Status of LENOS

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Overview

LENOS:

- Scientific motivations
- The LENOS method
- Proton energy shaper: status
- Lithium target: status

Other applications of the LENOS target:

- LAboratorio per la produzione di RAdionuclidi per la MEDicina (LARAMED): case study $^{62}Zn/^{64}Cu$ tandem production

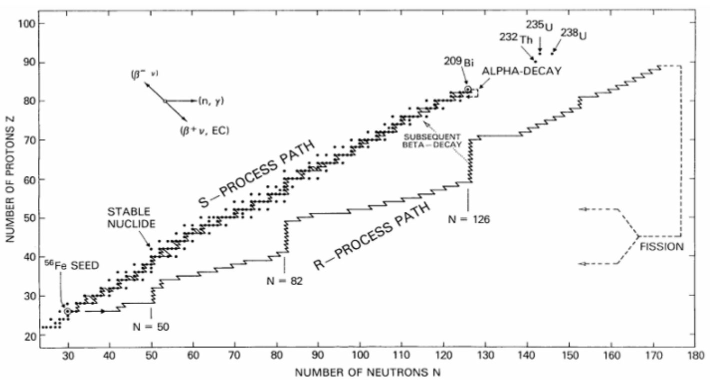
What would be LENOS?

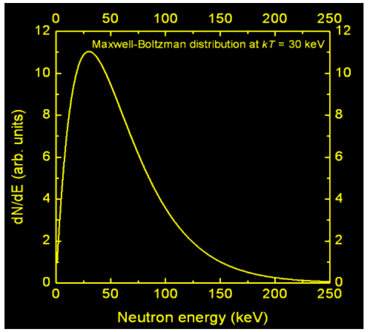
- Neutron facility (irradiation, ? TOF ?)
- Based on a method for the production of different neutron spectra
  - Nuclear Astrophysics.
  - Validation of Evaluated Data for energy and non-energy applications.
  - Medical physics applications.
  - Radiation damage tests (SEE)
  - Material science physics (neutron imaging)

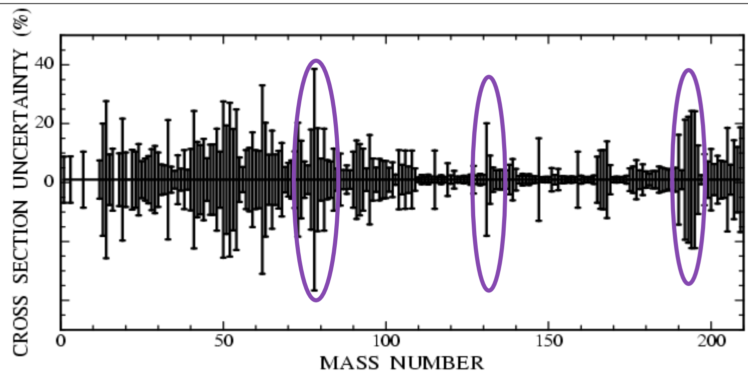
Motivations: Astrophysics

Nucleosynthesis of elements beyond Fe (B=8.8 MeV/A) are produced in stars by successive (n,γ) and β-decays.

The stellar velocity neutron spectrum is a Maxwell-Boltzmann distribution. Depending on the stellar site and the evolutionary stage of the star the most important kT are 8, 30 or 90keV, being 30 keV the standard temperature of reference.





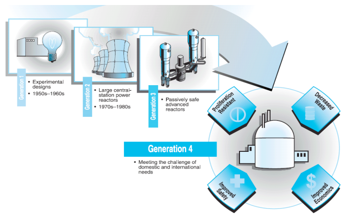


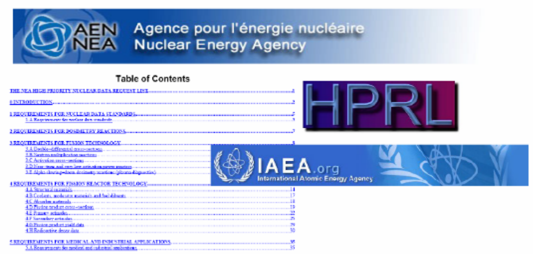
$$\frac{dN_A(t)}{dt} = N_{A-1}(t)\cdot n_n(t)\langle\sigma\cdot v\rangle_{A-1} - N_A(t)\cdot n_n(t)\langle\sigma\cdot v\rangle_A - \lambda_\beta(t)N_A(t)$$

$$MACS \equiv \langle\sigma\rangle = \frac{\langle\sigma\cdot v\rangle_A}{v_T} \longrightarrow$$

MACS (Maxwellian Averaged Cross Section)

Motivations: Validation of Evaluated Nuclear Data





Large request of data from the most important agencies (IAEA, NEA).

Some actinides for AFC and Gen-IV:

- Pu-239 fission in 1 keV – 1 MeV
- Pu-241 fission in 1 keV – 1 MeV
- U-238 capture in 2 – 200 keV
- Am-243 capture in fast and thermal energy range
- Am-241fission in fast energy range

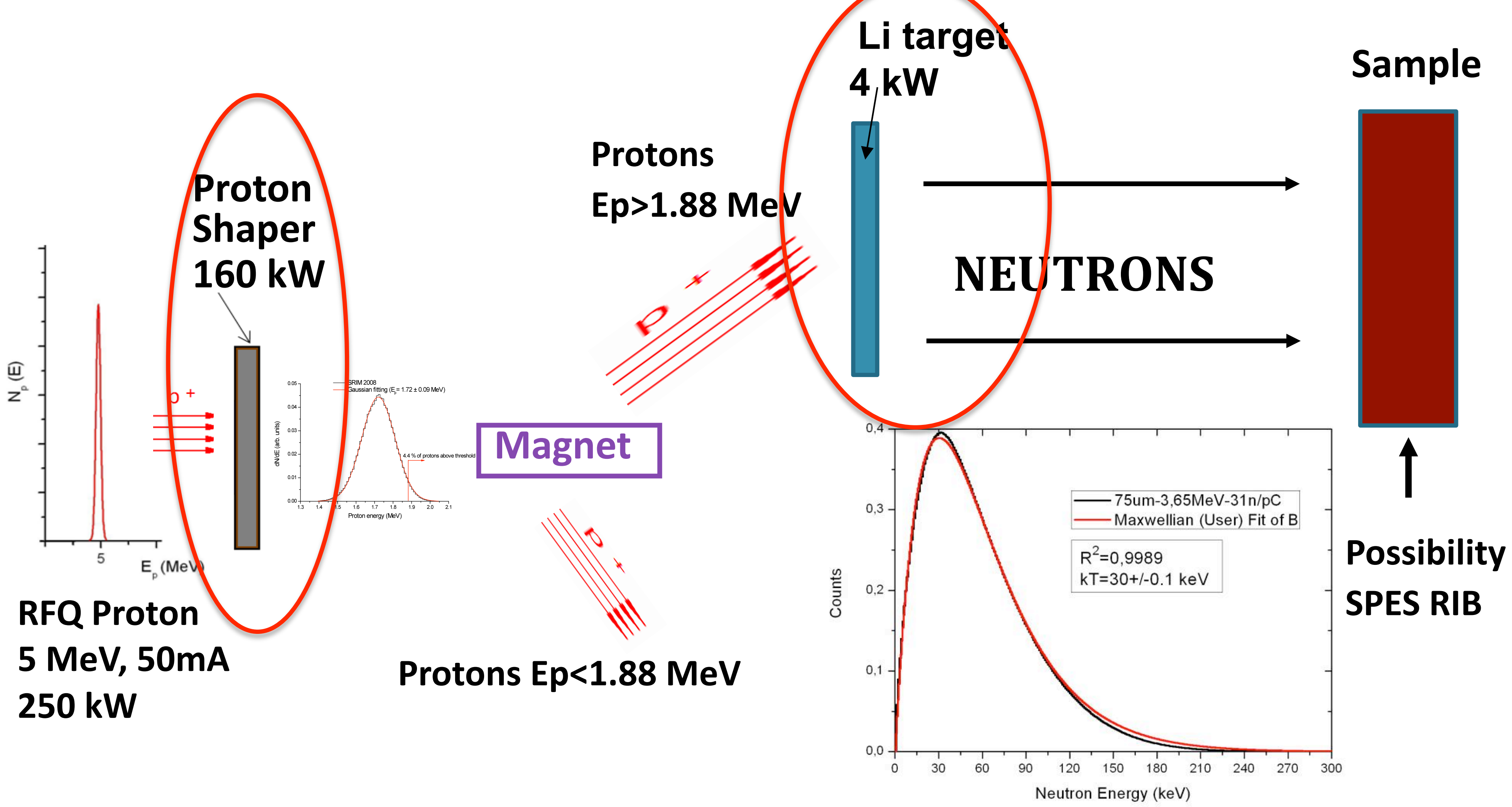
P. Oblozinsky, NNDC

Often large discrepancies between data bases (ENDF, JENDL, JEFF, BRONDL) for many already measured isotopes.

No measurements for some important isotopes (mainly radioactive).

Integral measurements are accurate. The epithermal integral measurement can be performed using a well-characterized neutron spectrum (for example, Maxwell-Boltzmann like).

