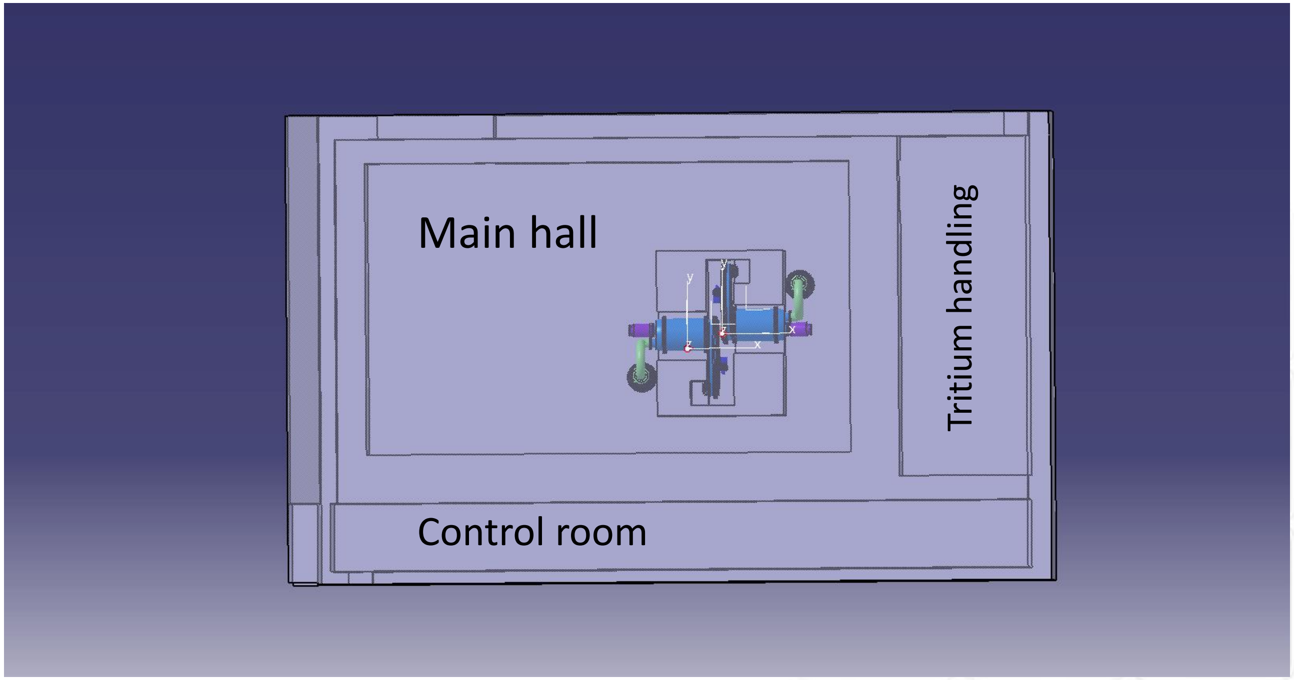


Samples irradiation point

one generator could be movable in order to change the irradiation volume

Layout


Main Shielded Building


Main hall
Tritium handling
Control room

Preliminary Cost Estimate

Ion sources PINI	6 M€
4 HVPS 160kV/25A + auxiliary	12 M€
BUNKER building +AUXILIARY	8 M€
Remote handling system	6 M€
Tritium plant	7 M€
Cooling system	5 M€
Rotating target vacuum chamber	6 M€
Total	***50 M€***
Contingency (20%)	***10 M€***

R&D Programme

- ✓To asses the use of PINI in a continuous mode;
- ✓Use the D+ beam to study the deuterium implantation in Titanium as a function of the power flux and the Titanium layer damage;
- ✓ Verification of the possibility of the continuous reforming the Titanium layer during operation;
- ✓Study the powerful D+ beam for thermo-mechanical and stress study of a rotating target prototype;
- ✓Study and optimize the heat removal from the target;

Conclusions

The cost, the required R & D activities and the necessary international consensus on the full project are delaying the IFMIF project toward a time scale not longer compatible with ITER and perhaps DEMO projects time schedule. On the other hand, it is worldwide recognized the necessity to start to collect data upon materials to be used for these projects

A facility like NSFS could be devoted to :

a) carry-out basic studies on neutron damage to materials irradiated with 14 MeV neutrons to validate damage calculation codes *(~ 1- 2 and up to 3 (using RF PINI) dpa/y);*

b) verify the influence of nuclear transmutation on the electric characteristics of ceramic insulators, optical fibers and window materials;

c) provide a neutron field were damage cross sections can be tested and/or measured;

d) address basic experimental information for the selection of low activation materials;

e) furnish reliable data about the radiation hardness of materials to be used for diagnostics;

Conclusions

f) produce neutron flux and spectra similar to that expected in a tokamak in order to allow for reliable test of electronics equipment and components to be used for diagnostics, remote handling etc. for ITER;

g) provide an intense 14 MeV neutron flux to study tritium production, breeding and behavior of TBM modules working in reactor like condition;

h) provide reliable amount of tritium production in TBM to assess methods for tritium handling;

i) study the effect of heavy neutron irradiation on tritium system components;

j) produce an harsh environment where manipulation and/or routine operation can be simulated or tested by remote handling and/or personnel in order to optimize the safety.

Thanks for your attention!!!

Questions???