Sketch of SPES/LENOS Layout

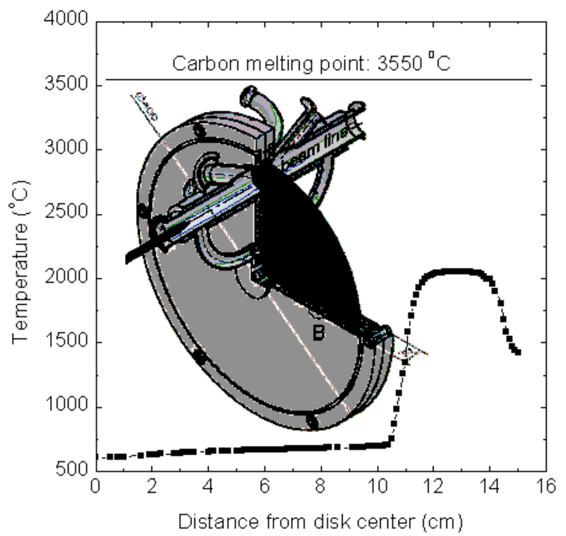


Expected Neutron Flux = $5 \cdot 10^{10}$ n/s·cm^2

SPES/LENOS Layout: Energy Shaper (1/3)

We decide to shape the proton beam by using the energy straggling and stopping power of charge particles when interact with a thin foil of material. General method: **multilayer energy shaper.**

LENOS foil material requirements :
Low atomic number and low density, high melting point, high emissivity, high thermal conductivity, high tensile strength.



→ **GRAPHITE foil**

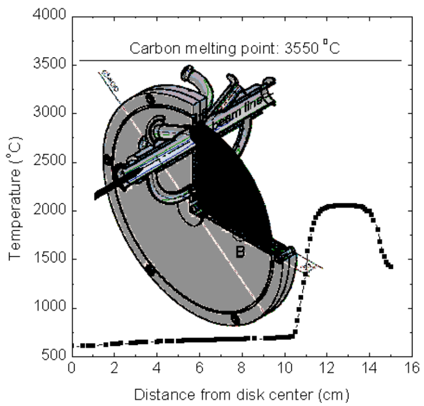
For lower power we can use a monolayer Aluminium foil.

P=2x80 kW for 50mA *ANSYS, Inc*

SPES/LENOS Layout: Energy Shaper (2/3)

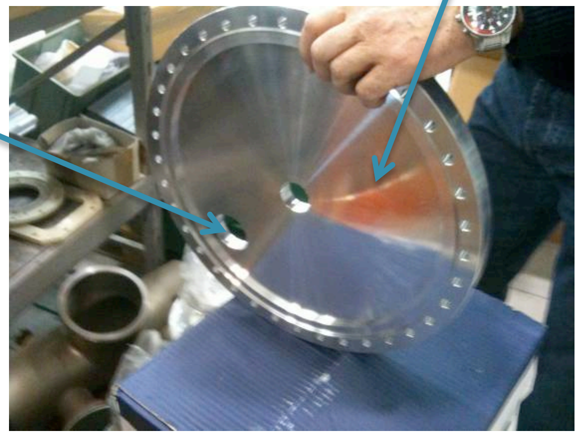
Graphite disk 70 μm thickness. Power to be dissipated about 50 kW, Mainly by radiation. Working temperature <2000°C

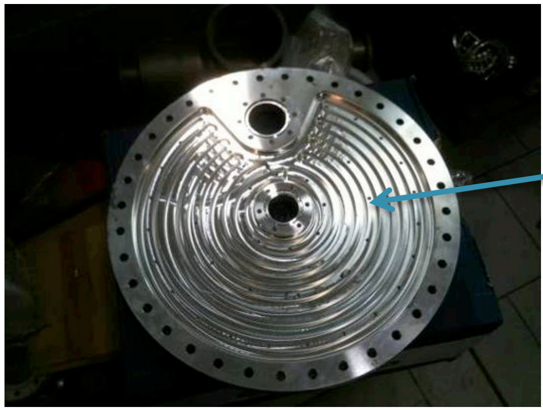
Construction material Al Ergal alloy



Internal part

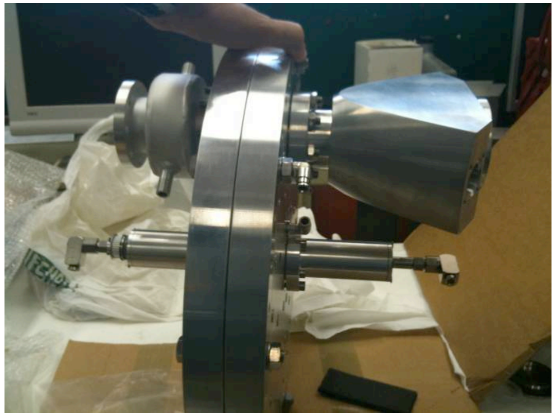
Beam entrance

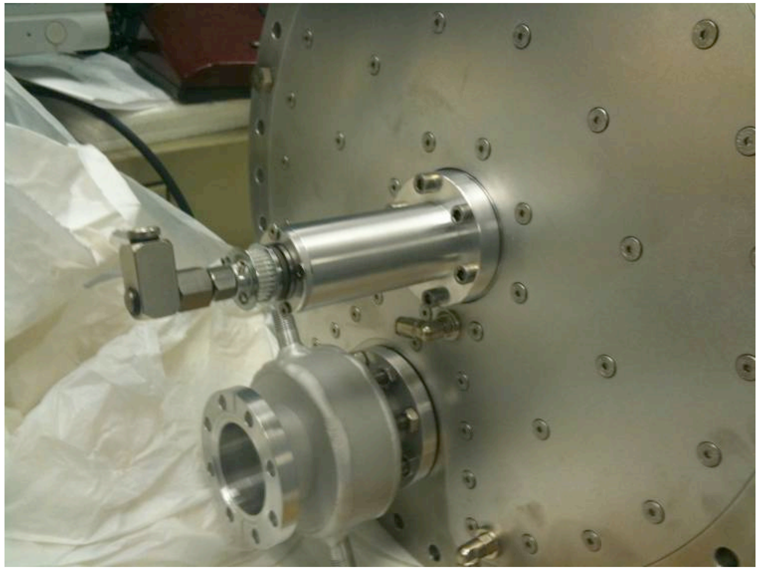


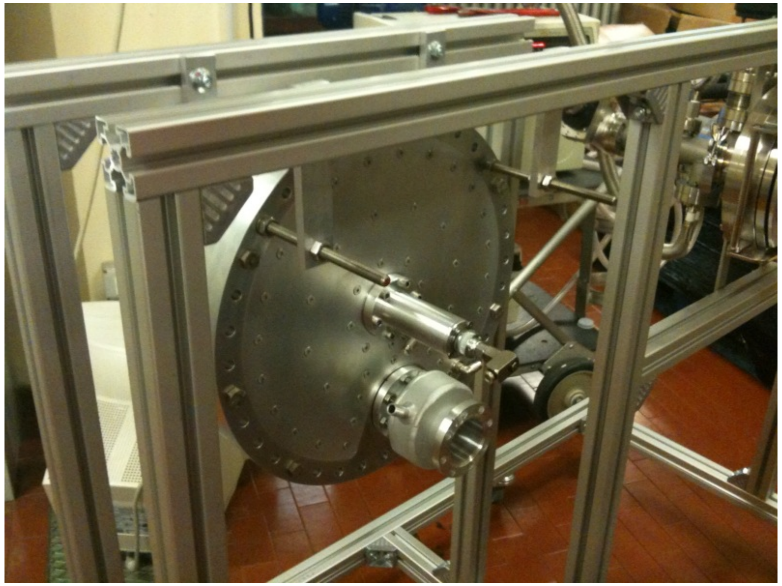


Water cooled serpentine

LENOS Layout: Energy Shaper (3/3)







Prototype almost completed

LENOS Layout: Lithium target (1/7)

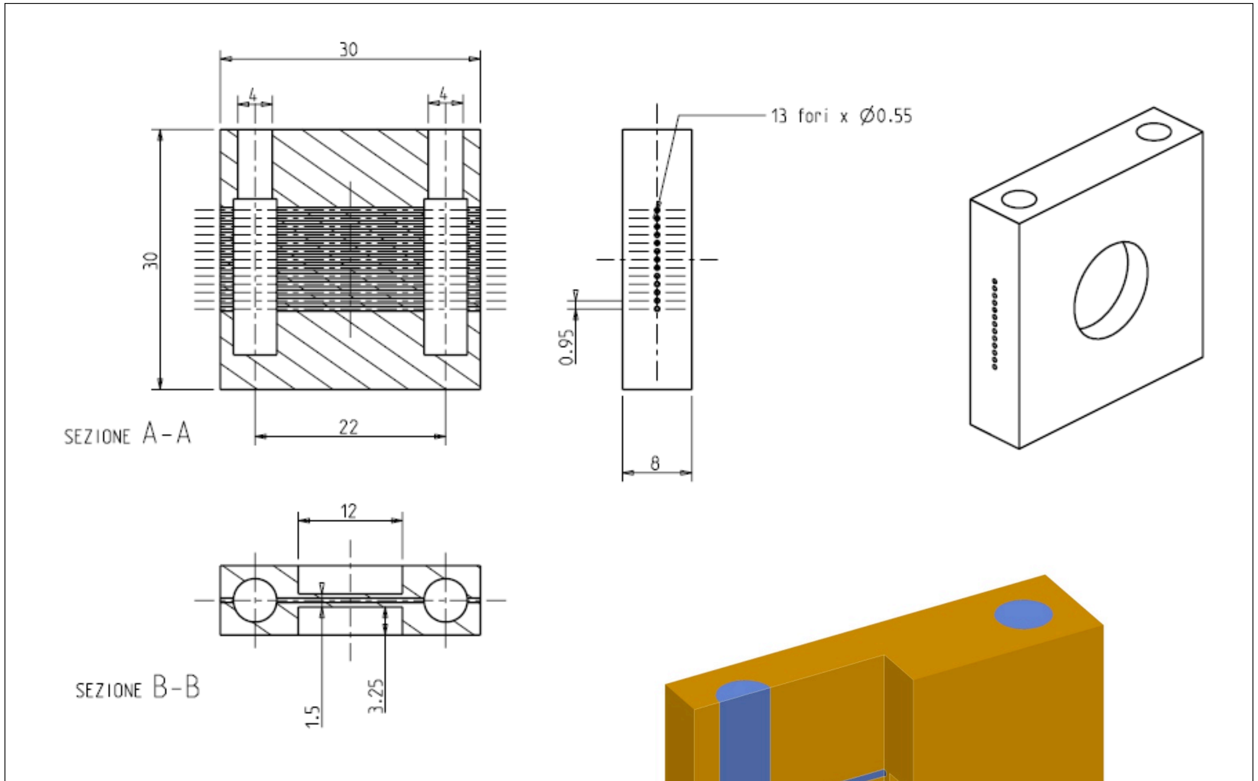
In order to dissipate so high specific power (about 3 kW/cm^2) a new generation of heat cooling device have to be implemented and developed.

The target must satisfy some constrains:

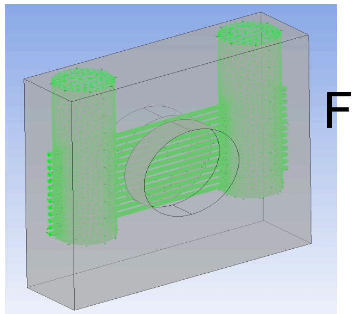
- Low mass (to avoid neutron backscattering and reduce radioactivity)
- Small thickness, in order to maximize the neutron flux (keeping the measuring sample in touch with the neutron producing surface) and reduce neutron spectra perturbation
- Low cost and easy to fabricate procedure, in order to replace the target often even during a measurements

Microchannels + liquid metal cooling medium

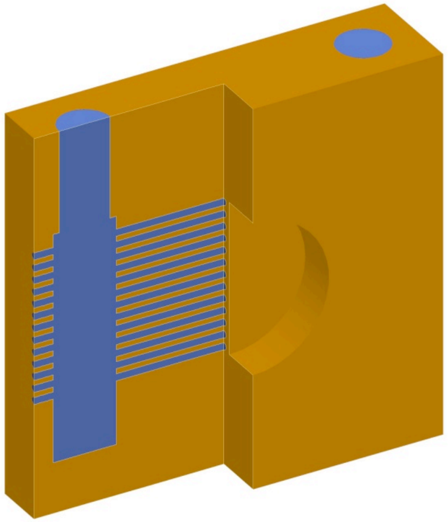
LENOS: Lithium target. Design. (2/7)



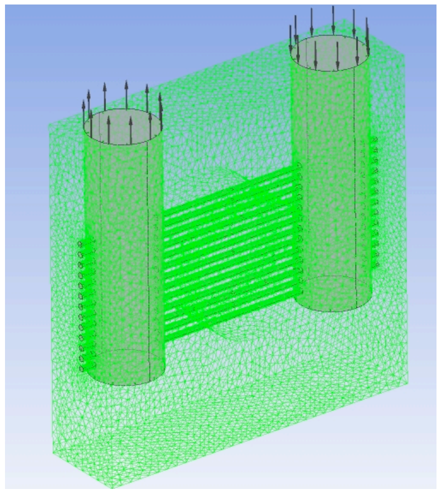
Cu Backing:
13 micro channels
14 mm long
0.45 mm diameter
0.95 mm spacing
0.5 wall thickness
6.4 mm in-out diam tube



Fluid domain



Solid domain



LENOS: Lithium target. Analytical results (3/7)

WATER		
parameters	description	value
c_p [J/kg K]	fluid specific heat	4181,7
λ_{Fl} [W/m K]	fluid thermal conductivity	0,6069
λ_{Cu} [W/m K]	target thermal conductivity	401
ν [Pa s]	fluid viscosity dinamic	0,0008899
ρ [kg/m^3]	fluid density	997
d [m]	diameter of the microchannels	0,00055
Pr	Prandtl number	6,131644142
v [m/s]	velocity in the microchannels	15
Re	Reynolds number	9242,89246
Nu	Nusselt number	73,77145321
α [W/m^2 K]	convection coefficient	81403,44537
$T_{av,fl}$ [ºC]	fluid average temperature	23
n	number of microchannels	13
q [W/m^2]	beam specific thermal power	4420970,641
q [W/cm^2]	beam specific thermal power	884,1941283
q [W]	beam thermal power on target	1000
T_s [ºC]		77,30937992
T_{beam} [ºC]	temperature on beam surface	124,6909261
T_{in} [ºC]	fluid inlet temperature	20
Q [m^3/s]	fluid volumetric flow	4,63287E-05
T_{us} [ºC]	fluid outlet temperature	25,17728529
	lithium thickness [m]	0,00004
$T_{s(Li)}$ [ºC]		126,7787516
λ_{Li} [W/m K]	gold thermal conductivity	84,7

GALINSTAN		
parameters	description	value
c_p [J/kg K]	fluid specific heat	365
λ_{Fl} [W/m K]	fluid thermal conductivity	36
λ_{Cu} [W/m K]	target thermal conductivity	401
ν [Pa s]	fluid viscosity dinamic	0,00221
ρ [kg/m^3]	fluid density	6363
d [m]	diameter of the microchannels	0,00055
Pr	Prandtl number	0,022406944
v [m/s]	velocity in the microchannels	15
Re	Reynolds number	23753,28054
Nu	Nusselt number	8,85821701
α [W/m^2 K]	convection coefficient	579810,5679
$T_{av,fl}$ [ºC]	fluid average temperature	50
n	number of microchannels	13
q [W/m^2]	beam specific thermal power	19231222,29
q [W/cm^2]	beam specific thermal power	3846,244458
q [W/]	beam thermal power on target	4350
T_s [ºC]		83,16811275
T_{beam} [ºC]	temperature on beam surface	117,338302
T_{in} [ºC]	fluid inlet temperature	20
Q [m^3/s]	fluid volumetric flow	4,63287E-05
T_{us} [ºC]	fluid outlet temperature	60,42821788
	lithium thickness [m]	0,00004
$T_{s(Li)}$ [ºC]		126,4203432
λ_{Li} [W/m K]	gold thermal conductivity	84,7

Different GaInSn eutectic alloys are commercially available with different thermophysical propierties

TABLE I. Summary of the thermophysical properties of liquid metals used in heat transfer applications and water for comparison. Experiments conducted as part of this study utilized a commercially available $Ga^{61}In^{25}Sn^{13}Zn^{1}$ alloy. The limited thermophysical property data for this alloy available to the authors includes a melting point of 8 °C and a density of 6500 kg/m^3 (Ref. 15).

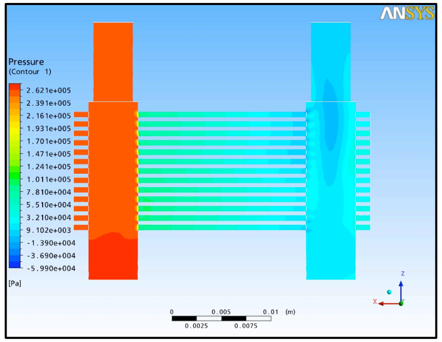
	Hg[a]	$Ga^{68}In^{20}Sn^{12}$[a]	$Na^{27}K^{78}$[a]	SnPbInBi[a]	Water[a]
Density (kg/m^3)	13 564.0[c]	6363.2[c]	868.2[c]	9230[e]	998.0[g]
Melting point (°C)	−38.87	10.5	−11	58	0
Heat capacity (J/kg/K)	139.068[c]	365.813[c]	982.1[c]	209[e]	4181[g]
Kinematic viscosity (10^{-6} m^2/s)	0.114 8[c]	0.348 09[c]	1.05[c]	4.04[e]	0.960[g]
Electrical conductivity (S/μm)	1.044 52[c]	3.307 37[c]	2.878[c]	1.28[e]	5.5×10^{-12}
Thermal conductivity (W/m/K)	8.716 9[c]	39[d]	21.8[c]	10[d]	0.606[g]
Prandtl Number ()[f]	0.024 8	0.020 8	0.0411	0.7793	6.62

- Calculations shows that ~1-3,5 kW/cm^2 could be dissipated. T_{Li}<152 °C. Melting point of Lithium is 182°C.
- Li (30μm) on a backing of Cu (1.5mm).
- Microchannels, GALINSTAN (**gal**lium, **in**dium **e stan**num $Ga_{68}In_{21}Sn_{11}$), alloy at T=15 °C

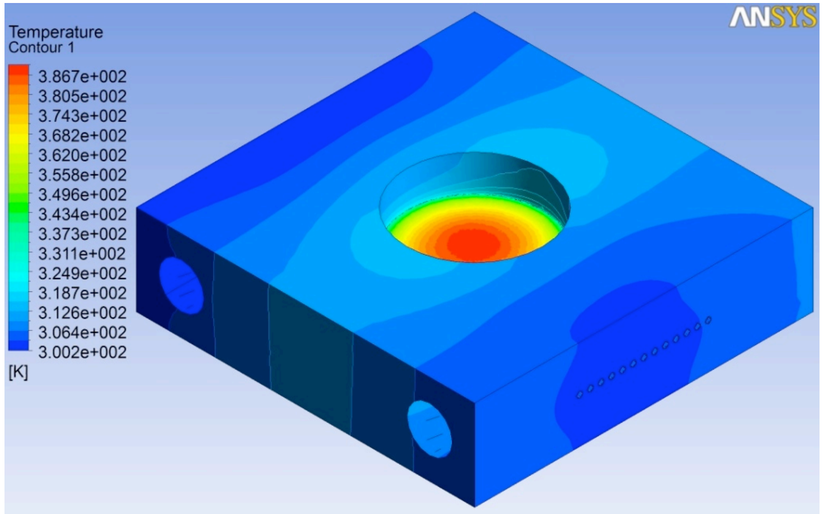
LENOS: Lithium target. ANSYS results (4/7)

Water cooled

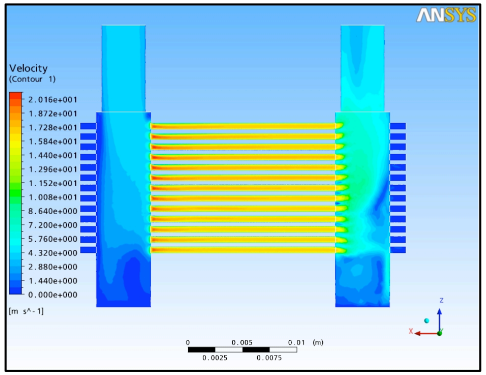
Pressure



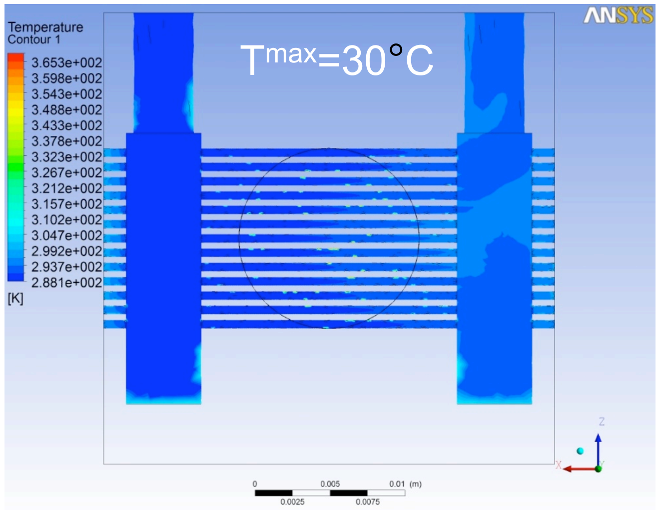
P^{in}=2.7 bar
ΔP=2.7 bar



Velocity



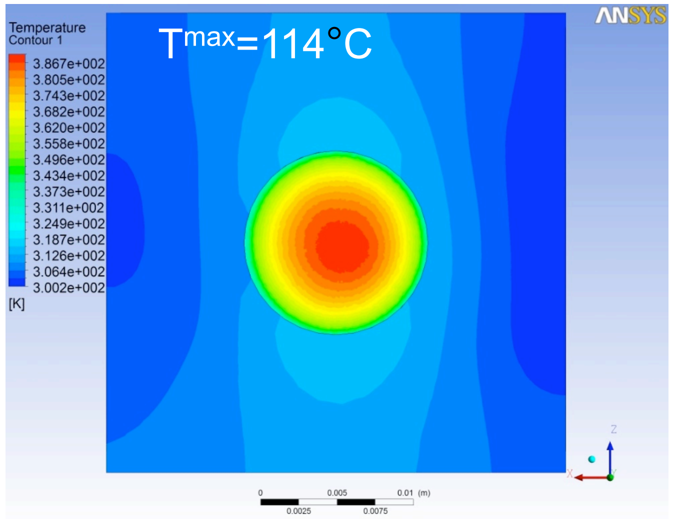
μ-channel fluid velocity =15m/s



Temperature

Li 40 μm
Mass flow=160l/h
Inlet fluid temperature=15°C
Beam Power=1000W
Flat beam profile

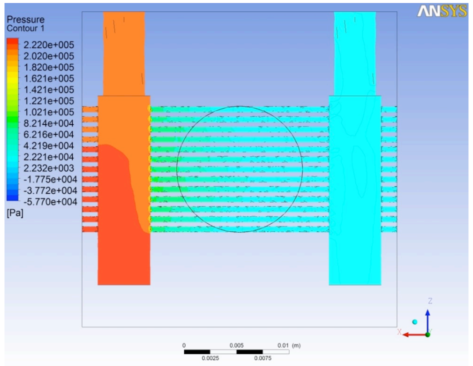
Melting point Li = 182°C



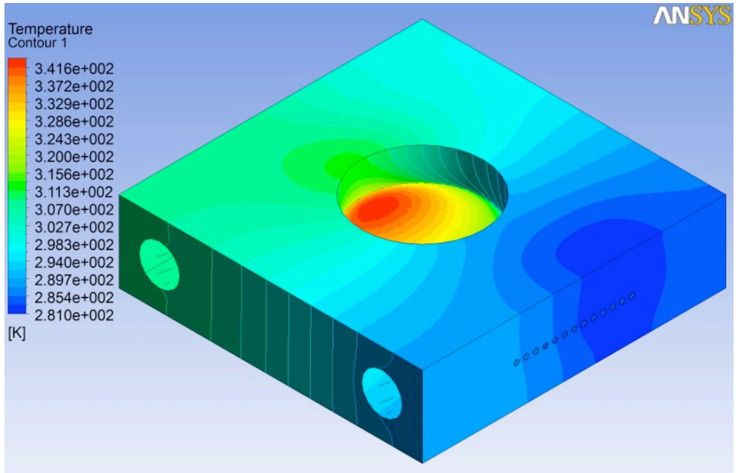
LENOS: Lithium target. ANSYS results (5/7)

SnInGa alloy cooled

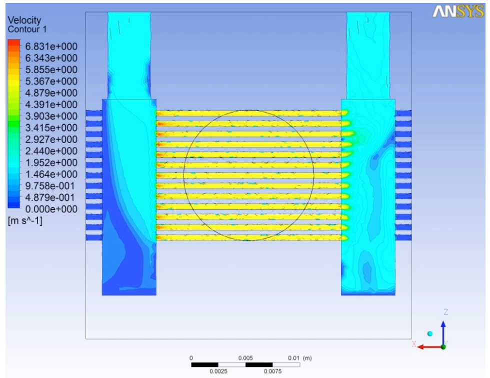
Pressure



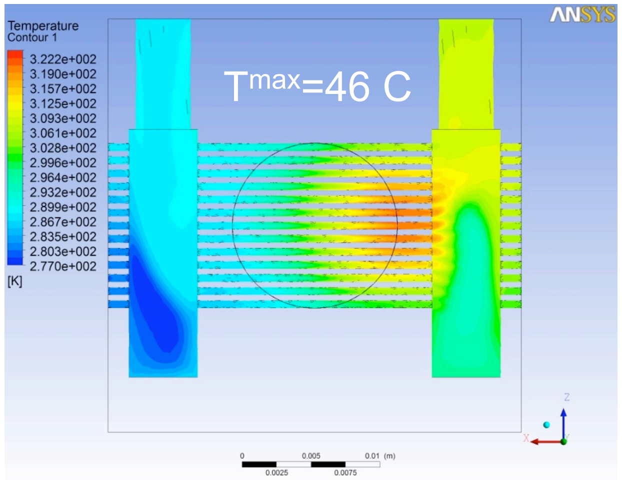
P^{in}=2.5bar
ΔP=2.5 bar



Velocity



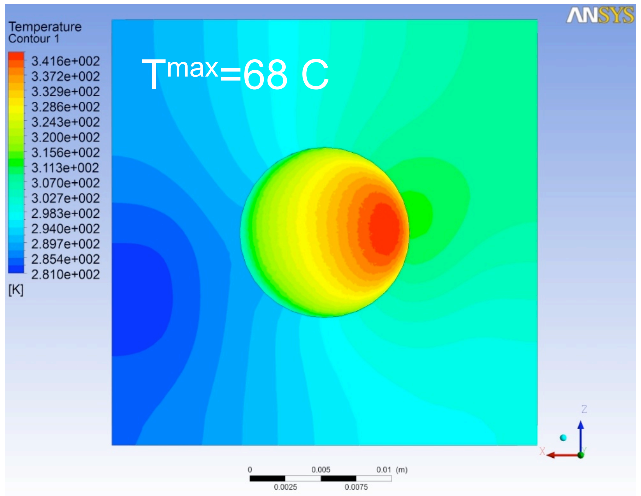
μ-channel fluid velocity =5 m/s



Temperature

Li 40 μm
Mass flow=55 l/h
Inlet fluid temperature=15°C
beam Power=1000W
Flat beam profile

Melting point Li = 182°C



LENOS: Lithium target. Comparison (6/7)

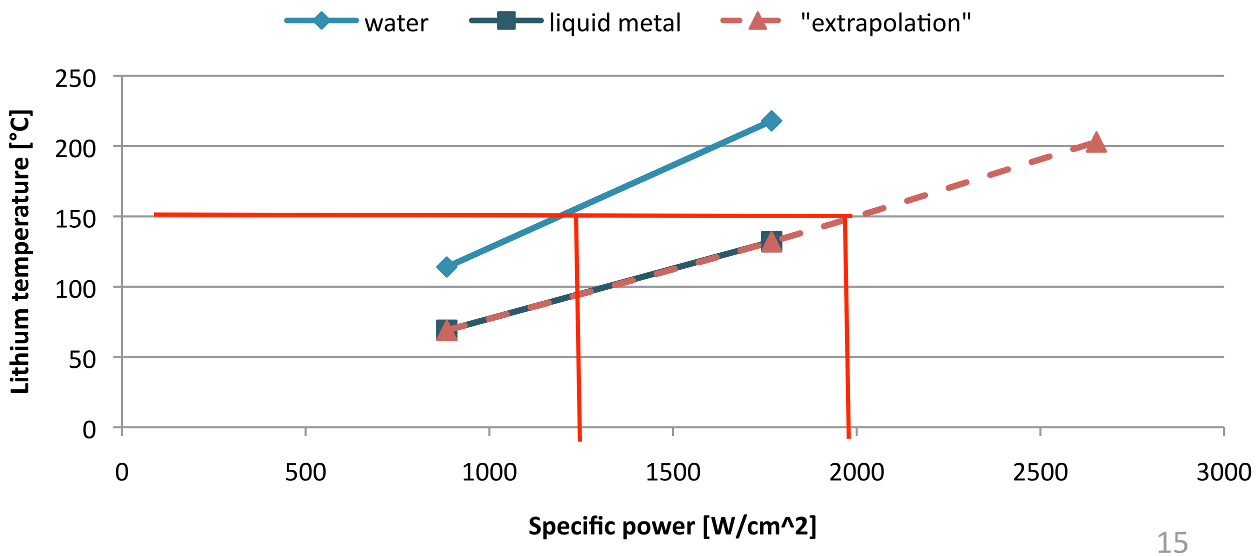
Analytical

WATER		
parameters	description	value
c_p [J/kg K]	fluid specific heat	4181,7
λ_{Fl} [W/m K]	fluid thermal conductivity	0,6069
λ_{Cu} [W/m K]	target thermal conductivity	401
v [Pa s]	fluid viscosity dinamic	0,0008899
ρ [kg/m^3]	fluid density	997
d [m]	diameter of the microchannels	0,00055
Pr	Prandtl number	6,131644142
v [m/s]	velocity in the microchannels	15
Re	Reynolds number	9242,89246
Nu	Nusselt number	73,77145321
α [W/m^2 K]	convection coefficient	81403,44537
$T_{av,fl}$ [ºC]	fluid average temperature	23
n	number of microchannels	13
q [W/m^2]	beam specific thermal power	4420970,641
q [W/cm^2]	beam specific thermal power	884,1941283
q [W]	beam thermal power on target	1000
T_s [ºC]		77,30937992
T_{beam} [ºC]	temperature on beam surface	124,6909261
T_{in} [ºC]	fluid inlet temperature	20
Q [m^3/s]	fluid volumetric flow	4,63287E-05
T_{us} [ºC]	fluid outlet temperature	25,17728529
	lithium thickness [m]	0,00004
$T_{s(Li)}$ [ºC]		126,7787516
λ_{Li} [W/m K]	gold thermal conductivity	84,7

GALINSTAN		
parameters	description	value
c_p [J/kg K]	fluid specific heat	365
λ_{Fl} [W/m K]	fluid thermal conductivity	36
λ_{Cu} [W/m K]	target thermal conductivity	401
v [Pa s]	fluid viscosity dinamic	0,00221
ρ [kg/m^3]	fluid density	6363
d [m]	diameter of the microchannels	0,00055
Pr	Prandtl number	0,022406944
v [m/s]	velocity in the microchannels	5
Re	Reynolds number	7917,760181
Nu	Nusselt number	7,305505188
α [W/m^2 K]	convection coefficient	478178,5214
$T_{av,fl}$ [ºC]	fluid average temperature	80
n	number of microchannels	13
q [W/m^2]	beam specific thermal power	11052426,6
q [W/cm^2]	beam specific thermal power	2210,485321
q [W/]	beam thermal power on target	2500
T_s [ºC]		103,113599
T_{beam} [ºC]	temperature on beam surface	122,7516388
T_{in} [ºC]	fluid inlet temperature	20
Q [m^3/s]	fluid volumetric flow	1,54429E-05
T_{us} [ºC]	fluid outlet temperature	89,70382393
	lithium thickness [m]	0,00004
$T_{s(Li)}$ [ºC]		127,9712027
λ_{Li} [W/m K]	gold thermal conductivity	84,7

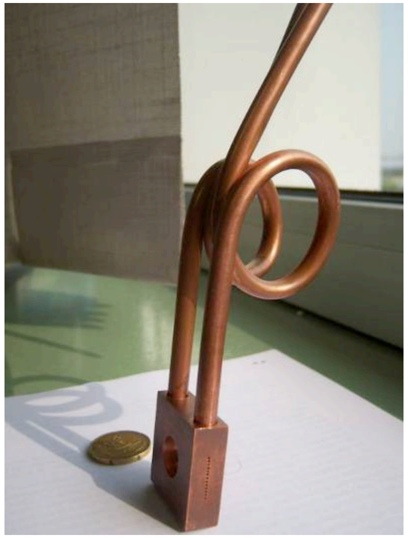
Good agreement for water, less for liquid metal

ANSYS



LENOS: Lithium target. Tests (7/7)

Copper backing has been successfully manufactured at LNL



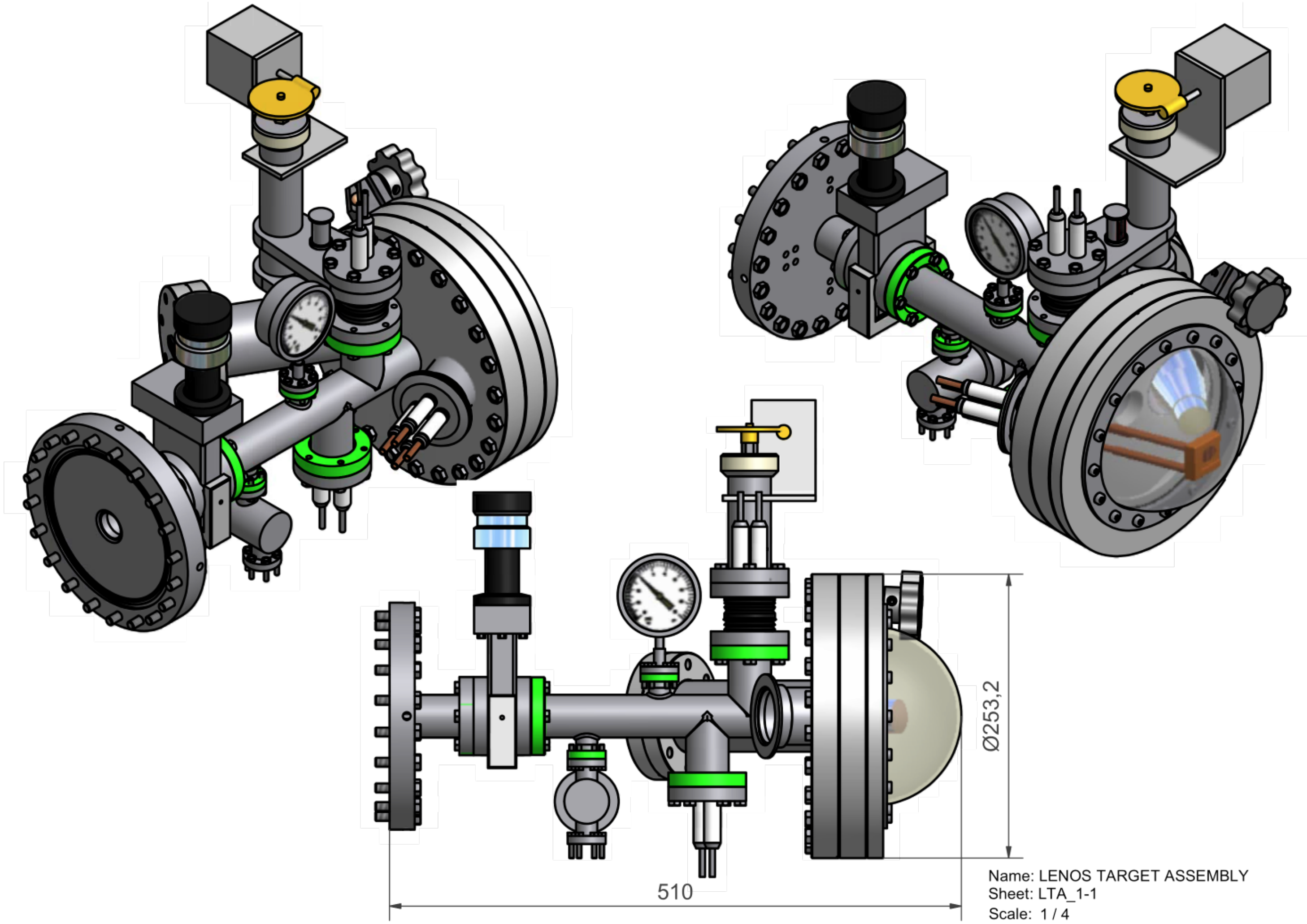
TIG test:
Measured power transfer: 3.4 kW
Not reached the Indium melting point

Preliminary Tests done depositing a thin Indium layer instead of Lithium.
Melting point of Indium 157°C.
Thermal conductivity of Indium is 81.6 W/(m·K).
Thermal conductivity of Lithium is 84.7 W/(m·K).

Heat spot

Oxyd-acethilene test:
Measured power transfer =1.5 kW
Not reached the Indium melting point

Lenos Target Assembly



LENOS: Validation of method. PTB-Germany

EXPERIMENT PROPOSAL

Neutron spectrum produced by Gaussian-shaped proton beam impinging on Lithium-7

Javier Praena[1], Pierfrancesco Mastinu[2],
Guido Martín-Hernández[3] and Nataliia Dzysiuk[2]

1) Universidad de Sevilla, CNA, Spain
2) Laboratori Nazionali di Legnaro, INFN, Padova, Italy
3) Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear, La Habana, Cuba

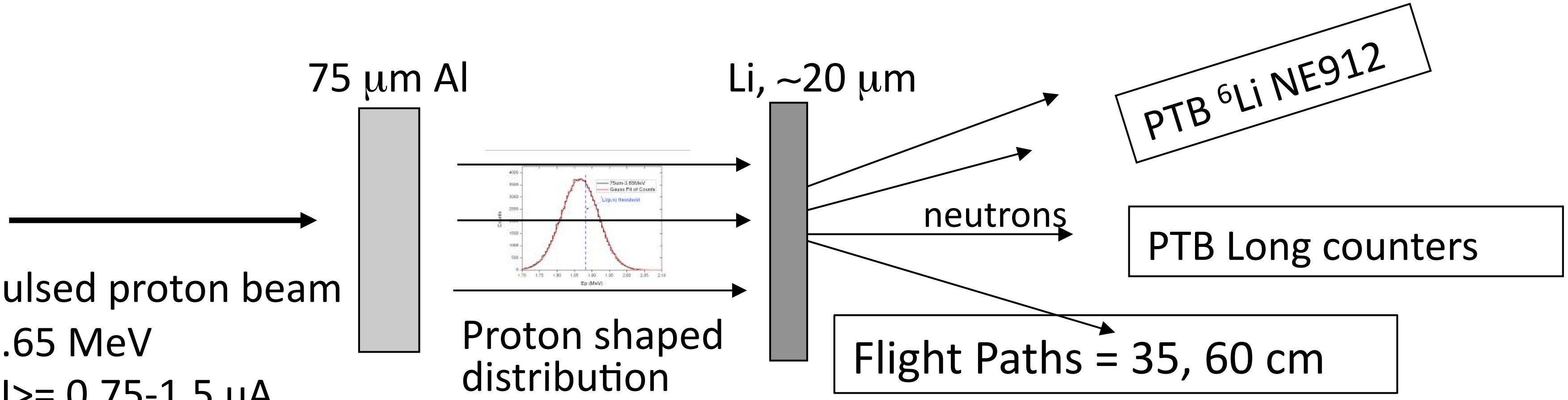
Already approved. Scheduled for April 2011

Since the power delivered at PTB is much lower than LENOS the setup can be simplified:

- Aluminum foil for proton shaping (instead of complex graphite rotating disk)
- No Copper backing for the metallic lithium target, provided by PTB.

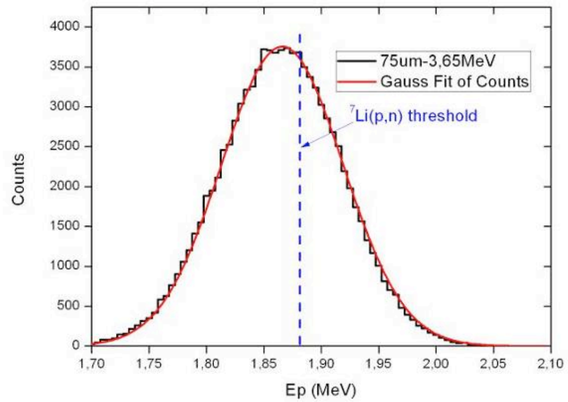
LENOS: Validation of method. PTB-Germany.

PTB setup. Neutron spectrum measurement by TOF technique.

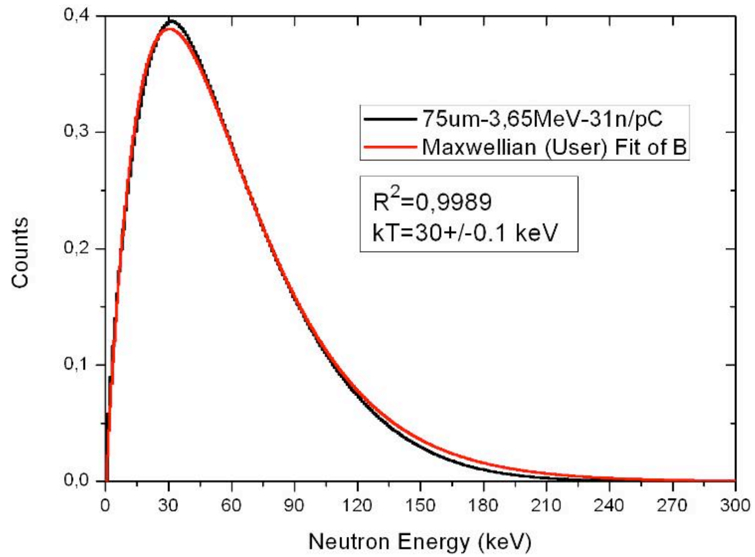


Pulsed proton beam
3.65 MeV
<I>= 0,75-1,5 uA
f=0.650-1.2 MHz
Δt=2 ns

E_c=1.87 MeV,
σ~53 keV



Expected result of the experiment



LENOS TARGET APPLICATION: LARAMED, THE MEDICAL RADIOISOTOPE PRODUCTION FACILITY@LNL

•Useful for:

•Solid, thin samples with good thermal conductivity

advantages

•Low mass of heat sink → low activation

•Low cost

• High Specific power → low mass sample, lower costs and less impurities (high specific activity)

•Easy to fabricate

disadvantages

•New and challenging system: developments and tests performance needed

• High working temperature possible with liquid metal cooling, but tests are needed to check erosion, corrosion and diffusion effects

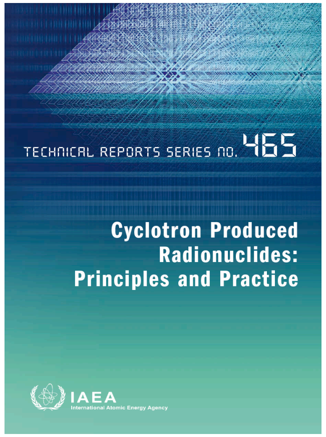
LENOS TARGET APPLICATION: LARAMED, THE MEDICAL RADIOISOTOPE PRODUCTION FACILITY@LNL

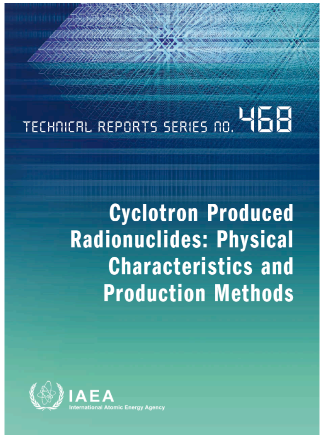
Among the several radionuclides of copper, **^{64}Cu** is the most commonly used for basic science investigations and clinical PET, and its production and use have now been reported in the United States, Europe, and Japan. Several companies, including MDSNordion (Canada), ACOM(Italy), Trace Life Sciences (United States), IBA Molecular (United States and Europe), and IsoTrace (United States) are supplying ^{64}Cu for use in preparation of radiopharmaceuticals.

- PET
- CANCER RADIOTHERAPY

$^{62}Zn/^{62}Cu$ generator can be used instead of the more common ^{18}F for PET. Problems related to the time distribution of the short lived (109.8 min) ^{18}F can be reduced. It can also be used instead of ^{99m}Tc.

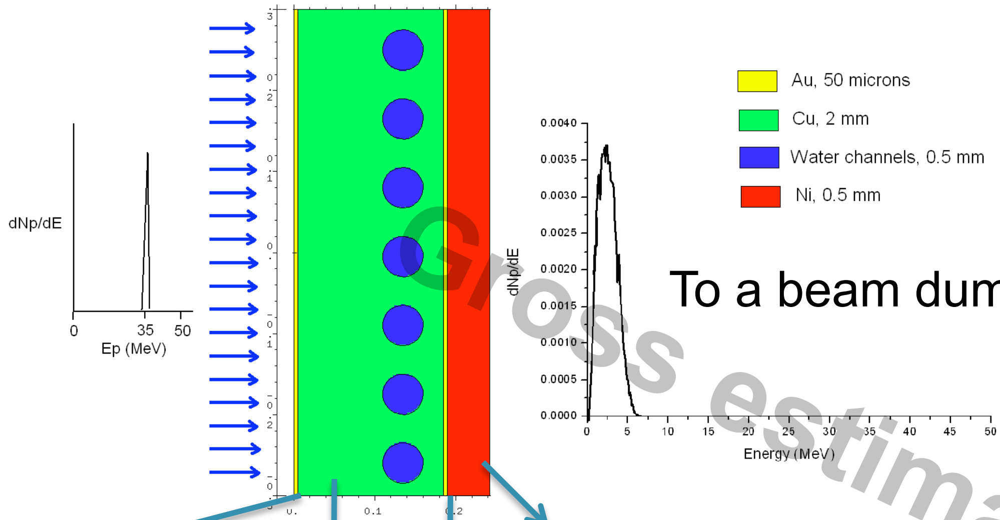
- PET





LARAMED: $^{64}Cu/^{62}Zn$ tandem production, single target

E_p=35 MeV, 300 uA

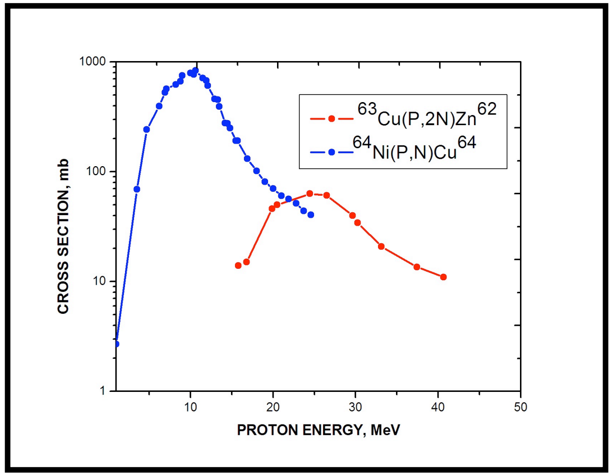


P 223 W
T 700

P 6 kW
2 Ci

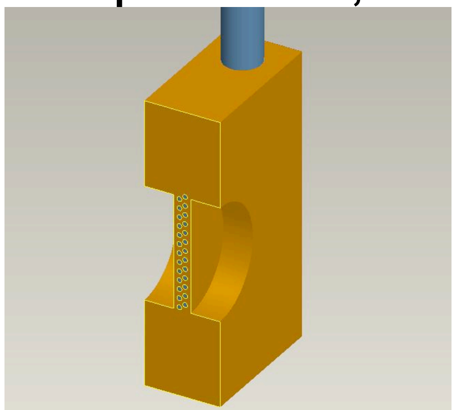
P 463 W
T 650

P 3.3 kW
T 850
5 Ci



Sublimation effects not taken into account

Beam spot size 1.2 cm
Total power to be dissipated 10,2 kW



$^{nat}Cu(p,x)^{62}Zn$:
T_{irr}=10 h , m=0.3 g T_{cool}=36 h

$^{64}Ni(p,n)^{64}Cu$:
T_{irr}= 10 h T_{cool}=36 h m=300 mg

I=300 uA

Proton energy distribution impinging on Ni

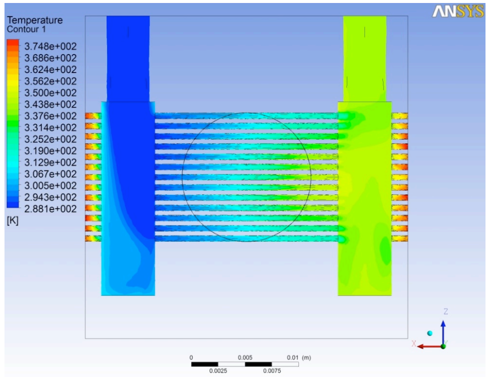
LARAMED: $^{64}Cu/^{62}Zn$ tandem production, single target

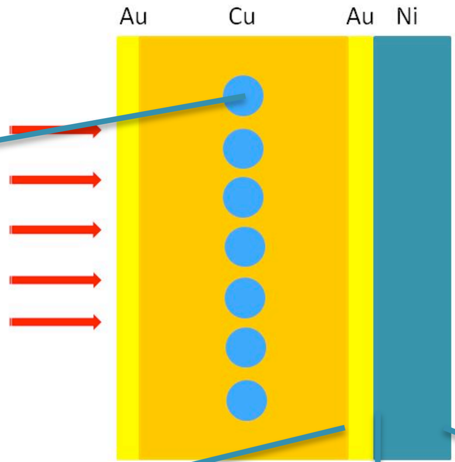
With water

Mass flow=160l/h → fluid velocity on pipes=15m/s water inlet temperature=15°C

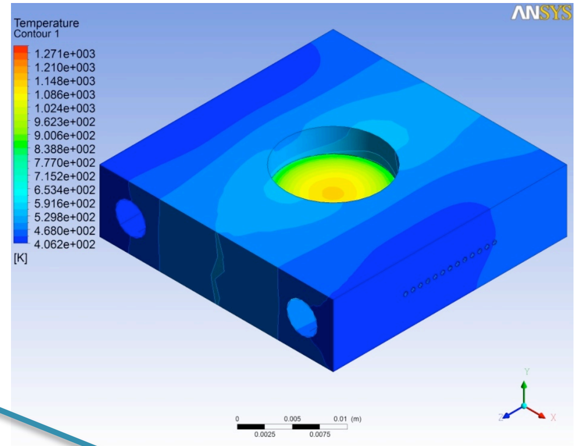
Total dissipated power=105kW

On fluid

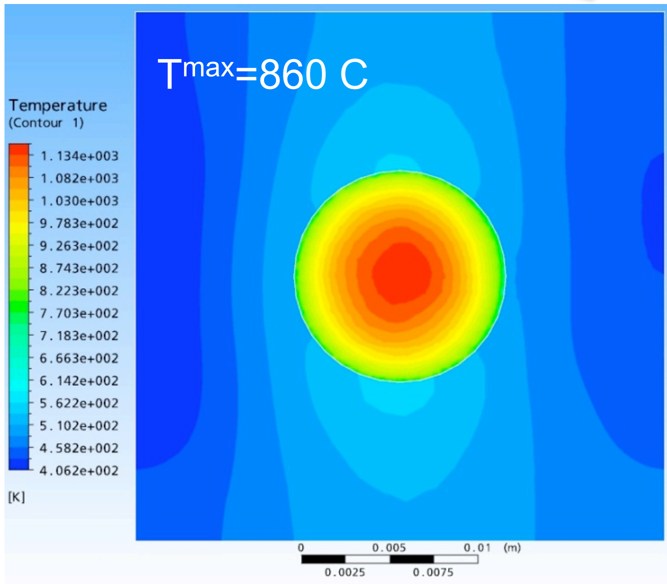




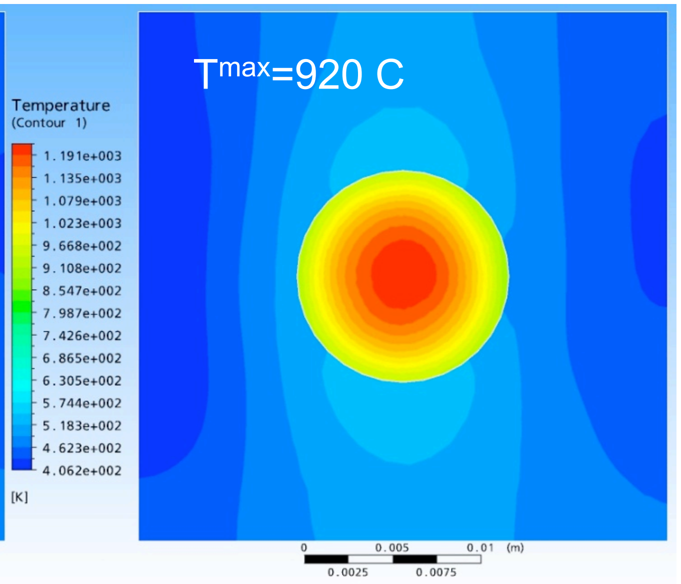
On target



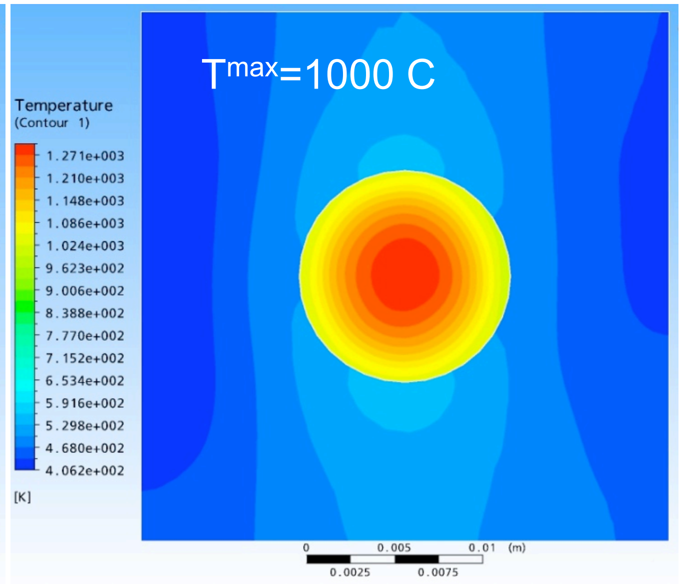
On Cu surface



On Au surface

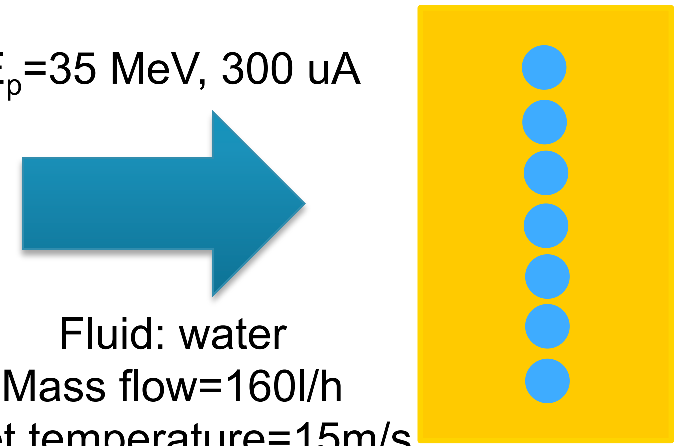


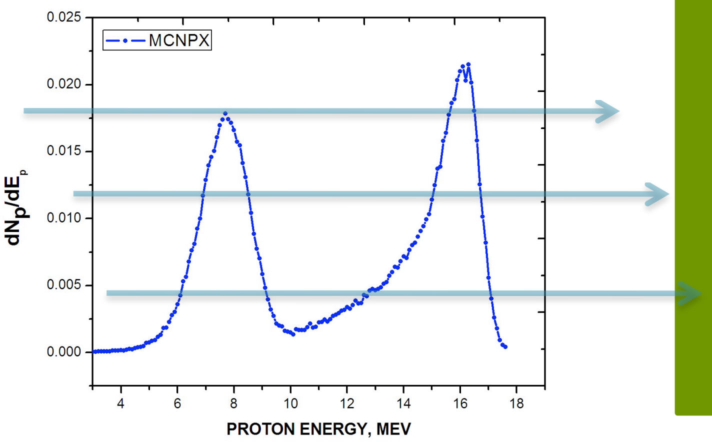
On Ni surface

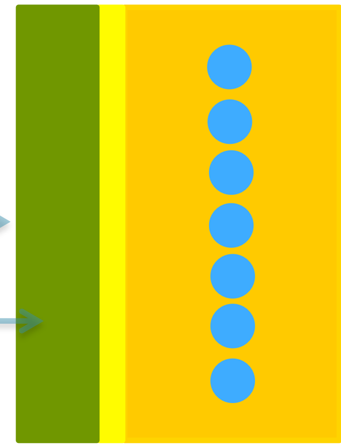


LARAMED: $^{64}Cu/^{62}Zn$ tandem production, two targets

E_p=35 MeV, 300 uA







Fluid: water
Mass flow=160l/h
Inlet temperature=15m/s

^{1}Cu 2 mm

P = 6042 W

^{2}Ni 0,52 mm

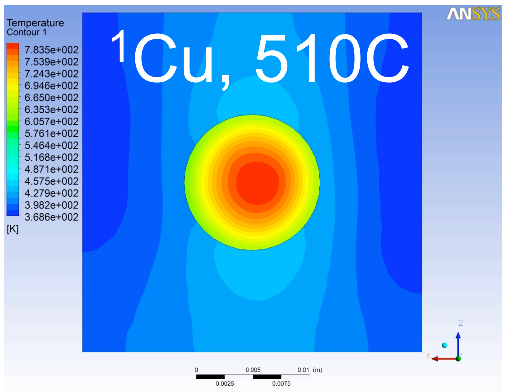
P = 3258 W

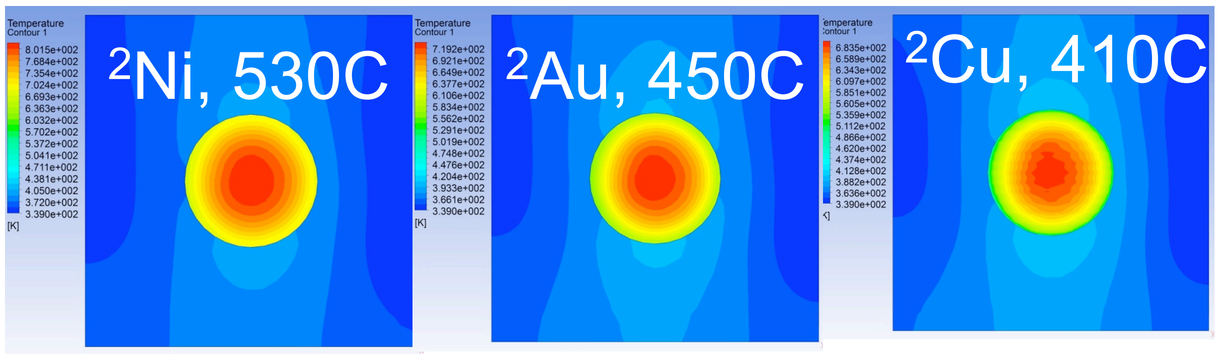
^{2}Au 1,5 mm

P = 650 W

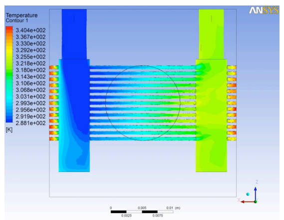
^{2}Cu 1,5 mm

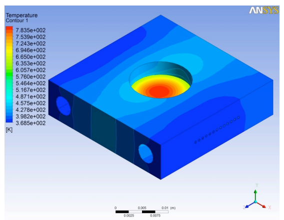
P = 550 W

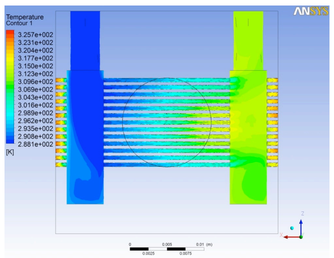


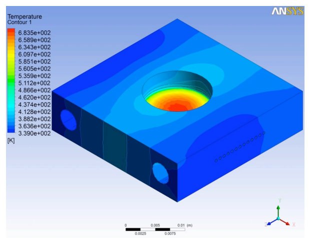


T^{max}(Fluido)=45 C









CONCLUSIONS

LENOS:

1. Energy shaper yet constructed, under vacuum tests.
2. Cooper backing for Lithium target yet constructed, heat tests
3. Significant discrepancies between analytical calculations, FEM calculations and heat tests.

LARAMED:

1. LENOS target seems to be usable for radioisotope production.
2. For a class of materials competitive target.
3. More detailed calculations needed.

REQUESTS

- Beam power tests with the specific power of working conditions.
- Performance tests needed with water and liquid metal.
- Target life time tests (erosion, corrosion, diffusions…).

Energy of emitted particles

Positron emission products of ^{64}Cu

Fraction	Maximum energy (MeV)	Average energy (MeV)
0.174	0.653	0.2782

Electron emission products of ^{64}Cu

Fraction	Maximum energy (MeV)	Average energy (MeV)
0.390	0.578	0.1902

Photon emission: 0.511 MeV (34.8%), 1.346 MeV (0.473%)

IAEA Tech Rep Ser 468, 2009

LENOS TARGET APPLICATION: LARAMED, THE MEDICAL RADIOISOTOPE PRODUCTION FACILITY@LNL

Among the several radionuclides of copper, ^{64}Cu is the most commonly used for basic science investigations and clinical PET, and its production and use have now been reported in the United States, Europe, and Japan. Several companies, including MDSNordion (Canada), ACOM(Italy), Trace Life Sciences (United States), IBA Molecular (United States and Europe), and IsoTrace (United States) are supplying ^{64}Cu for use in preparation of radiopharmaceuticals.

- PET
- CANCER RADIOTHERAPY

With a half-life of 12.7 h, ^{64}Cu is ideally suited for PET studies that require a longer-lived nuclide:

distribution of ^{64}Cu radiopharmaceuticals to facilities other than the production site is possible,

imaging can be conducted as long as 48 h after tracer administration.

Moreover, because ^{64}Cu has a maximum positron energy of 0.66 MeV, similar to that of ^{18}F, the resulting PET images are of high quality and are the best obtainable with any of the positron-emitting radionuclides of copper.

The 38.5% β^- emission of ^{64}Cu opens the possibility of therapeutic applications